Osteology

The Proximal Femur

The form of the femur is relatively complex, with bows and twists that distort its basically tubular structure. The anterior bow of the midportion of the femur is well recognized and has even been built into some current prostheses. This is commonly envisioned as an anterior bow because of the position that the separate femur assumes when it is placed on a horizontal surface, resting on the posterior margin of the trochanter and the posterior aspects of the condyle (Figure 1.1A). However, in vivo the orientation is somewhat different. In the erect position, the central portion of the femur is more in the coronal plane of the body, with the distal portion inclined posteriorly to the knee and the proximal portion inclined anteriorly to the acetabulum (Figure 1.1B).

The posterior bow of the proximal femur is just as constant as the midportion anterior bow, but it seems to have been unrecognized or considered of no importance by most designers of femoral stems. The central portion of the proximal posterior bow is opposite the level of the lesser trochanter. This bow is constant. It is also noteworthy that the radius of curvature does not seem to change dramatically with the size of the femur. The length of the curve increases with increasing femur size from the base of the neck until the curve reverses distal to the lesser trochanter, but the radius of the curve is relatively constant.

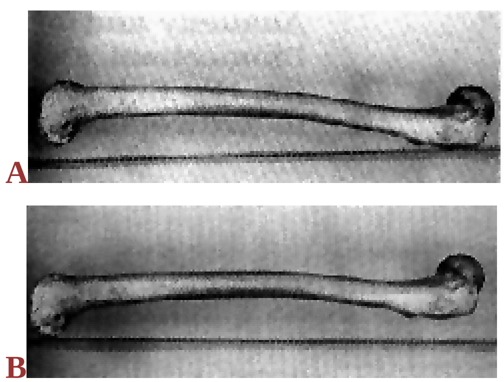


Figure 1.1 A, Photo of skeletal femur resting on table top; B, same femur positioned in the neutral plane, as it is in the body.

The Neck-Shaft Angle

The head of the femur considerably overhangs the femoral shaft. This occurs because the neck makes an oblique angle with the shaft of an average of 135° (3). Although there is considerable variability in both the neck-shaft angle and neck length, in general the center of the femoral head is extended medially and proximally by the femoral neck so that the center of the femoral head is at the level of the tip of the trochanter. The effect of the overhanging head and neck is to lateralize the abductors, which attach to the greater trochanter, from the center of rotation (center of the femoral head). This increases the torque generated by the abductors and reduces the overall force necessary to balance the pelvis during single leg stance. Reducing this level arm (coxa valga) increases total load across the hip, and coxa vara reduces it to the extent it increases the lever arm. (Coxa vara with a short neck would have a negative affect.)

Figure 1.2 Photograph of a femur viewed from the end, showing anteversion of the head and neck.

Femoral Anteversion

The coronal plane of the femur is generally referenced to the posterior distal femoral condyles. When oriented in this plane, it can be seen that the proximal femur, including the femoral head and neck, are rotated anteriorly. This is commonly referred to as femoral head-neck anteversion. However, it is really a combination of a torsional change in the intertrochanteric part of the femur and a further anteversion of the femoral neck based upon this torsion. The sum of this change is that the adult femoral head and neck are in a plane 10-15° anteriorly oriented to the coronal plane (3, 5; Figure 1.2).

This can be very different in pathologic cases, particularly hip dysplasia and congenital hip displacement where torsional changes can be as much as 80°. Such abnormal relationships are much more frequently a true torsion rather than an abnormal relationship between the femoral head, neck, and greater and lesser trochanters. This is an important distinction when considering what changes may be indicated in handling such patients who present for total hip replacement. For prostheses intended to achieve maximal purchase in the proximal femur, it may be necessary to first change the relationship between the proximal and the distal femur.

It is important to view the hip three dimensionally in order to establish criteria for forming prosthesis geometry that is anatomical. Both CAT scans of the proximal femur in normal patients and transection of properly oriented, referenced, and marked cadaver femurs can assist in this understanding. We feel that the intertrochanteric region of the hip is important for long-term fixation and stability, while the diaphyseal region distal to the lesser trochanter is principally important for initial fixation and stability of the components. Therefore our analysis will concentrate in these regions.

Figure 1.3 A-P x-ray of femur showing the well developed compression and tension trabecular patterns of the proximal femurs.

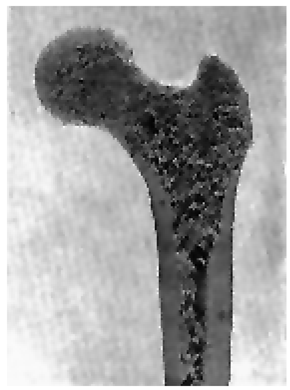


Figure 1.4 Coronal cut through the proximal femur showing the distribution of cancellous bone and particularly the striking diminution distal to the lesser trochanter.

Distribution of Cancellous Bone in the Proximal Femur

A critical look at a good quality anteroposterior (A-P) x-ray of the femur gives a good idea of the distribution of cancellous bone in the femur (Figure 1.3). Even though the orientation of the trabecular pattern may be significantly disturbed in the diseased hip, the overall distribution of cancellous bone is still the same. It appears to be a characteristic of the articulating ends of long bones that the broad ends, covered with articular cartilage, are supported principally by cancellous bone and a very rudimentary cortex in the form of a subchondral plate. The forces applied to the articular surfaces are carried by the cancellous bone out to the cortex. It does not appear to be a coincidence that where the cortex reaches its full thickness, the cancellous bone essentially stops. The distribution of cancellous bone that is suggested in the x-ray is vividly illustrated in the coronal cut through a dessicated femur (Figure 1.4).

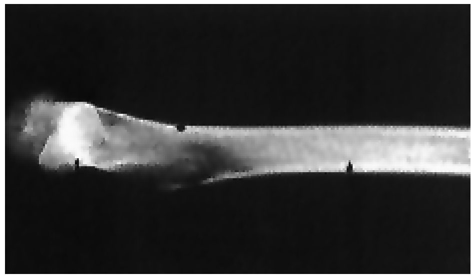


Figure 1.5. Direct lateral x-ray of the femur. Arrows mark the structures that limit the windows of access for a straight-stem prosthesis.

Cross-Sectional Analysis

As a part of the development of the shape and sizes for the PCA hip stem, we x-rayed 86 North American cadaver femurs in the A-P and true lateral position to determine the form of the proximal femur and distribution of cancellous bone. A detailed examination of one of those normal bones is representative for the shape of the normal human femur. Particularly on the lateral x-ray, the posterior bow of the proximal femur can be seen with its apex opposite the lesser trochanter (Figure 1.5). The three aspects of the anatomy of the femur that limit the access of stems that are straight in the lateral plane are the posterior margin of the femoral neck, the anterior margin of the cortex opposite the lesser trochanter, which represents the apex of the posterior bow of the femur, and the posterior cortex of the shaft where the bow of the femur is reversing into an anterior bow.

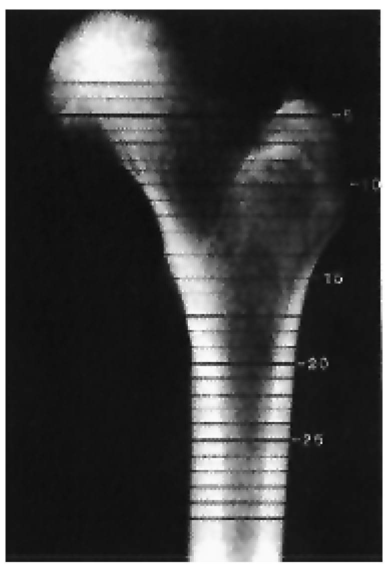


Figure 1.6. A-P x-ray of the proximal femur with overlay indicatinng the levels of transection.

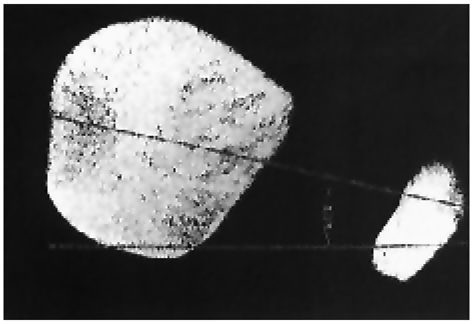


Figure 1.7. Slice 3 through the tip of the trochanter and center of the femoral head. The constant horizontal line represents the coronal plane in this and subsequent x-rays. Total anteversion is 13°.

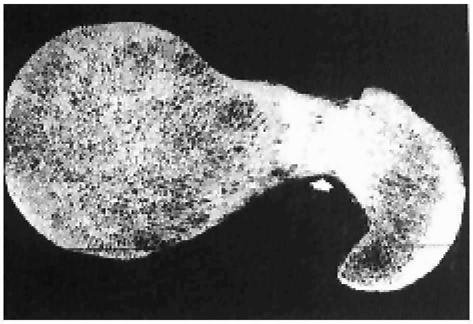


Figure 1.8. Slice 5. Arrow marks the posterior margin of the femoral neck. Its anterior level blocks the sinking of a straight stem prosthesis posteriorly to get past the bow in the femur at the level of the lesser trochanter.

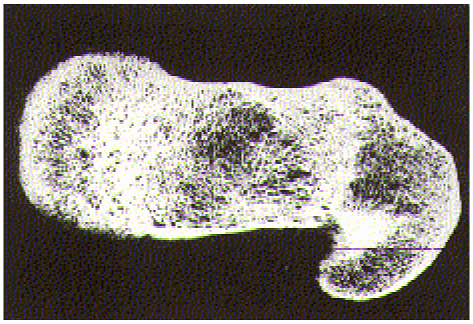


Figure 1.9. Slice 7. Note the dense cancellous bone in proximity to the relatively thin cortex.

The femur was sliced into 30 cross-sectional views that then were subjected to contact radiography to show the form of the cortical outline and the distribution of the cancellous bone. The levels of the cuts and their numbers are shown on an A-P x-ray (Figure 1.6). From slice 3 at the tip of the greater trochanter, it can be seen that this corresponds to the center of the femoral head (Figure 1.7). At slice 5 the superior margin of the femoral neck is transected, and it can be seen how far the posterior margin of the neck is anteriorly oriented (Figure 1.8). Slice 7 in the intertrochanteric region shows the distribution of the cancellous bone and particularly the density of the trabecular pattern near the regions of the cortex, which itself is relatively thin (Figure 1.9). In slice 10 through the calcar, the trabecular pattern is somewhat looser, but again clearly dense within 2 or 3 mm of the cortex all around the cortical margin, with the exception of the posterior intertrochanteric ridge (Figure 1.10). Slice 13 represents the area approximately 1 cm above the lesser trochanter, and again the density of the cancellous bone can be seen to follow the cortical outline (Figure 1.11). Slice 15 is through the lesser trochanter, and between slice 15 and slice 17, a dramatic change in the density of the cancellous bone can be seen (Figures 1.12 and 1.13). When comparing this back to the A-P x-ray (see Figure 1.6), the compression-oriented trabeculae, which are located in the medial aspect of the head and neck and insert into the calcar, can be seen to end at the level of the lesser trochanter, and the tension trabeculae, which arc from the lateral trochanter into the head and intersect the compression trabeculae at nearly right angles, can also be seen to end at the same level. Therefore, the distribution of cancellous bone is limited to an area proximal to the inferior margin of the lesser trochanter and the lateral flare at the base of the greater trochanter. Below this area there are only a few coarse trabecular filaments in direct apposition to the cortical margins.

When comparing slice 13 with slice 17, it can be seen that there is a dramatic change in the density of the cortical outline itself; so it appears that as the trabeculae carry the stress progressively out to the cortex, the cortex gradually takes over, and the cancellous bone is no longer needed as a vehicle for stress transfer. This carefully oriented transectional analysis of the proximal femur also shows the rotational orientation of various levels of the femur. The constant transverse line represents the coronal plane. At the level of slice 20, it can be seen that the femoral shaft is basically a circular tube with no particular rotational orientation (Figure 1.14). However, at slice 15, which is through the level of the lesser trochanter, the anterior cortex already can be seen to be anteverted a few degrees. This degree of anteversion has increased slightly at slice 13. The degree of twist of the proximal femur is a little more difficult to evaluate proximal to slice 12 since the intertrochanteric area is irregularly shaped. However, in looking at transection at level 3, which is at the tip of the trochanter, approximately 13° of femoral anteversion can be seen in this specimen. The anteversion has already begun at the level of the lesser trochanter, continues throughout the intertrochanteric region, and is completed in the anteversion of the femoral neck.

By superimposing the cross sections from the proximal base of the neck, the level of the lesser trochanter, and the level of the tip of a typical prosthesis, the limit to the window of common opening for a straight stem prosthesis can be seen (Figure 1.15). The straight stem would bind proximally at the posterior margin of the neck, in the mid-portion at the anterior cortex, and distally at the posterior cortex. A larger stem prosthesis would have the tendency to blow out the posterior neck as the stem follows the anterior bow of the midfemur or to punch through the posterior cortex 5-6 in. down the shaft.

Although some of the pathology of the adult hip is a result of abnormal anatomy, the vast majority of patients presenting for total hip replacement have degenerative changes superimposed on a relatively normal anatomy. Therefore it should be possible to fit the majority of the patients who need total hip replacement with prostheses based on a careful analysis of the form and cancellous bone distribution of the normal human femur.

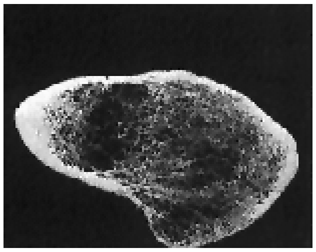


Figure 1.10. Slice 10. The density of the cancellous bone parallels the cortical outline, with the exception of the posterior intertrochanteric ridge.

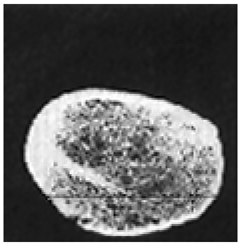


Figure 1.11. Figure 13, 1 cm above the lesser trochanter. The anterior cortex shows some anteversion in relation to the coronal plane.

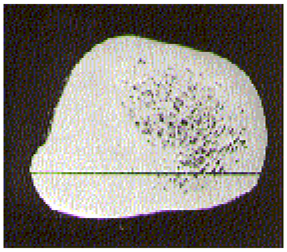


Figure 1.12. Slice 15 through the lesser trochanter, showing hte end of the dense cancellous bone, thickening of the cortex, and the beginning of anteversion.

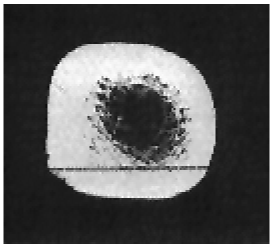


Figure 1.13. Slice 17. The cortex is now fully developed and the cancellous bone is rudimentary.

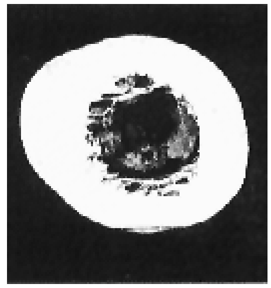


Figure 1.14. Slice 20. the diaphysis is essentially a cortical tube with little rotational orientation and only a small amount of cancellous bone.

Acetabulum

The acetabulum is formed by the confluence of the ilium, pubis, and ischium at the triradiate cartilage. With the fusion of this cartilage at the completion of growth, the form and orientation of the acetabulum are fixed. The normal bony acetabulum is slightly less than a hemisphere, but its functional dimensions are extended by the tough fibrocartilaginous labrum. There is some controversy in the literature concerning the orientation of the acetabulum. Getz (2), Steindler (9), and von Lanz (11) all give figures for acetabular anteversion of around 4O° (38- 42°). They made their measurements with the pelvic brim approximately horizontal, where it can be seen that the acetabula are obviously facing forwards (Figure 1.16). However, in the erect position, the anterior-superior iliac spines and pubic symphysis are in the same plane and the acetabulae are not as obviously anteverted (Figure 1.17). McKibbin measured 30 each adult male and female pelvises, oriented this position, and recorded an average anteversion of 14° (5-19°) for men and 19° (10-24°) for women (6). When the pelvis is flexed, as it is in sitting, the forward facing of the acetabulum is accentuated. In the erect position, the anterior-superior iliac spines and the symphysis pubis lie in the coronal plane. In this position, the acetabulum opening is directed approximately 45° laterally and 15° forward. Flexion of the pelvis on the lumbar spine increases the apparent anteversion without greatly changing the apparent lateral opening, whereas lumbar lordosis does the opposite.

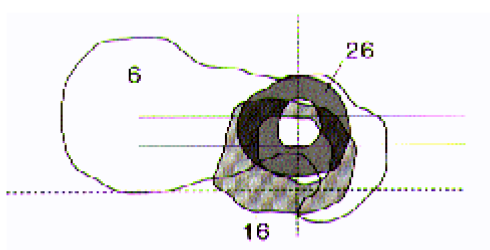


Figure 1.15. Superimposition of slices 6, 15 and 26 give an end-on view of the proximal femur. The common A-P window for a straight stem prosthesis is narrowed by the posterior margin of the neck (slice 6), the anterior cortex of slice 15, the posterior cortex of slice 26. The slices have been oriented against a common coronal plane reference.

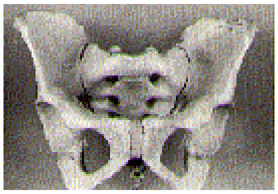


Figure 1.16. With the pelvis positioned so that the brim is nearly horizontal, the acetabula obviously face forward.

Figure 1.17. In the neutral position (anterior-superior iliac spines and pubic symphysis all in the coronal plane) the acetabular anteversion is less marked.

Figure 1.18. Standard A-P x-ray of the hip suggests that the body of the ilium is very broad. Acetabular rim is outlined with malleable wire.

Because of the oblique orientation of the acetabulum to the coronal plane, an A-P view of the pelvis gives a view of the acetabulum that does not give a true picture (Figure 1.18). Judet internal and external rotation views coupled with the A-P and the cross-table lateral x-rays are necessary to give a better representation of this complex structure (Figures 1.19-21). As with the femur, transverse sections and CAT scan sections of the acetabulum are helpful in constructing the accurate three-dimensional image that is so important for correct component placement at total hip arthroplasty (Figure 1.22).

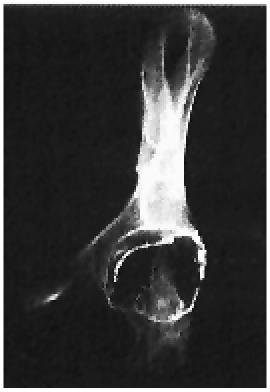


Figure 1.19. Internal Judet view shows the body of the ilium in its true thickness and an end-on view of the acetabulum.

Figure 1.20. External Judet view shows the width of the body of the ilium and the anterior and posterior margins of the acetabulum overlapping.

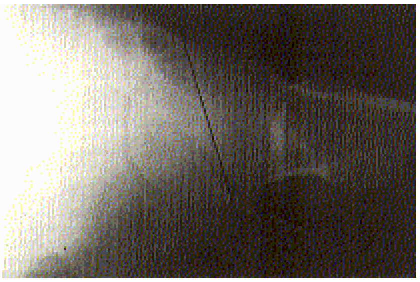
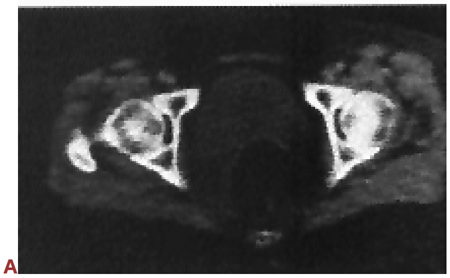


Figure 1.21. Cross-table lateral x-ray shows the forward facing acetabulum.

A



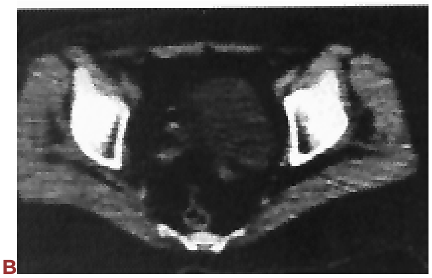
B


Figure 1.22. **A,** CAT scan of the acetabulum through the midsection shows apparent anteversion. **B,** More proximal cut. Compare thickness of body of the ilium to "apparent" thickness in Figure 1.18 and true thickness in Figure 1.20.

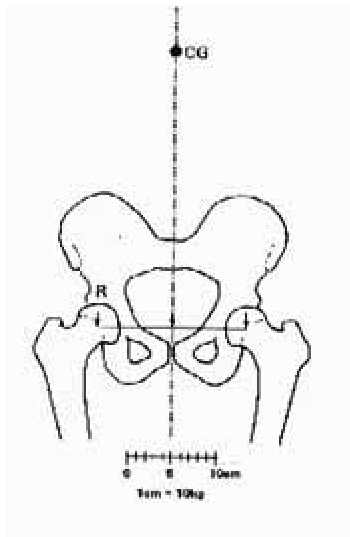


Figure 1.23. Schematic showing the direction and magnitude of the load on the femoral head in symmetrical two-leg stance. [Redrawn from Pauwels F. Biomechanics of the Locomotor Apparatus. springer Verlag, New York, 1980 (7).]