Summary

The hip is a unique joint that possesses both mobility and stability because of its anatomic configuration. This joint is crucial to athletic activities involving the lower extremity, such as running, jumping, and kicking, as well as to the generation and transference of forces for activities involving the upper extremity. The tremendous loads that the hip withstands result from muscular, gravitational, and joint reaction forces inherent in weight-bearing. This article reviews the anatomy and biomechanics of the hip as a foundation for the evaluation and treatment of athletes with hip disorders.

Key Words: Hip, Anatomy, Biomechanics

Anatomy of the Hip

Osseous Anatomy

The hip joint is a highly congruent ball-and-socket joint comprising the acetabulum and femoral head. The concavity of the acetabulum develops in response to the presence of a spherical femoral head. Within the acetabulum of a child, the physis of the ilium, ischium, and pubis converge as the triradiate cartilage. Embryologically, the acetabular fossa is discernible by 8 weeks to 9 weeks of fetal development. By the 17th week of development, the joint cavity has cleaved with the formation of a synovial layer. Ossification of this phisreal complex is completed by the age of 16 years to 18 years. The acetabular opening is oriented in an anterior, lateral, and inferior direction, whereas the head of the femur faces the acetabulum in a medial, cranial, and anterior direction. The coverage of the weightbearing surface of the femoral head is primarily related to the degree of inferior acetabular tilt as measured by the center-edge angle of Wiberg. This angle is formed by one line connecting the lateral rim of the acetabulum with the center of the femoral head, and a second line extending vertically from the center of the femoral head (Fig. 1). A center edge angle of less than 20° is considered abnormal and implies an acetabulum with a more vertical orientation with less coverage of the femoral head.

The acetabular labrum is a fibrocartilaginous structure attached to the bony acetabular rim analogous to the labrum of the shoulder. The labrum deepens the acetabulum from less than one-half of its spherical volume to greater than one-half of this volume, thus adding stability to the joint. The labrum is widest at the posteroinferior acetabular quadrant (mean, 6.4 mm ± 1.7 mm) and thickest at the anterosuperior quadrant (mean, 5.5 mm ± 1.5 mm).

The hyaline articular cartilage of the acetabulum is thickest (range, 1.75 mm–2.5 mm) at the superior region where the weightbearing forces are greatest, and thinnest at the posteromedial region (range, 0.75 mm–1.25 mm). A central, nonarticulating depression, known as the acetabular fossa, is occupied by a fat pad known as the pulvinar. This fibrofatty tissue contains vascular branches from the obturator artery and nerve endings from the posterior branch of the obturator nerve. The articular cartilage surface of the acetabulum surrounds this fossa in a horseshoe configuration with a gap inferiorly. The transverse acetabular ligament—the inferior continuation of the acetabular labrum—traverses this nonarticulating notch. The ligamentum teres passes from the acetabular fossa...
to the fovea centralis on the medial aspect of the femoral head, slightly posterior and inferior to center. This strong triangular-shaped structure is attached inferiorly to the transverse acetabular ligament and is composed of well-organized collagen fibers in a banded configuration. The exact function of this ligament is unclear, though it likely assists in stabilization of the hip because its rupture often gives rise to symptoms of hip instability and pain.

The head of the femur forms approximately two-thirds of a sphere with a diameter in the range of 45 mm to 56 mm in the adult. It is entirely covered with hyaline cartilage except for the fovea centralis. The hyaline cartilage covering the femoral head is thickest (approximately 2.5 mm) on its superior, medial, and slightly posterior surface. Accordingly, it is this region of the femoral head that is the primary contact point with the acetabulum during weightbearing.

The neck of the femur is approximately 5 cm long in the adult. The angle of inclination between the femoral neck and femoral shaft in the frontal plane is 125° ± 5° in the skeletally-mature hip, though this angle can be as great as 150° in the newborn. In the axial plane, the femoral neck forms an angle of torsion with the transcondylar axis of the femur. This angle is oriented anteriorly an average of 14° in adults. At the junction of the femoral neck and shaft, the greater trochanter projects superolaterally and the lesser trochanter projects posteromedially. The orientation of these bony prominences significantly influences the function of the muscles that insert on them (see below).

During weightbearing activities, the proximal femur is subjected to tremendous tensile and compressive stresses, especially at the intertrochanteric and subtrochanteric regions. Trabecular bone patterns develop to resist these deforming forces. Ward described these trabecular patterns and attributed their orientation to the directional alignment of weight-bearing stress exerted on the proximal femur (Fig. 2). These trabeculae consist of a primary compressive group, which arises from the medial subtrochanteric cortex and ascends superiorly into the weightbearing femoral head, and a primary tensile group, which spans from the foveal area of the femoral head, through the superior femoral neck, and into the lateral subtrochanteric cortex. Secondary compressive, secondary tensile, and a greater trochanteric group complete the pattern of trabecular orientation. The calcar femorale is a dense plate of bone extending laterally from the posteromedial femoral cortex to the posterior aspect of the greater trochanter. The calcar is thickest at its medial aspect and gradually thins as it extends laterally.

Capsular Anatomy

A strong fibrous capsule encloses the hip joint that aids in the maintenance of hip stability. Proximally, the capsule attaches to the bony rim of the acetabulum approximately 6 mm to 8 mm from the labrum. At its distal (femoral) insertion, the anterior capsule attaches to the intertrochanteric line and greater trochanter, whereas the posterior capsule attaches just proximal to the posterior intertrochanteric line. Although most of the capsular fibers run longitudinally parallel to the femoral neck, a smaller subset of fibers, the zona orbicularis, encircles the femoral neck. This condensed group of circular fibers reinforces the hoop stresses encountered by the acetabular labrum. The inner surface of the capsule is lined by the synovium of the hip joint. The synovial lining also covers the acetabular fossa, labrum, and intracapsular portion of the femoral neck.

Three extracapsular ligaments connect the pelvis and femur to reinforce the hip capsule (Fig. 3). These ligaments are tight with the hip in extension, and are most slack in the combined positions of flexion, abduction, and external rotation. The iliofemoral ligament (ligament of Bigelow) is the strongest of the three. It extends from the anterior inferior
iliac spine (in two separate bands) to the anterior ilio¬
trochanteric line in an inverted-Y configuration. The primary role of the iliofemoral ligament is to resist hyperextension of the hip.12 The pubofemoral ligament attaches proximally to the superior pubic ramus and distally to the inferior femoral neck in order to provide resistance to hip hyperabduction.12 The ischiofemoral ligament, the thinnest of the three, extends from the ischial rim of the acetabulum, across the posterior¬
femoral aspect of the hip joint, to insert on the femoral neck. Its primary function is to stabilize the joint in extension.12

Blood Supply

The hip joint receives its blood supply from several sources. The acetabulum is supplied by three main arteries: the obturator, the superior gluteal, and inferior gluteal (Fig. 4A). The superior gluteal artery supplies both the superior and posterior portions of the acetabulum, and the inferior gluteal artery supplies the inferior and posterior portions.8 The acetabular branch of the obturator artery provides the primary blood supply to the medial aspect of the acetabulum.4 A smaller, terminal branch of the posterior division of the obturator artery, known as the foveal artery, traverses the ligamentum teres to supply a small area of the femoral head around the fovea centralis.12 The recess between the capsule and labrum is lined with highly vascularized, loose connective tissue. A group of three to four small blood vessels is found in a circumferential pattern within the substance of the labrum and along the labrum–bone junction.5

The medial and lateral circumflex femoral arteries sup¬ply the blood flow to the majority of the femoral head and neck (Fig. 4B). The lateral epiphyseal artery, a branch of the medial circumflex artery, is of particular importance because it supplies more than one-half of the femoral head.13 The ascending artery, which arises from the lateral circumflex artery, pierces the joint capsule close to its femoral attach¬ment and gives off multiple subsynovial retinacular arteries that ascend parallel to the femoral neck (Fig. 4B). These arteries are prone to interruption of flow in the presence of increased intracapsular pressure from either infection or frac¬ture.14


FIG. 4. Vascular supply to the hip joint. A: The blood supply to the acetabulum is provided by branches of the obturator, superior gluteal, and inferior gluteal arteries. B: The blood supply to the femoral head and neck is provided by the medial and lateral circumflex femoral arteries, both direct branches of the femoral artery.
Joint Innervation

Similar to its vascular supply, the hip joint receives multiple innervations primarily involving the hip capsule. The posterior articular nerve, a branch of the nerve to the quadratus femoris,\(^4\) provides the most extensive nerve supply to the hip joint, including the posterior and inferior regions of the capsule and the ischiofemoral ligament.\(^4\) Superiorly, the hip capsule is innervated by the superior gluteal nerve. Anterior innervation of the capsule is provided, primarily, by direct branches of the femoral nerve. However, the anteromedial and anteroinferior regions are supplied by the medial articular nerve, which arises from the anterior division of the obturator nerve.\(^4\) The ligamentum teres is innervated by the posterior branch of the obturator nerve.\(^7\) Sensory nerve end organs and ramified free nerve endings are found in the acetabular labrum, suggesting that the labrum may provide nociceptive and proprioceptive feedback to and from the hip joint.\(^16\)

Muscles of the Hip: Their Actions and Innervations

Almost two dozen muscles act on the hip joint to produce six fundamental motions: flexion, extension, abduction, adduction, internal rotation, and external rotation (Table 1). Many of these muscles have several actions on the hip joint that depend on joint position. Furthermore, in the case of muscles spanning both the hip and the knee, the position of the knee affects the function of the muscles on the hip.

The strongest hip flexor is a muscular complex known as the iliopsoas, which is comprised of the psoas major, psoas minor, and iliacus muscles.\(^4\) This muscle group originates from the transverse processes of the 12th thoracic through the fifth lumbar vertebrae, anterior surface of the iliac crest, and anterior sacrum. These three muscles merge distally to form a singular tendinous insertion on the lesser trochanter.\(^4\) Other hip flexors include the rectus femoris and the sartorius, though they are clearly secondary to the iliopsoas in regard to force generation.\(^4\)

### TABLE 1. Muscles active on the hip joint: their origin, insertion, and innervation

| Action         | Muscle                  | Origin                                                              | Insertion                             | Innervation                              |
|----------------|-------------------------|                                                                     |                                      |                                         |
| Flexion        | Iliopsoas (iliacus, psoas major, psoas minor) | T12–L5 transverse processes, iliac crest, and sacrum              | Lesser trochanter                     | Femoral nerve                           |
|                | Rectus femoris          | AIIS and anterosuperior acetabulum                                 | Superior patella                      | Femoral nerve (L2–L4)                   |
|                | Tensor fascia latae     | ASIS and iliac crest                                               | Iliotibial tract                      | Superior gluteal nerve (L4, L5)         |
|                | Sartorius               | ASIS                                                                | Anteromedial tibial plateau           | Femoral nerve (L2, L3)                  |
| Extension      | Gluteus maximus         | Outer cortex of ilium, posterior sacrum and coccyx                 | Posterior iliotibial tract and gluteal tuberosity | Inferior gluteal nerve (L5, S1, S2)   |
|                | Biceps femoris          | Ischiatic tuberosity                                               | Fibular head and posterolateral tibial plateau | Tibial branch of sciatic nerve (L5, S1, S2) |
|                | Semimembranosus         | Ischiatic tuberosity                                               | Postero medial tibial plateau         | Tibial branch of sciatic nerve (L5, S1, S2) |
|                | Semitendinosus          | Ischiatic tuberosity                                               | Antero medial tibial plateau          | Tibial branch of sciatic nerve (L5, S1, S2) |
| Abduction      | Gluteus medius          | Anterior gluteal line                                              | Lateral surface of greater trochanter | Superior gluteal nerve (L4, L5, S1)     |
|                | Gluteus minimus         | Outer cortex of ilium                                              | Anterior surface of greater trochanter | Superior gluteal nerve (L5, S1)         |
| Adduction      | Tensor fascia latae     | ASIS and iliac crest                                               | Iliotibial tract                      | Superior gluteal nerve (L4, L5)         |
|                | Adductor magnus         | Inferior pubic ramus, ischiatic tuberosity                        | Gluteal tuberosity and adductor tubercle of medial femur | Obturator nerve (L2, L3) and sciatic nerve (L2–L4) |
|                | Adductor longus         | Body of pubis                                                      | Middle third of linea aspera          | Obturator nerve (L2–L4)                 |
|                | Adductor brevis         | Inferior ramus and body of pubis                                  | Proximal linea aspera and pectineal line | Obturator nerve (L2–L4)                 |
| Internal rotation | Gluteus medius          | Anterior gluteal line                                              | Lateral surface of greater trochanter | Superior gluteal nerve (L4, L5, S1)     |
|                | Gluteus minimus         | Outer cortex of ilium                                              | Anterior surface of greater trochanter | Superior gluteal nerve (L5, S1)         |
| External rotation | Tensor fascia latae     | ASIS and iliac crest                                               | Iliotibial tract                      | Superior gluteal nerve (L4, L5)         |
|                | Obturator internus      | Inner surface of obturator membrane                                | Medial greater trochanter             | Nerve to obturator internus (L5, S1)    |
|                | Obturator externus      | Outer surface of obturator membrane, pubic ramus, and ischiatic membrane | Trochanteric fossa                   | Obturator nerve (L3, L4)               |
|                | Superior gemellus       | Ischiatic spine                                                    | Posterior greater trochanter          | Nerve to obturator internus (L5, S1)    |
|                | Inferior gemellus       | Ischiatic tuberosity                                               | Posterior greater trochanter          | Nerve to quadratus femoris             |
|                | Piriformis              | Anterior surface of sacrum and sacrotuberous ligament              | Posterosuperior greater trochanter    | Ventral rami of S1 and S2              |
|                | Quadratus femoris       | Lateral border of ischiatic tuberosity                             | Quadrate tubercle                     | Nerve to quadratus femoris              |

Adapted from Robbins.\(^4\)

AIIS = anterior inferior iliac spine; ASIS = anterior superior iliac spine.
The gluteus maximus, a large and powerful muscle that inserts on the posterolateral iliotibial tract and gluteal tuberosity, is the chief extensor of the hip. The three hamstring muscles—the biceps femoris, semimembranosus, and semitendinosus—originate at the ischial tuberosity and cross the knee joint to insert on the posteromedial tibial plateau (semitendinosus) and fibular head (biceps femoris). These three muscles also function as hip extensors when the knee is in an extended position.

The main abductors of the hip are the gluteus medius and gluteus minimus, both originating from the outer cortex of the ilium and inserting on the greater trochanter. Compromise in the function of the hip abductors can lead to a Trendelenburg gait pattern manifested as a compensatory upper-body shift towards the involved side in order to maintain the center of gravity over the compromised hip joint, thus preventing pelvic drop.

The primary hip adductors are the adductor longus, adductor brevis, and adductor magnus. These muscles originate from the inferior pubic rami, ischial tuberosity, and pubis, with insertion sites on the adductor tubercle (adductor magnus) and along the linea aspera located on the medial aspect of the femur.

Although no muscle group acts as the primary internal rotator of the hip, the tensor fascia latae, anterior portion of the gluteus medius, and gluteus minimus work in concert to cause internal hip rotation as a secondary function. External hip rotation is produced by a group of small muscles that originate at the pelvis and insert primarily along the posterior aspect of the greater trochanter and proximal femur. These muscles include the obturator internus, obturator externus, superior gemellus, inferior gemellus, piriformis, and quadratus femoris.

BIOMECHANICS OF THE HIP WITH IMPLICATIONS FOR THE ATHLETE

There is considerable literature addressing hip biomechanics during static weightbearing conditions (e.g., single- and double-leg stance) and dynamic situations (e.g., walking and stair-climbing). Despite the relevant role played by the hip joint in various athletic pursuits, there has been relatively little written pertaining to hip biomechanics in the athletic population.

Hip Motion

The hip possesses great stability because of its anatomic congruity, and also has considerable mobility within six degrees of freedom. Hip range of motion is greatest in the sagittal plane. Active hip flexion is 120° with the knee flexed and 90° with the knee fully extended. Passive hip flexion is approximately 140° with the knee flexed. Active hip extension is 10° to 20°, and passive extension is as much as 30°. Tightness of the rectus femoris or the iliofemoral ligament can limit hip extension when the knee is flexed. Normal hip abduction is at least 50° and adduction 30° (limited by the opposite extremity and the tensor fascia lata). Internal and external rotation of the flexed hip may range from 0° to 70° and 0° to 90°, respectively. Internal rotation is limited by the short external rotator muscles (obturator internus and externus, superior and inferior gemelli, quadratus femoris, and piriformis) and the ischiofemoral ligament. External rotation is limited by the lateral band of the iliofemoral ligament, the pubofemoral ligament, the internal rotator muscles, and the degree of femoral neck anteversion. Ultimately, the degree of hip motion in each plane is dependent upon the overall flexibility of the athlete. Certain sports, such as gymnastics, demand more hip flexibility than other sports, such as marathon running. As people age, there is a progressive decrease in the range of ambulatory hip motion because of a corresponding decrease in stride length.

Gait Cycle: Walking

The hip joint has the primary role of lower extremity advancement during gait. The arc of hip motion during the walking cycle is approximately 40° to 50°, with an average of 30° to 40° of flexion and 5° to 10° of extension. The walking gait cycle consists of two phases: the stance phase, which is 60% of the cycle, and the swing phase, which constitutes the remaining 40%. The stance phase is considered the period during which the foot is on the ground, beginning at initial contact and ending at toe-off. There is a double-support phase in which both feet are on the ground for approximately 20% of the total gait cycle. It is this portion of the gait cycle that defines walking. Perry has further subdivided the stance phase into five secondary phases: initial contact, loading response, midstance, terminal stance and preswing (Fig. 5). The swing phase is defined as the period during which the foot is in the air, beginning at toe-off and ending at initial heel contact. This phase has also been subdivided into three secondary phases: initial swing, midswing, and terminal swing (Fig. 5).

During the double-support phase of walking, the body’s center of gravity falls just posterior to the axis of the hip joint in the sagittal plane, creating a slight posterior tilt of the pelvis on the femoral head. This rotatory tilt is counterbalanced by the passive tension of the anterior hip capsule and extracapsular ligaments. As a result, little or no muscle activity is needed to maintain this sagittal plane equilibrium.

Both internal and external rotational motions occur at the pelvis, femur, and tibia during the walking cycle. Total pelvic rotation spans a 10° arc. Maximum internal rotation is seen at initial ground contact, reaching a maximum at approximately 15% of the gait cycle. Maximum external rotation occurs at toe-off. The pelvis also demonstrates rotatory motion in the sagittal (anterior tilt) and coronal (pelvic drop) planes of 4° and 7°, respectively (Fig. 6). Muscle activity during the gait cycle is a coordinated sequence of events resulting in the smooth transition from one phase to the next. At initial ground contact, the hamstrings and gluteus maximus contract to aid in hip extension. At midstance, the abductors stabilize the pelvis with the
gluteus medius and gluteus minimus, providing lateral stabilization into terminal stance. The gluteus maximus, gluteus medius, and probably the gluteus minimus increase activation intensity throughout the loading response of the stance phase and then taper off by the end of midstance. The posterior fibers of the tensor fascia lata exhibit moderate activity at the onset of the loading response (25% of manual muscle testing). The anterior fibers activate later and to a lesser degree (10% of manual muscle testing), but their activity persists into terminal stance. The role of the iliotibial band during the walking cycle is based on functional interpretations of previous investigators who suggested that this structure acts as a dynamic tension band, or guy wire, which can reduce femoral diaphyseal bending stresses by as much as 30%.

In the transition from stance to swing, the hip flexors (iliopsoas, rectus femoris, sartorius, and anterior fibers of the iliotibial band) advance the limb from preswing to midswing. The rectus femoris is the first muscle to activate in preswing. It is followed by contractions of the sartorius and the iliacus in early swing. The gracilis and other adductors are also active during initial swing, though only for a short time.

The hip adductors and hamstrings activate during the transition from the swing to the stance phase because the dynamic forces controlling the limb tend to flex and abduct the hip. These muscles also function to control acceleration of the hip joint to ensure the precise placement of the foot on the support surface in anticipation of stance. The concentric–eccentric coactivation of agonist–antagonist muscle groups during the transition of joint directional motion helps to stabilize the hip but also increases the forces on the joint. The muscle activities, motion measurements, and their timing during all eight phases of gait are summarized in Table 2.

**Gait Cycle: Running**

An understanding of the walking gait cycle is useful because it can be used to compare the differences between walking, jogging, and running. During the walking cycle, one foot is on the ground at any one time. As the pace of walking becomes progressively faster, the single-stance phase lengthens in proportion to the degree of shortening of the double-stance phase. Running is defined as occurring when the double-stance phase is omitted during the gait cycle. It is at this point that a float phase, a period of non-support where both feet are off the ground, occurs that lasts approximately 30% of the gait cycle. The total period of weightbearing is also reduced in running, compared with walking, such that the swing phase constitutes 70% of the running gait cycle and
the stance phase makes up the remaining 30% 35 (Fig. 7). This is in contrast to the 40% to 60% swing–stance ratio noted during walking.

One of the other significant differences between the walking and running cycle is the decrease in total cycle time. An average walker takes 120 steps per minute with a gait cycle time of 1 second. 34 A jogger traveling at a pace of 6 mph has a cycle time of 0.7 seconds, whereas a runner moving at a pace of 12 mph has a gait cycle lasting only 0.6 seconds. Therefore, the duration of the run cycle is 60%, and the jog cycle is 70% of the duration of the walk cycle. 36 This reduction in total weightbearing time during running implies a corresponding reduction in the time allocated for shock absorption, deceleration, foot stabilization, and acceleration.

Several subtle changes occur in the running gait cycle when the velocity of running increases. First, there is an increase in total hip range of motion. 37 Second, the center of gravity of the leg approaches the hip because of the increased degree of knee flexion. Therefore, less torque is needed to bring the leg forward during swing despite the higher angular velocity and acceleration. 37 Third, the rectus femoris demonstrates more activity as a hip flexor in the swing phase than a knee extensor in the stance phase when the velocity of gait increases. 37

During running, the forward propulsion of the body occurs from the swinging leg and arm motion rather than from the stance limb, as verified by electromyographic studies. 38,39 The concentric contractions that propel the body forward with the greatest amplitude are the hip flexors (iliopsoas and rectus femoris) and knee extensors (vastus intermedius, vastus medialis, and vastus lateralis) during late swing. 38

Many of the biomechanical events described during running occur simultaneously to produce a coordinated sequence of movements in both the upper and lower extremities. The body’s center of gravity reaches peak height during the float phase. There is also a slight forward lean throughout the running cycle, primarily because of increased hip flexion. The differences in flexion–extension and abduction–adduction of the hip during walking, jogging, and running are illustrated in Figure 8.

Before initial contact, there is a reversal of hip flexion, rapid knee extension, and dorsiflexion of the ankle. These events prepare the body for impact at the terminal float phase. Once impact occurs, there is a ground reaction force of

---

**TABLE 2. Eight phases of the gait cycle**

<table>
<thead>
<tr>
<th>Phase of Gait</th>
<th>Hip Position</th>
<th>Active Muscle(s)</th>
<th>Occurrence During Cycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stance</td>
<td></td>
<td></td>
<td>0–2</td>
</tr>
<tr>
<td>Initial contact</td>
<td>30° of flexion</td>
<td>Hamstrings and gluteus maximus</td>
<td></td>
</tr>
<tr>
<td>Loading response</td>
<td>30° of flexion</td>
<td>Hamstrings and gluteus maximus</td>
<td>0–10</td>
</tr>
<tr>
<td>Midstance</td>
<td>0° of flexion-extension</td>
<td>Gluteus medius, gluteus minimus, and tensor fascia lata</td>
<td>10–30</td>
</tr>
<tr>
<td>Preswing</td>
<td>10° of extension</td>
<td>Iliacus</td>
<td>30–50</td>
</tr>
<tr>
<td>Terminal stance</td>
<td>0° of flexion-extension</td>
<td>Iliacus and adductor longus</td>
<td>50–60</td>
</tr>
<tr>
<td>Swing</td>
<td></td>
<td></td>
<td>60–73</td>
</tr>
<tr>
<td>Initial swing</td>
<td>20° of flexion</td>
<td>Iliopsoas, rectus femoris, gracilis and sartorius</td>
<td></td>
</tr>
<tr>
<td>Midswing</td>
<td>20° to 30° of flexion</td>
<td>Iliopsoas, gracilis, and sartorius</td>
<td>73–87</td>
</tr>
<tr>
<td>Terminal swing</td>
<td>30° of flexion</td>
<td>Hamstrings and gluteus maximus</td>
<td>87–100</td>
</tr>
</tbody>
</table>

---

**FIG. 7. The running gait cycle. Adapted from Montgomery. 38**
approximately 150% to 200% body weight, a forward shear force of 50% body weight, and a medial shear force of 10% body weight. These forces are distributed throughout the joints of the lower extremity.

All of the muscles of the lower extremity increase activity as the pace of running increases. There is also a significant increase in the percentage of the gait cycle demonstrating muscle activity as the running pace increases. This phenomenon is necessary for the maintenance of joint stability throughout the lower extremity. The degree of eccentric muscle contraction about the hip also increases as the pace of running increases.

Muscle activity about the hip during running has been individually quantified as in the walking cycle (Fig. 9). The hip abductors possess the same period of activity at all gait speeds. They become active in late swing and remain active for 50% of the stance phase. The peak power of the hip abductors is approximately 1 watt/kg. The hip abductors function to stabilize the stance leg hemipelvis at the time of initial contact to prevent excessive sagging of the swing leg hemipelvis. The hip adductors are active during the last third of the stance phase in walking but are active throughout the entire stance and swing phases of jogging and running.

The adductor magnus, gluteus maximus, and tensor fascia lata are all active during the loading response of the stance phase to stabilize the hip when there is forward momentum (Fig. 9). Thus, as the lower extremity accepts the body’s weight, the muscles about the hip and knee contract to stabilize these joints. At heel strike, there is a rapid extension of the hip, flexion of the knee, and dorsiflexion of the ankle. Internal rotation of the entire limb produces calcaneal eversion and a subsequent unlocking of the transverse tarsal joints. This results in a flexible foot that helps absorb energy at impact.

Adduction of the hip also occurs at the time of impact. Once the swinging leg has passed the stance leg and the center of gravity is in front of the stance leg, the pelvis begins to externally rotate, which is initiated by the swinging leg. This external pelvic rotation causes progressive inversion of the calcaneus and subsequent stabilization of the transverse tarsal joint and long arch of the foot. This hindfoot stabilization lasts for half of the stance phase before the onset of knee flexion.
extension and ankle plantar flexion, which mark the beginning of push-off.39

The long head of the biceps acts to initiate hip extension in the stance phase of running as the center of gravity moves in front of the knee (Fig. 9). There is also progressive abduction of the hip as the joint extends. Progressive hip extension during the stance phase is accomplished through the synergistic function of both the hamstrings and gluteus maximus muscles.39 The rectus femoris, iliopsoas, tensor fascia lata, and adductor magnus are all active to control hip extension and prepare the hip for flexion. The action of these muscles during the loading phase also helps with hip joint stability in both the sagittal and coronal planes.38

The hamstrings have longer periods of activity in the swing and stance phases of jogging and running, compared with walking. The hamstrings are active for the last 50% of the swing phase in jogging and for the last 25% of the swing phase in running.39 They are active during the initial 50% of the stance phase of both jogging and running, and they function synergistically with the gluteus maximus to bring about rapid hip joint extension during running.39 The short head of the biceps acts primarily to control the knee and has little or no function at the hip.

During the swing phase of the running cycle, there are concurrent concentric and eccentric contractions of the various muscles controlling the hip.38 In midswing, the iliopsoas and rectus femoris exhibit peak concentric activity as hip flexors (Fig. 9). The tensor fascia lata and adductor magnus also assist in hip flexion and function to stabilize the pelvis. The semimembranosus and long head of the biceps contract eccentrically to control hip flexion. The gluteus maximus assists the hamstrings in this function, but only during a rapid running pace.38 In late swing, the semimembranosus, long head of the biceps, and gluteus maximus are all eccentrically active in initiating hip extension in order to limit hip flexion (with assistance from the adductor magnus, which can extend the hip from a flexed position). The semimembranosus and long head of the biceps act primarily on the hip and do not assist the short head of the biceps in producing knee flexion.34,38,39 The rectus femoris eccentrically controls knee flexion while concentrically flexing the hip during the swing phase.

At the beginning of the float phase, there is rapid hip flexion by the iliopsoas and rectus femoris and corresponding passive knee flexion and ankle dorsiflexion.39 In mid-float, hip flexion is at its peak and active knee extension begins. Rapid adduction of the hip occurs during the last half of swing. At terminal swing, there is a rapid reversal of hip flexion, the initiation of hip extension, and knee extension.36 During the last 25% of swing, the hip extensors, hamstrings, quadriceps, and ankle plantar flexors are all active to prepare for initial ground contact.39

**Hip Forces During Activity**

When standing with both feet on the ground, each hip experiences a load of approximately one-third to one-half of body weight.41 This force increases to approximately 2.5 times to 4 times body weight when standing on one leg. With single-leg stance, counterbalancing forces maintain the pelvis level. The force of contraction of the hip abductors (gluteus medius and gluteus minimus) balances the forces acting on the hip from the contraction of other muscles and from gravitational forces. This pull of the abductors must be more than that of body weight because the distance from the hip’s center to the body’s center of mass is about 2.5 times longer than that of the lever arm of the abductors (Fig. 10). However, Inman28 noted that it is not only the abductors that help stabilize the pelvis in single-leg stance, but the forces of the tensor fascia lata and iliotibial band, as well.

During the swing phase of gait, the hip experiences various forces resulting from limb acceleration and deceleration and from the effect of muscle contractions (eccentric and concentric) and ligamentous constraints. Ground reaction forces that are present during stance are not a factor during the swing phase. The forces acting on the hip are also larger than expected in the swing phase. This is because the body...
rolls over the femoral head during this phase so the abductors do not have to work as hard as in single-leg stance. Also, as the extremity increases in mass, greater force is needed to generate the angular velocity required for forward propulsion. Therefore, a greater degree of muscle pull is required, which generates greater compressive force on the femoral head. Clinically, patients with osteoarthritis develop a compensatory gait pattern to lessen this compressive effect. By shifting the ipsilateral trunk and pelvic center of mass over the hip, there is a subsequent decrease in the abductor moment arm, which reduces the degree of force required from the abductors to maintain the pelvis level. This results in an overall reduction in the joint reactive force on the hip joint. Correspondingly, a loss of 1 lb. of body weight can lessen the force acting on the hip by approximately 3 lb.42

The contact pressure in the hip during walking gait is approximately 5 Mpa, which is roughly 25 times the amount of pressure in a car tire.43 With loaded walking (carrying as much as 20 kg), hip joint loads can reach 8 times body weight.43 Considering a contact area of the hip of approximately 2 cm, the compressive force can reach a maximum of 65 Mpa during joint loading.42,43 In the dynamic setting, the hip experiences forces from a number of sources, including the ground reaction force, gravity, body acceleration, and muscle contraction. Running can produce loads between 4.5 times to 6 times body weight, even though the abductors work less than during walking.44,45 This is because of the increase in the ground reaction force associated with running. Forces up to 7.5 times body weight act on the hip during fast walking and ascending or descending stairs.46 It is thought that the synovial fluid in the healthy hip helps withstand 90% of this load so that the articular cartilage matrix does not have to be subjected to these extremely large compressive forces.4 These loads on the hip change in direct proportion to the change in speed and effort exerted by the subject during activity.

How the hip joint, and particularly the proximal femur, responds or adapts to these loads has been an area of investigation for many years. It has been proposed that the lateral (or superior) femoral neck is loaded in tension, and the medial (or inferior) aspect is loaded in compression. Wolff47,48 championed the idea that the proximal femur experiences an average, or habitual, loading condition during normal weight-bearing activities. This was conceived as a bending moment that occurs during single-leg stance whereby the superior aspect of the femoral neck receives tensile stress while the inferior aspect undergoes compressive stress.49 This concept is strongly rooted in the seemingly obvious conclusion that the trabecular patterns observed in thin coronal sections on AP roentgenograms are adaptations along the lines of stress that are typically transmitted across the hip.48-51 This conception was important in the original formulation of Wolff’s Law of mechanically-mediated bone adaptation.

These and other studies that have described the habitual presence of a bending moment across the hip may not be accurate. This is because they are not based on direct in vivo force measurements, but on calculated, or assumed, magnitudes and directions of muscle or gravitational and inertial forces.31,42,46,52,53 Under this theory, the lateral trabeculae of the femoral neck would be expected to be at a right angle to the medial trabeculae if one was loaded in tension and the other in compression. However, these trabecular lines are at a 60° angle to one another in the coronal plane.54 The lateral trabeculae are also directly in line with the abductors, tensor fascia lata, and iliopecto muscles, which would imply that the medial and lateral trabecular systems are actually both under a degree of compression. This concept is supported by a cadaveric study by Skedros et al., who showed that the collagen fibers of the cortical bone in the lateral and medial aspect of the femoral neck are both obliquely oriented, thus implying a habitual compressive loading pattern. A hypothesis to explain this finding is that the musculature around the hip (particularly the abductors) acts to compress the femoral head into the acetabulum, creating a net compressive force on the superior and inferior aspect of the femoral neck. If the superior aspect of the femoral neck were only under tension then there would be no need for bone to form, because the uncalcified cartilage has the same tensile strength as bone with less weight per unit volume.55 According to Wolff’s Law, bone will form where stresses are applied to it. In this way, the bone strives toward an optimized structure for both mobility and strength.

Implications for Athletic Activity

There is a paucity of literature pertaining to the biomechanics of the hip during sports other than running. One such study56 calculated the loads on the hip joint in various skiing activities by combining video data and a simple muscle model with an accepted mathematical method. For alpine skiing, the calculated loads on the hip joint were 4.1 times to 7.8 times body weight.56 The loads were less for long turns on flatter hills, and greater for short turns on steeper inclines. For cross-country skiing (without ski pole) the calculated loads on the hip were 4.0 times to 4.6 times body weight. Mogul skiing was associated with loads on the hip that were much higher, ranging from 8.3 times to 12.4 times body weight.56

Landing is an activity common to many athletic activities. Devita and Skelly57 investigated the effects of landing stiffness on the lower extremity. A soft landing occurs with the knee flexed greater than 90°, and a stiff landing occurs with the knee flexed less than 90°. These authors found that the hip and knee sustain higher ground reaction forces and absorb more energy with soft landings, whereas the ankle experiences higher ground reaction forces and absorbs more energy with stiff landings. They attributed these findings to the greater degree of hip and knee flexion associated with a soft landing technique that results in a greater degree of energy absorption by these two joints. The highest muscle moment and power calculations were found in the hip joint in both landing techniques. The hip extensor moment works eccentrically to reduce hip flexion velocity, especially in stiff landings. The greater extensor moment in the stiff landing
of the knee and hip extensors compared with the muscles supporting the ankle. As the height of the landing increases, lower extremity posture becomes more flexed, and the hip extensors become increasingly involved in energy dissipation. There is also a shift in energy absorption from distal to proximal muscle groups as the mechanical demands on the lower extremity increase, as in an increase in landing height.

The biomechanics governing the forces involved with landing may be sport-specific. McNitt-Gray found that gymnasts had lower average maximum ground reaction forces when landing from 3 different heights compared with recreational athletes. The gymnasts also reached a peak ground reaction force value 6.3 msec faster in the landing phase than recreational athletes at all landing heights. It appears that gymnasts are less sensitive to increases in landing forces when landing from 3 different heights compared with recreational athletes because of their ability to reduce maximum ground reaction force values during landing. This ability to reduce landing stresses may result in gymnasts being less susceptible to injury because of their apparent ability to attenuate impact forces.

Clinical Implications for Athletes

Decreased hip motion or muscular weakness about the hip could potentially affect athletic performance and put the athlete at risk for injury. Fixed flexion contractures of the hip have been implicated as a cause of low back pain because of the increased lordotic strains placed on the lumbar spine. Professional ice hockey players have been shown to lack approximately 10° of hip extension. Yet this has not been shown to predispose these athletes to injury. On the contrary, the relatively poor flexibility noted in some long-distance runners appears to be beneficial in that they exhibit a more economical gait pattern compared to more flexible runners. This phenomenon is thought to result from the reduced muscular demands needed to stabilize a relatively stiff hip.

Muscular imbalance about the hip has been shown to place ice hockey players at risk for adductor strains. Tyler et al. analyzed hip abduction and adduction strength in 81 professional hockey players before two consecutive seasons. Adduction strength was found to be 18% lower in players who subsequently sustained an adductor strain compared with adduction strength of the uninjured players. Moreover, a player was 17 times more likely to sustain an adductor strain if his adductor strength was less than 80% of his abductor strength. It remains to be determined whether preseason strength training is effective in reducing the incidence of adductor strains in athletes identified at risk.

References