Chapter 1

Anatomy and Biomechanics of Hip

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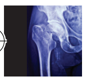
1 Anatomy and Biomechanics of Hip

Introduction

The hip is a classical ball-and-socket diarthrodial joint. It has a joint cavity and the joint surfaces are covered with articular cartilage; it has a synovial membrane producing synovial fluid; and it is surrounded by a ligamentous capsule.[1]

Bony Anatomy



The cup-shaped acetabulum is formed by the innominate bone with contributions from the ilium (up to 40% of the acetabulum), ischium (40%), and the pubis (20%).[2] The actual articular surface appears lunate shaped when looking into the acetabulum. Within the lunate, or horseshoe-shaped, articular cartilage is a central area—the central inferior acetabular fossa. This fat-filled space houses a synovial covered fat pad and also contains the acetabular attachment of the ligamentum teres. Inferior to this, the socket of the hip is completed by the inferior transverse ligament.

Attached to the rim of the acetabulum is the fibrocartilaginous labrum. It plays a role in normal joint development and in distribution of forces around the joint.[3–5] It has also been suggested that it plays a role in restricting movement of synovial fluid to the peripheral compartment of the hip, thus helping exert a negative-pressure effect within the hip joint.[6] The labrum runs around the circumference of the acetabulum, terminating inferiorly where the transverse acetabular ligament crosses the inferior aspect of the acetabular fossa. It attaches to the bony rim of the acetabulum and is quite separate from the insertion of the capsule.[7] The labrum receives a vascular supply from the obturator and the superior and inferior gluteal arteries.[8] These ascend in the reflected synovial layer on the capsule and enter the peripheral aspect of the labrum.

The femoral head is covered with a corresponding articular cartilage beyond the reaches of the acetabular brim to accommodate the full range of motion. The covered region forms nearly 60 to 70% of a sphere. There is an uncovered area on the central area of the femoral head—the fovea capitis—for the femoral insertion of the ligamentum teres. The ligamentum teres, while containing a blood supply, does not contribute to the stability of the joint.

The head of the femur is attached to the femoral shaft by the femoral neck, which varies in length depending on body size (**Fig. 1.1**). The neck-shaft angle is usually 125 ± 5 degrees in the normal adult, with coxa valga being the condition when this value exceeds 135 degrees and coxa vara when the inclination is less than 120 degrees.

The importance of this feature is that the femoral shaft is laterally displaced from the pelvis, thus facilitating freedom for joint motion. If there is significant deviation in angle outside this typical range, the lever arms used to produce motion by the abductor muscles will be either too small or too large. The neck-shaft angle steadily decreases from 150 degrees after birth to 125 degrees in the adult due to remodeling of bone in response to changing stress patterns. The femoral neck in the average person is also rotated slightly anterior to the coronal plane. This medial rotation is referred to as femoral anteversion. The angle of anteversion is measured as the angle between a mediolateral line through the knee and a line through the femoral head and shaft. The average range for femoral anteversion is from 15 to 20 degrees (**Fig. 1.2**). The neck is most narrow midway down the neck.

Vascular Anatomy

Mainly three sources of vascular supply are noted: a small vessel found within the ligamentum teres (present in nearly 80% of the population), a supply from the medullary canal, and an anastomosis of vessels creeping around the femoral neck. This latter supply is perhaps the most important—the vessels ascend toward the femoral head in the synovial lining

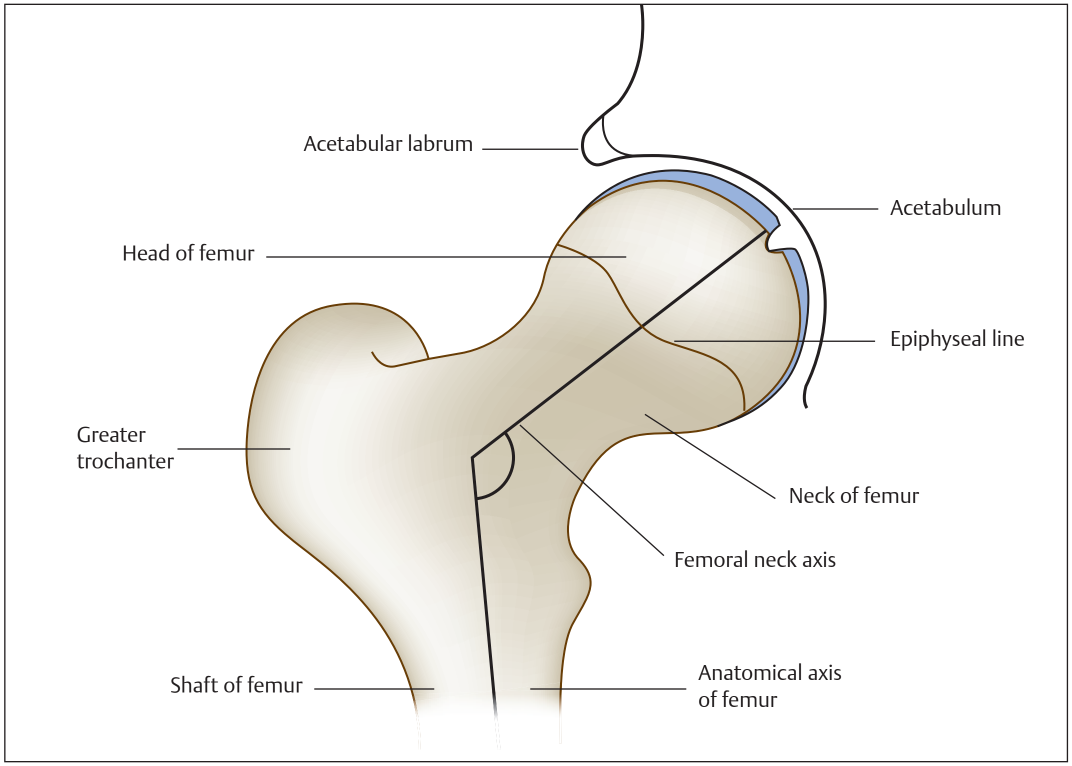


Fig. 1.1 Bony anatomy of hip.

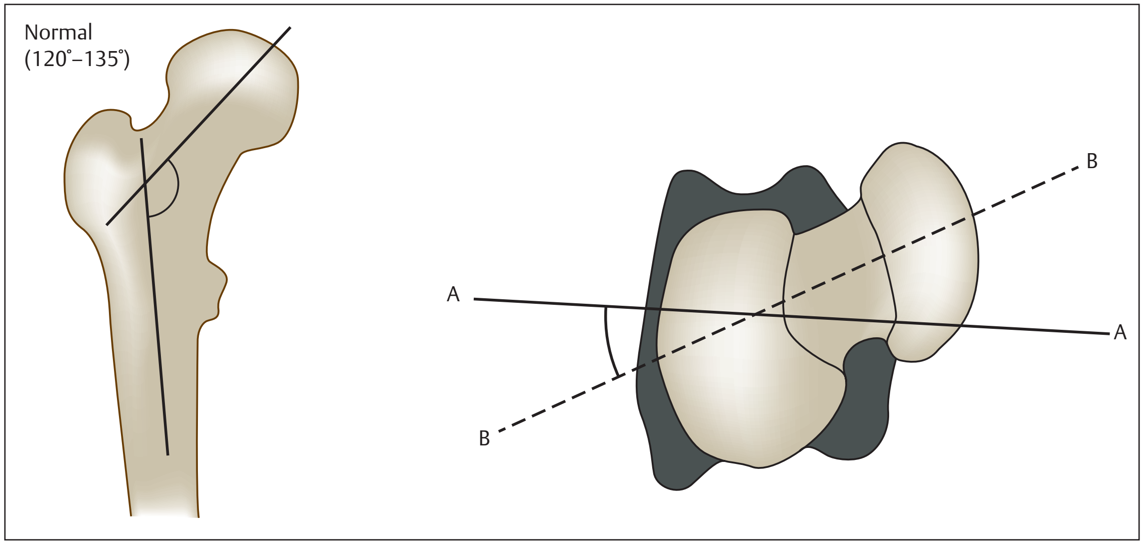
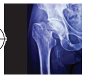


Fig. 1.2 Anteversion.

that is reflected onto the femoral neck. These vessels arise posteriorly, chiefly from the medial circumflex femoral artery (MCFA) that braches off the deep femoral artery. The lateral circumflex artery makes less of a contribution (**Fig. 1.3**).

Extracapsular arterial ring at the base of the femoral neck is formed posteriorly by a large branch of MCFA; anteriorly by smaller branches of lateral circumflex femoral artery (LCFA); and with minor contributions from superior and inferior gluteal arteries. Ascending cervical branches give rise to retinacular arteries and subsynovial intra-articular ring. Artery of ligamentum teres is derived from obturator or MCFA. It is inadequate to supply femoral head with displaced fractures; it forms the medial epiphyseal vessels; only small and variable amount of the femoral head is nourished by artery of ligamentum teres.

Femoral Neck Fracture



Fracture of the femoral neck disrupts intraosseous cervical vessels (**Fig. 1.4**). Portion of the neck that is intracapsular has essentially no cambium layer in its fibrous covering to participate in peripheral callus formation; hence, healing is dependent on endosteal union alone. Femoral head nutrition is then dependent on remaining retinacular vessels, and supply from the ligamentum teres. Position achieved at reduction is a significant factor in development of avascular necrosis (AVN). In fractures of neck of femur, valgus reduction may end up in kinking of lateral epiphyseal vessels and tethering of medial epiphyseal vessels in ligamentum teres; valgus and rotatory malposition may result in AVN.

Ligaments and Capsular Anatomy

The joint capsule is strong. While the ball and deep socket configuration naturally gives the hip great stability, the ligamentous capsule undoubtedly contributes significantly. The capsule is formed by an intertwining of three separate entities.

The iliofemoral ligament can be seen anterior to the hip in the form of an inverted “Y.” It spans, in a spiraling fashion, from its proximal attachment to the ilium to insert along the intertrochanteric line. It is taut in extension and relaxed in flexion, keeping the pelvis from tilting posteriorly in upright

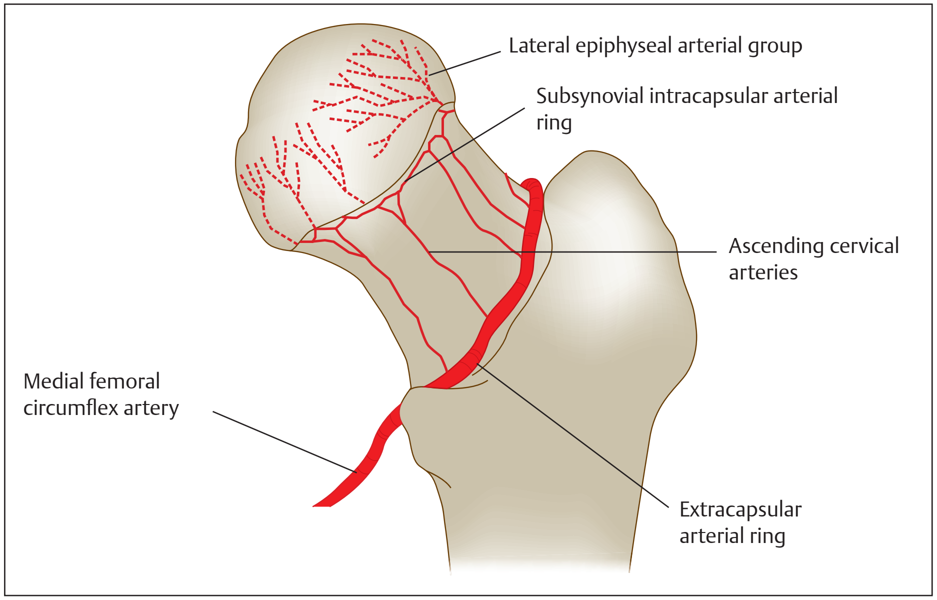


Fig. 1.3 Vascular anatomy.

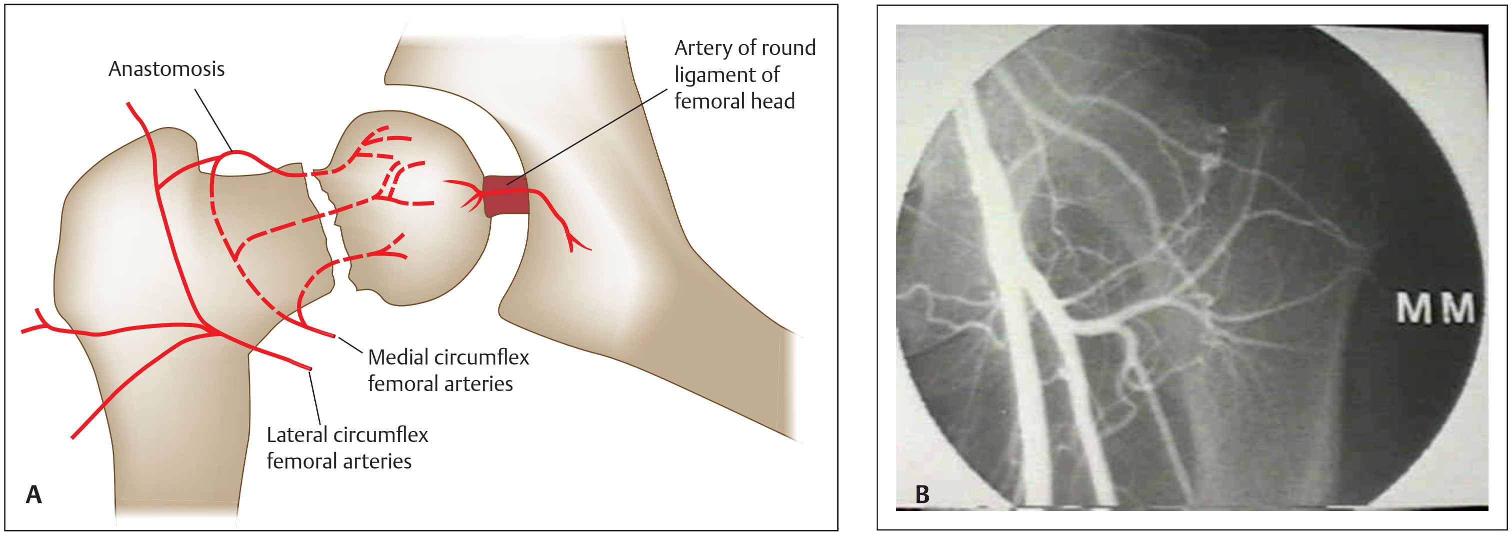


Fig. 1.4 **(A and B)** Vascular disruption after fracture neck femur.

stance and limiting adduction of the extended lower limb. It is the strongest ligament in the body with a tensile strength greater than 350 N[3]. Inferior and posterior to the iliofemoral ligament and blending into its medial edge, the pubofemoral ligament contributes to the strength of the anteroinferior portion of the capsule. This is perhaps the weakest of the four ligaments. Posteriorly, the ischiofemoral ligament completes the main ligamentous constraints—from its ischial attachment medially it inserts laterally on the superolateral aspect of the femoral neck, medial to the base of the greater trochanter.

While the ligamentous capsule is very strong, two weak points can be noted: the first anteriorly between the iliofemoral and pubofemoral ligaments, and the second posteriorly between the iliofemoral and ischiofemoral ligaments. Although dislocation is rare in the native hip, with extreme external trauma, the hip can dislocate through either of these weak points.[2]

There are two further ligaments at the hip joint. One, the ligamentum teres which contributes little in the way of stability to the hip and can be torn in traumatic dislocations. Some propose that it plays a role in joint nutrition.[9]

The second is the zona orbicularis or angular ligament. This encircles the femoral neck like a button hole and again plays little role in stability.

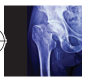
Neurovascular Anatomy

The anterior and posterior portions of the hip have separate innervations. Anteromedially, the joint is supplied by articular braches of the obturator nerve. The anterior aspect is contributed by branches of the femoral nerve. The posterior aspect is innervated laterally by branches of the superior gluteal nerve. Medially contributions come from articular branches from the nerves to quadratus femoris and also articular branches from the sciatic nerve.

Surgeons approaching the hip must be aware of the surrounding neurovascular structures. The key structures anteriorly include the femoral (lateral to medial) nerve, artery, and vein. These run together out from the pelvis underneath the inguinal ligament. They can be located using surface anatomy in slim individuals midway between the anterior superior iliac spine (ASIS) and the pubic tubercle. Fortunately, they are well separated from the hip joint by the iliopsoas muscle.

Posteriorly, the sciatic nerve, arising from the lumbosacral plexus, emerges below the piriformis from the pelvis and enters the thigh between the greater trochanter laterally and the ischium medially. The nerve can be divided high by the piriformis in the greater sciatic foramen in nearly 10 to 12% of the population.[2,3]

Superior to the sciatic nerve, and also exiting through the sciatic notch, are the superior gluteal nerve and accompanying artery. These two structures supply both gluteus medius and minimus while running in a posterior to anterior direction between them. Bleeding can be encountered during the posterior approach to the hip when the rich vascular anastomosis at the lower border of quadratus femoris is encountered.[1,10] This consists of the ascending branch of the first perforating artery, branches of the MCFA and LCFA, and the descending branch of the inferior gluteal artery.[3]



Muscular Anatomy

The musculature of the hip and thigh is invested in a fibrous layer—the fascia lata. This is a continuous fibrous sheath surrounding the thigh. Proximally, it is attached to the inguinal ligament, lip of the iliac crest, posterior aspect of the sacrum, the ischial tuberosity, the body of the pubis, and the pubic tubercle. Its inelasticity functions to limit bulging of the thigh muscles, thus improving the efficiency of their contractions.[3]

The major flexor of the hip joint is iliopsoas. This comprises psoas major and minor, and iliacus. The largest and most powerful extensor of the hip is gluteus maximus. It is also the most superficial. Running from the lateral aspect of the dorsal sacral surface, posterior part of the ilium, and thoracolumbar fascia, it inserts into the iliotibial tract and gluteal tuberosity on the femur.[2,3] It is also involved in external rotation of the hip with innervation from the inferior gluteal nerve. Its upper and lower fibers contribute to abduction and adduction, respectively.

The principal abductors include gluteus medius and minimus. Lying beneath the fascia lata, the proximal insertion of gluteus medius into the iliac crest is almost continuous with it. From its broad-based proximal attachment it appears like an upside-down triangle inserting into a relatively narrow base on the lateral aspect of the greater trochanter.

Gluteus minimus is deep again to gluteus medius arising proximally from the gluteal surface of the ilium and inserting deep to the gluteus medius on the anterolateral aspect of the greater trochanter: both gluteus medius and minimus are innervated by the superior gluteal nerve.

The tensor fascia lata (TFL) runs from the ASIS inserting distally into the iliotibial tract. It is also a flexor of the hip joint and internally rotates it. Piriformis runs laterally from the pelvic surface of the sacrum to the apex of the greater trochanter of the femur. It also contributes to external rotation and extension of the hip. Posteriorly, inferior to the piriformis are the short external rotators, all running in a horizontal fashion. From superior to inferior, these consist of the superior gemelli, obturator internus, inferior gemelli, and quadratus femoris. All play a role in external rotation and adduction of the hip and all receive branches from L5-S1 in the sacral plexus.[2,3]

Hip adductors include the obturator externus arising from the outer surface of the obturator membrane and inserting into the trochanteric fossa. It also contributes to external rotation and has its innervation from the obturator nerve. Adductor longus, magnus, and brevis contributes to external rotation of the hip along with adduction.

As previously stated, the muscles of the hip joint can contribute to movement in several different planes depending on the position of the hip, which is caused by a change in the relationship between a muscle's line of action and the hip's axis of rotation. This is referred to as the "inversion of muscular action" and most commonly manifests as a muscle's secondary function. For example, the gluteus medius and minimus act as abductors when the hip is extended and as internal rotators when the hip is flexed. The adductor longus acts as a flexor at 50 degrees of hip flexion, but as an extensor at 70 degrees.

In addition to providing stability and motion for the hip, muscles act to prevent undue bending stresses on the femur. When the femoral shaft undergoes a vertical load, the lateral and medial sides of the bone experience tensile and compressive stresses, respectively. To resist these potentially harmful stresses, as might occur in the case of an elderly person whose bones have become osteoporotic and susceptible to tensile stress fractures, the TFL acts as a lateral tensioning band.

Types of Trabeculae

1. Principal compressive/medial compressive trabeculae
2. Secondary compressive/lateral compressive trabeculae
3. Principal tensile trabeculae
4. Secondary tensile trabeculae
5. Greater trochanteric trabeculae

The trabeculae in the upper part of femur are arranged in five groups:

1. *The Principal Compressive Group*: This extends from medial cortex of the shaft to the upper end of the head in a slightly curved radial fashion. They are the thickest and most closely packed trabeculae in the upper end of the femur.
2. *The Secondary Compressive Group*: This arises from the medial cortex of the shaft below the principal compressive group and curves upward and laterally toward the greater trochanter. These trabeculae are thin and widely placed.
3. *The Principal Tensile Group*: Thickest among the tensile groups, these trabeculae arise from the lateral cortex immediately below the greater trochanteric group and are curved upward and inward across the neck of the femur to end in the inferior portion of the femoral head.
4. *The Secondary Tensile Group*: Trabeculae of this group arise from the lateral cortex below the principal tensile group and arch upward and medially across the upper end of the femur and end irregularly after crossing midline.
5. *The Greater Trochanteric Group*: Consists of some slender poorly defined trabeculae arising from the lateral cortex just below the greater trochanter and sweep upward to end near its superior surface.

In the neck of the femur, principal compressive, principal tensile, and secondary compressive trabeculae enclose a roughly triangular area containing some thin loosely arranged trabeculae. This area is called Ward triangle. Singh et al[11] graded the osteoporosis according to the trabecular pattern loss as follows (**Fig. 1.5**):

Grade VI: Normal, all groups of trabeculae visible on roentgenogram.

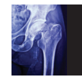
Grade V: There is an apparent accentuation of the structure of the principal compressive and principal tensile group of the trabeculae. Secondary tensile trabeculae are no longer clearly visible and Ward triangle looks empty and more prominent.

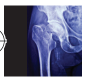
Grade IV: Tensile trabeculae are markedly reduced in number. The secondary compressive trabeculae are completely resorbed so that the Ward triangle opens up lateral side. Primary tensile trabeculae can however be traced in the outer portion continuous from the lateral cortex to the femoral head.

Grade III: It indicates definite osteoporosis. There is break in continuity of the principal tensile trabeculae opposite the greater trochanter, but they are clearly seen in the upper part of the femoral neck where they are still comparable to the principal compressive group in density.

Grade II: Only prominent trabeculae visible are principal compressive group. All other groups are being more or less completely resorbed. It is an index of moderately advanced osteoporosis.

Grade I: Even the principal compressive trabeculae do not stand out in the roentgenogram and are markedly reduced in number. It indicates severe osteoporosis.





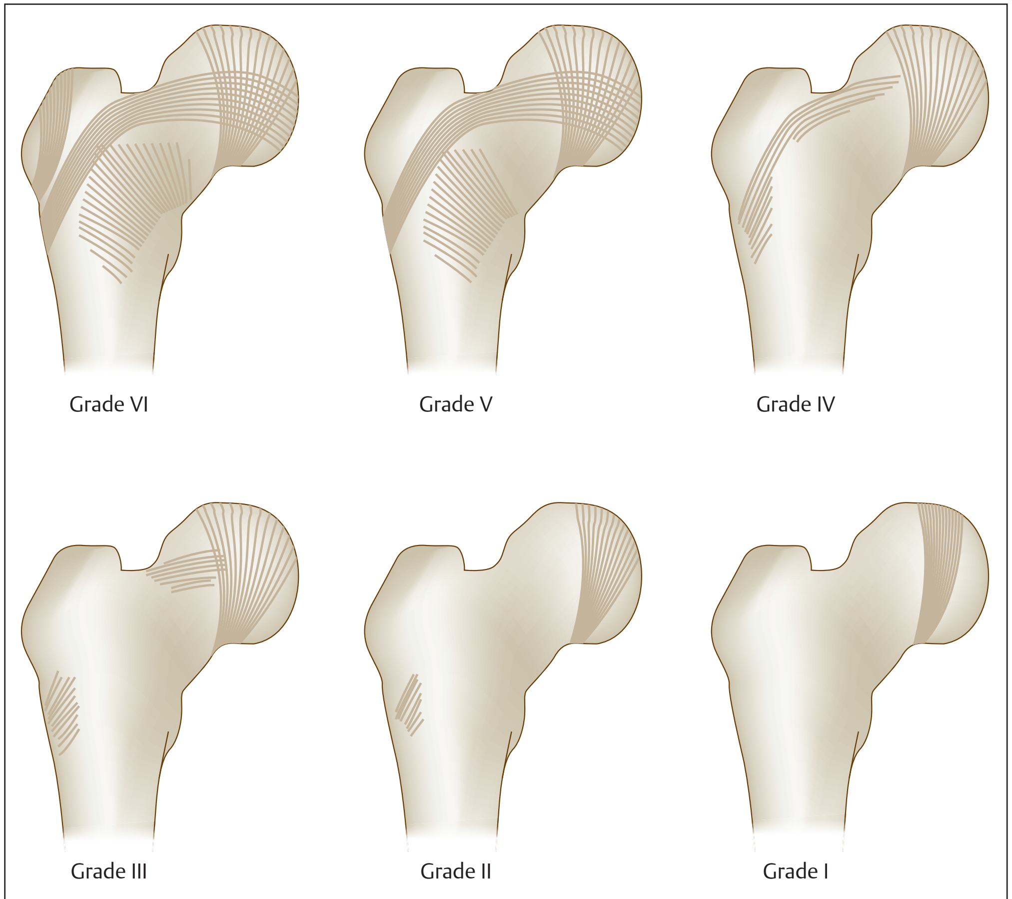


Fig. 1.5 Singh index on osteoporosis according to the trabecular pattern.

Biomechanics of the Hip

The importance of the normal hip in any athletic activity is emphasized by the role this joint plays in movement and weight bearing. Some areas that have benefited from advances in hip biomechanics include the evaluation of joint function, the development of therapeutic programs for treatment of joint problems, procedures for planning reconstructive surgeries, and the design and development of total hip prostheses.[12] Biomechanical principles also provide a valuable perspective to our understanding of mechanism of injury.

Two-Dimensional Analysis of Joint Forces at the Hip Joint

Basic analytical approaches to the balance of forces and moments about the hip joint can be useful in estimating the effects of alterations in joint anatomy or different treatment modalities on the hip joint reaction force.[12] The static loading of the hip joint has been frequently approximated with a simplified, two-dimensional analysis performed in the frontal plane. When the weight of the body is being borne on both legs, the center of gravity is centered between the two hips and its force is exerted equally on both hips. Under these loading conditions, the weight of the body minus the weight of both legs is supported equally on the femoral heads, and the resultant vectors are vertical. In a single leg stance, the effective center of gravity moves distally and away from the supporting leg since the non-supporting leg is now calculated as part of the body mass acting upon the weight-bearing hip. This downward force exerts a turning motion around the center of the femoral head—the moment is created by the body weight, and its moment arm, a distance from femur to the center of gravity.

The muscles that resist this movement are offset by the combined abductor muscles. This group of muscles includes the upper fibers of the gluteus maximus, the TFL, the gluteus medius and minimus, and the piriformis and obturator internus. The force of the abductor muscles also creates a moment around the center of the femoral head; however, this moment arm is considerably shorter than the effective lever arm of body weight. Therefore, the combined force of the abductors must be a multiple of body weight.

The magnitude of the forces depends critically on the lever arm ratio, which is that ratio between the body weight moment arm and the abductor muscle moment arm (a:b).[13] Typical levels for single leg stance are three times bodyweight, corresponding to a level ratio of 2.5. Thus, anything that increases the lever arm ratio also increases the abductor muscle force required for gait and consequently the force on the head of the femur as well.

People with short femoral necks have higher hip forces, other things being equal. More significantly, people with a wide pelvis also have larger hip forces. This tendency means that women have larger hip forces than men because their pelvis must accommodate a birth canal.[14] This fact may be one reason that women have relatively more hip fractures and hip replacements because of arthritis than men do. It is also conceivable that this places women at a biomechanical disadvantage with respect to some athletic activities, although studies do not always show gender differences in the biomechanics of running, particularly endurance running.[15]

Normally the tissues and bones of the hip joint function without causing pain, but various diseases and injuries can damage the tissues so that the deformations associated with loading are painful.[13]

Management of painful hip disorders aim to reduce the joint reaction force. Bearing in mind the basic principles outlined, this can be achieved by reducing the body weight or its moment arm, or helping the abductor force or its moment arm. Increase in body weight will have a particularly harmful effect on the total compressive forces applied to the joint.

The effective loading of the joint can be significantly reduced by bringing the center of gravity closer to the center of the femoral head (decrease the moment arm b). This can be accomplished by limping, however the lateral movements required take a considerable amount of energy and is a much less efficient means of ambulation.

Another strategy to reduce joint reaction force involves using a cane or walking stick in the opposite hand. The moment produced from both the cane and abductor muscles together produce a moment equal and opposite to that produced by the effective body weight.

The two-dimensional static analysis indicates that the joint reaction force can be reduced by 50% (from 3 times body weight to 1.5 times body weight) when approximately 15% body weight is applied to the cane.[12] The substantial reduction in the joint reaction force, predicted when a cane is used for support, arises because the cane–ground reaction force acts at a much larger distance from the center of the hip than the abductor muscles. Thus, even when a relatively small load is applied to the cane, the contribution it makes to the moment opposing body weight is large enough to significantly decrease the demand placed on the abductor muscles (**Figs. 1.6 and 1.7**).

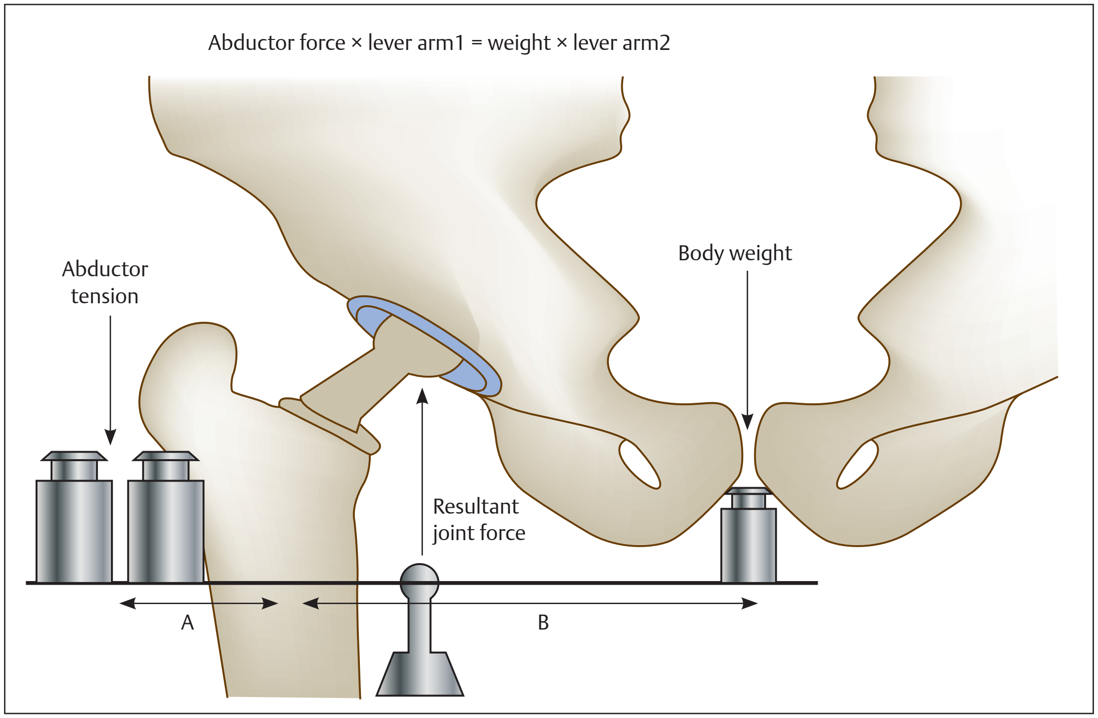


Fig. 1.6 Forces on hip.

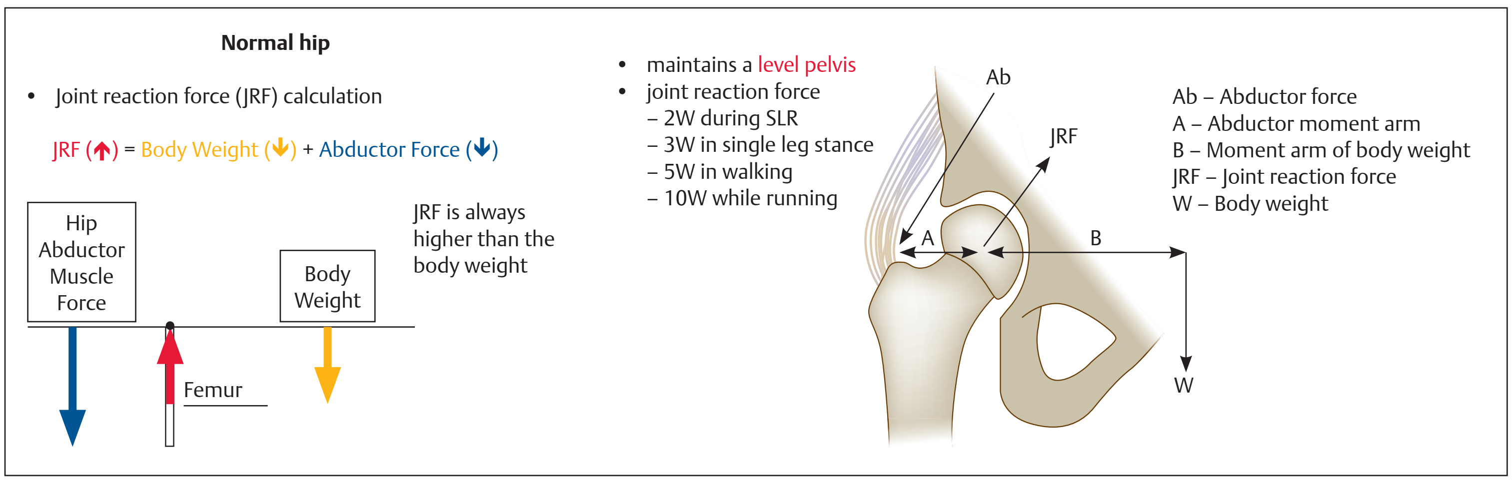


Fig. 1.7 Joint reaction forces.

In Vivo Measurements of Joint Forces at the Hip

Walking transmits significant body weight to the hip joint, while jogging, running, and contact sports generate significantly greater forces. To verify the estimates of hip joint forces made using free-body calculations, many in vivo measurements have been performed using prostheses and endoprostheses instrumented with transducers (strain gauges). Rydell was the first to attempt measuring direct hip joint forces using an instrumented hip prosthesis,[16] which yielded force magnitudes of 2.3 to 2.9 times body weight for single leg stance and 1.6 to 3.3 times body weight for level walking.[17]

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