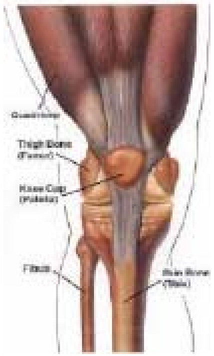
An Analysis of the Muscles Which Act at the Hip and Knee Joints Part I



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Abstract

The lower extremity can be viewed as a complex-kinetic chain. Articulations span through multiple axes, and degrees of movement. Moreover, extreme loads are borne by elaborate shock-absorption systems. For this reason, an integrated approach is essential to the understanding of this particular system. The following paper reviews the structure of the sacroiliac joint, hip complex, and knee articulations. Additionally, the concept of impaired and hyper mobility will be addressed. The former is of particular importance, as imbalances, if left untreated, can have deleterious and degenerate effects on all three joints mentioned thus far, as well as the spine. Finally, it is the intention of this review to prepare the athlete to enhance his or her ability to stimulate optimal growth in the anterior, medial, and posterior musculature of the thigh region.

Introduction

The lower extremity provides locomotion to the user. Further, in the sport of bodybuilding, musculature acting within this region serves as the athlete's base of support. When underdeveloped, a tremendous disadvantage is created regardless of how sound the rest of the body is. We begin our discussion with a detailed analysis of the hip and knee joints. Our main concern is directed toward the articulations formed by the innominate bone and the head of the femur, as well as the bicondylar joint between the distal aspect of the femur, and the proximal aspect of the tibia.

The Hip Joint

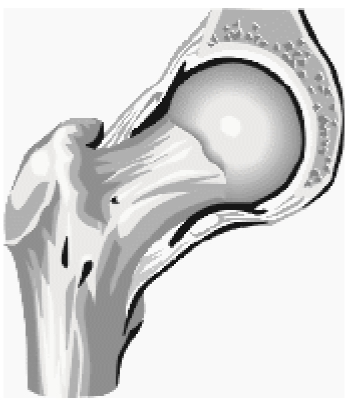
Above you can clearly see the head of the femur articulate with the acetabulum of the ox coxae. You can also see on the superior aspect of the hip the iliac crests, as well as the sacroiliac joint, on the medial aspect of the picture.

Human skeletal architecture can be divided into two gross sections, known as the appendicular and axial regions. The latter contains the spine, ribs, sternum, and hyoid bone, while the former is composed of everything which branches off either directly or indirectly from the central axis. Those which are directly connected are associated with the girdles, and include the pelvis, and clavicles. They are named such because they connect the upper and lower limbs to the body's central axis. We are concerned with the pelvic girdle, and will focus on it.

The pelvic region is made up of a left and right coxal bone (coxal means hip), the sacrum, and the coccyx. However these are also known as the os coxae. The os stands for bone, where as the coxae stands for hip. Finally, several anatomists simply refer to it as the innominate bone, which is literally translated as the "no name bone (15)." The hip bones are extremely complicated, and are themselves comprised of three separate bones, which fused during your development. Our primary concern, however, will not be to dissect each of these sections (the ilium, ischium and pubis), but rather to focus on key landmarks for the time being. The coxal bones connect or rather form a joint with each other anteriorly (to the front). This is your groin region, and the joint formed is known as the pubis symphysis. They connect to the fourth region of the spine posteriorly (to the rear) via the sacral iliac joint. Recall from my article on Spine Mechanics, that the sacrum are a series of five fused vertebrae. It is the lateral--or outside--aspect of this region which articulates (forms a joint with) the os coxae. If you look in the mirror, you should be able to see the outline of your hip bones. These are known as the iliac crests and are easily palpable. As stated, each innominate bone is comprised of three different bones. The Iliac crest can be found on the superior Illium. Because the illium articulates with the sacrum, the sacral illiac joint is its name. This is the most stable joint in the entire body for three reasons. To begin, the bony fit--or congruency between the illium and sacrum--is fantastic. Secondly the strongest ligaments in the body cross and support it. Finally, some of the largest muscles in the human body (i.e. the gluteus maximus) cross the joint.

A second region which you must be familiar with is the ischial tuberosity. This bone makes up the infero-posterior aspect of the hip. A tuberocity is literally a protrusion on a bone, which has some form of attachments to it, such as muscles or ligaments. Interestingly enough, you are actually sitting right now on your ischial tuberocities! You can feel them as two protrusions which lie in the gluteal region, where you would normally sit.

Thirdly, it is of utmost importance to understand what, in less technical terms, can be called the hip socket, which fits the head of the femur (your leg bone) spectacularly! This socket is known as the acetabulum, and is formed as all three bones of the hip meet or form a junction.



The above illustration shows you how amazing the
fit is between the head of the femur and the acetabulum.

The acetabulum is located on the lower and frontal aspect of the hip. It is interesting to note that the name acetabulum means vinegar cup, due to its deep hemispherical shape (15). To deepen it further, a ring of cartilage known as the labrum lines the rim of the socket (5, 8).

The leg bone--or femur--articulates with the acetabulum with its head, which forms approximately two thirds of a complete sphere (8). To gain a greater grasp of this region, it helps to compare the shoulder joint to the hip joint.

1. The shoulder joint is meant for reaching, pulling, and manipulative action, and therefore requires incredible mobility. In order to accommodate this, it must give up a great amount of stability. The Hip joint, on the other hand, must bear extreme loads which are passed on from the entire upper body. It therefore must be extremely stable.

2. The bony fit between the head of the humerus is not very good at all. The femur is composed of a much greater sphere than the humerus. Additionally, the glenoid fossa--or socket for the arm--is shallow, whereas the acetabulum is deep. Due to this fact, the humeral head is normally only in partial contact with the glenoid fossa. However, the head of the femur fits so well into its socket, that if you removed all ligaments and muscles, it would still stay in place! Such a fit is also caused by a

layer of articular hyaline cartilage (a smooth, glassy, virtually frictionless material) which furthers the congruence between the femoral head and the hip socket.

There is, however, an ever so slight incongruence, which increases the contact between the cartilage of the acetabulum and that of the femur. This serves to increase lubrication between the joint (19). The matching surfaces of these bones do much more than maintain stability; they also serve to properly transmit the weight of the body. This is because a large region of the joint associates during any particular movement. The greater the area bearing the load, the lower the stress borne by the joint (Stress = Force / Area; if the contact area is greater, the pressure is less).

3. The ligaments which cross the joint in the lower extremity are extremely strong, whereas the ligaments in the shoulder joint are relatively weak. We need to analyze these amazing supporting structures.

Firstly, the hip articulation is covered completely by a joint capsule. I explained what this type of structure was in my article on elbow flexion.
Here is a review (19):

> *A joint capsule is a fantastic contraption. Think of it as a protective sleeve made of tough, connective tissue....Its purpose is to encapsulate the joints discussed and keep fluid inside of the joint spaces. You see, inside of the capsule is a membrane which secretes what is known as synovial fluid (classified as a synovial joint). As oil lubricates a machine, so too synovial fluid provides a virtually frictionless environment to the encapsulated articulations. You can test it out right now by flexing and extending the elbow quickly. Such movements are so smooth due to the fantastic fit of the bones (which also provides stability), the hyaline, and finally the lubricating fluid.*

This capsule attaches proximally along the rim of the acetabulum and near the end of the femoral neck distally. The ligaments are actually quite easy to remember. Recall that the acetabulum is made up of the junction three bones. Each ligament attaches to the rim of the acetabulum. These bones are the pubis, which is the anterior aspect of the hip, the ischium, which is posterior and inferior, and the illium, which is the superior bone. The first fibrous supporting structure is the iliofemoral ligament. It attaches to the superior aspect of the rim of the acetabulum, which is comprised of the ilium. The ischiofemoral originates on the ischium, or more posterior aspect of the rim, while the pubofemoral (the more anterior bone) originates on the pubis. All three structures insert approximately inferior to the neck of the femur. The following is an outline of the ligaments functions (15, 5, 8):

Iliofemoral - resists hyperextension and lateral rotation of the hip joint
Ischiofemoral - resists hyperextension, reinforces the capsule posteriorly, and resists medial rotation
Pubofemoral - resists hyperextension, and excessive abduction of the hip.

Note how much resistance there is to hyperextension. To explain, you need to realize that the alignment of the collagen fibers in the ligaments and joint capsule are both parallel and circular. What occurs is that, like a Chinese finger trap, they clamp down on the bony contents within, and hold the femoral head to the acetabulum when faced with extensor tensions.

Movements Allowed At the Hip

Using your knowledge of the ligaments, we can see why the range of motion in the hip joint changes for particular movements.

Flexion – Note above that I did not say that one of the major three ligaments resisted flexion. This is because each of these becomes slack during this movement, which allows for a wide range of propulsive movements. Flexion of the hip can be defined as a decrease in angle between the anterior aspect of the femur and the trunk. Numerous studies indicate that approximately 120 to 125 degrees flexion can occur in normal subjects (16, 17, 2, 7, 18).

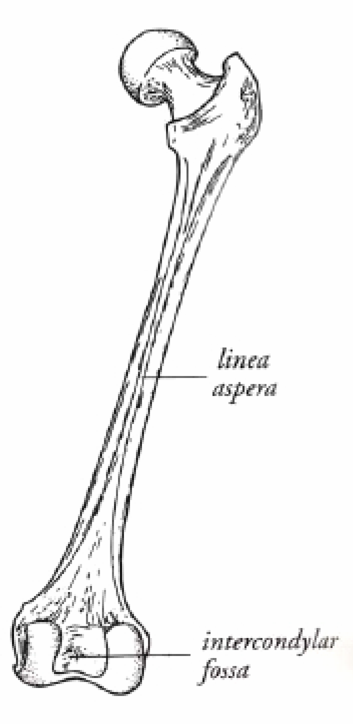
Extension – Extension of the hip can be defined as an increase in the angle between the anterior aspect of the femur and the trunk. Studies show a varying range of extension. For example, Roach and Miles examined 821 males and 862 females, age 25-74, and found that they had a range of motion which ranged from 19 plus or minus 8 degrees (17).

Adduction – This occurs when the thigh is brought closer to the midline of the body (i.e. when you bring your knees together, you have to adduct your thighs to do so). Boone and Azen found 26.9 plus or minus 4.5 degrees of motion here (2).

Abduction – Abduction takes place when you take the femur away from the midline of the body. The range is 45.9 plus or minus 9 degrees of motion (2).

Internal and External Rotation – If you lay down on the ground in a supine position with your toes pointed straight upward, you can test these two movements. When in this position, simply rotate the hip so that the feet are pointed outward; this is lateral or external rotation. If you rotate such that the toes are facing inward, you have just internally rotated the hip. It is interesting to see how the hip effects foot positioning. This is a vital point, and refers to the chain-like system of the lower extremity, a chain which will be discussed shortly. Both internal and external rotation appear to be similar. Roass and Anderson found that they both ranged around 33-34 degrees, as did Roach and Miles (16, 17).

Landmarks on the Femur



We will now overview the femur with the above picture in mind. I will also review the above structures.

1. The head of the femur is smooth and spherical and articulates with the acetabulum of the hip.

2. The neck is below the head. You will see in future articles that this is a subject of great interest to those involved in biomechanics. Unfortunately, it is also a site of fracture in older individuals. It faces both compressive and tensile forces (to further understand these forces, I recommend reviewing the mechanics of bone tissue part 2 ( )). However, this can be prevented, especially at an earlier age. Females who train need at least 1200 milligrams of calcium daily. This is perfectly safe. According to Dr. Yates and colleagues from the Journal of American Dieting Association, an upper limit of 2500 mg daily of exogenous calcium can be taken safely (12). Other studies have shown up to 3500 mg increased bone density and lowered cholesterol (12). The theory is to build up your calcium stores now before estrogen levels drop in older age. Think of it as being no different than preparing yourself for retirement. The difference is that you may start losing bone earlier than you retire. I would highly recommend increasing calcium levels.

3. The Greater and Lesser Trochanter – These are projections on the femur which serve as attachment sites for extremely important muscles of the hip.

4. Shaft – As can be seen, the shaft is extremely long. As is the humerus, the shaft

is more circular at the top, but then widens out near the bottom as it spans into the epicondyles.

5. The lateral and medial condyles – These are articulation sites for the hinge joint between the femur and the tibia. Note that on the posterior aspect of these condyles lie the intercondylar fossa. On the distal aspect of the femur, in between the condyles, lies the surface for your knee cap (patella).

6. Epicondyles – Epi (or outside) the condyles lie these lateral and medial landmarks. They also serve as muscular attatchment sites.

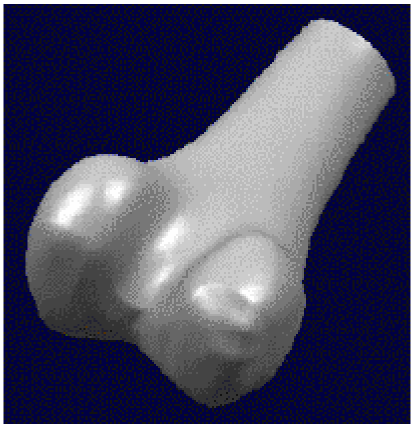
7. The linea Aspera – On the dorsal aspect of the femur, you will notice an almost v shaped ridge called the L. Aspera. Important muscles such as the adductors find their attachment on this landmark.

The Tibio-femoral Joint

The above is an artificial knee joint.

The Tibio-femoral joint (knee joint) is extremely complex. Taking a reductionist approach, we will analyze the femoral condyles first. From the above landmarks, you realize that the femur thickens from its anterior and posterior aspects, as well as its medial and lateral segments. In order to understand why, picture a building which relies on columns for its base of support.

The thickening shown above provides greater weight-bearing ability by the structure (recall area's relationship to stress), much the way it does in the thigh bone. Stability is also enhanced. The condyles are situated distally, and are convex. That is, they curve in a circular manner toward the proximal (this term denotes an aspect on a bone which is closer to the root of a limb; it is the opposite of distal) region of the tibia. Note also that the two condyles are separated by the intercondylar fossa.



The architecture is similar to a rocking chair.

Think of the supporting lateral and medial legs as the condyles, and the separation between them as the intercondylar fossa.

Such a

comparison allows one to better visualize how flexion and extension could occur in the knee joint.

Take a close look at the following x-ray:

The anterior aspect curves to the front much less than it does to the rear of the bone. This allows for a high range of flexion (such as that which occurs in a leg curl) with less extension, as well as with greater weight-bearing ability while standing.

The proximal end of the tibia has accommodating structures to receive the thigh bone. Its condyles are concave, which means that they curve inward. Additionally, there is a projection called the intercondylar eminence, which fits in between the indentation superior to it on the femur.

The knee joint is known as a modified hinge joint. Its main movements are flexion and extension, but lateral and medial rotation also occur (below I discuss the extent to which these occur). Bony fit within this system is no where near that of the hip joint. Therefore, a high reliance on ligamentous/muscular support for stability is needed.

To understand flexion and extension, realize that a combination of movements must occur. First, flexion takes place when the posterior leg (in anatomical terms it is proper to call the lower leg the leg, and the upper leg the thigh) is drawn closer to the posterior thigh, while extension is the opposite.

A decrease in the angle between the two bones can occur as the femur rolls backward. However, if this movement were to continue, the bone would literally fall off of its base of support (i.e. lose contact with the tibia below). You might say that a better solution would be to have the femur and tibia act like a bearing system. That is, where the femur glides back and forth during flexion and extension. The problem here is that friction would be borne by only one region and degenerate, cartilaginous diseases would rear their ugly head.

To get the best of both worlds, the Lord designed a system which uses the entire surface, in that both gliding and rolling take place. Therefore, a greater region bears these friction forces.

Supporting Structures of the Knee

One classification of a synovial joint is that the ends of each bone involved are coated in hyaline cartilage, which further reduces friction. Loads borne at the knee are extremely high. Ateshian et al. found that the average thickness was from 2-3 mm on the femur, tibia, and patella. In addition, this thickness in particular areas reached as high a 6 millimeters (12)! Such measurements surpass all others in the body and reflect the need to absorb large loads and forces.

Additional structures also serve as shock-absorbers, the meniscus being of prime interest. Think of a washer.

The menisci are two cartilaginous rings, which are sometimes referred to as the washers of the knee joint. However, they go beyond this. First, one meniscus is attached to the rim of the medial condyle of the tibia, while another is attached to the lateral condyle. They are also secured by ligaments. Gries et al. states that this structure "*participate(10) in load bearing, shock absorption, joint lubrication, and joint stability (6)."* Fithian, in the journal of Clinical Orthopedics, states that, *"The menisci serve several important biomechanical functions in the knee. They distribute stresses over a broad area of articular cartilage, absorb shocks during dynamic loading, and probably assist in joint lubrication. These functions enhance the ability of articular cartilage to provide a smooth, near-frictionless articulation and to distribute loads evenly to the underlying bone of the femur and tibia (4).*"

1. Shock absorption – This is accomplished by the elasticity of the tissue. Kobayashi et al., when studying this structure in the journal "Knee," reveals the fact that, **"***Biomechanical studies have shown that the human meniscus has various mechanical functions; in our mechanical tests, specimens of human meniscus (part I of this study) demonstrated unique viscoelastic properties (13)."* The architecture is astonishing. From the above study conducted by Fithian, we find that, *"the menisci are one-half as stiff in compression and dissipate more energy under dynamic loading than articular cartilage. Energy dissipation, or shock absorption, by the menisci is the result of high frictional drag caused by low permeability of the matrix, which is about one-sixth as permeable as articular cartilage. The dynamic shear modulus of meniscal tissue is only one-fourth to one-sixth as great as that of articular cartilage (4)."*

2. Lubrication – This ring-like cartilage is slightly mobile. As such, it distributes synovial fluid during movement at the tibio-femoral joint.

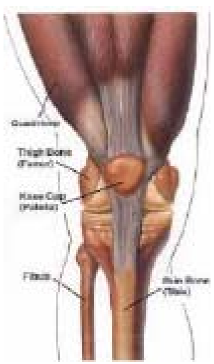
3. The menisci also serve to increase the area on contact between the thigh and leg bones, which has the affect of increasing load-bearing ability.

4. In addition to the above research, studies show a correlation between removal of the meniscus and the acceleration of articular cartilage degeneration (14).

Joint Capsule and Ligament Support

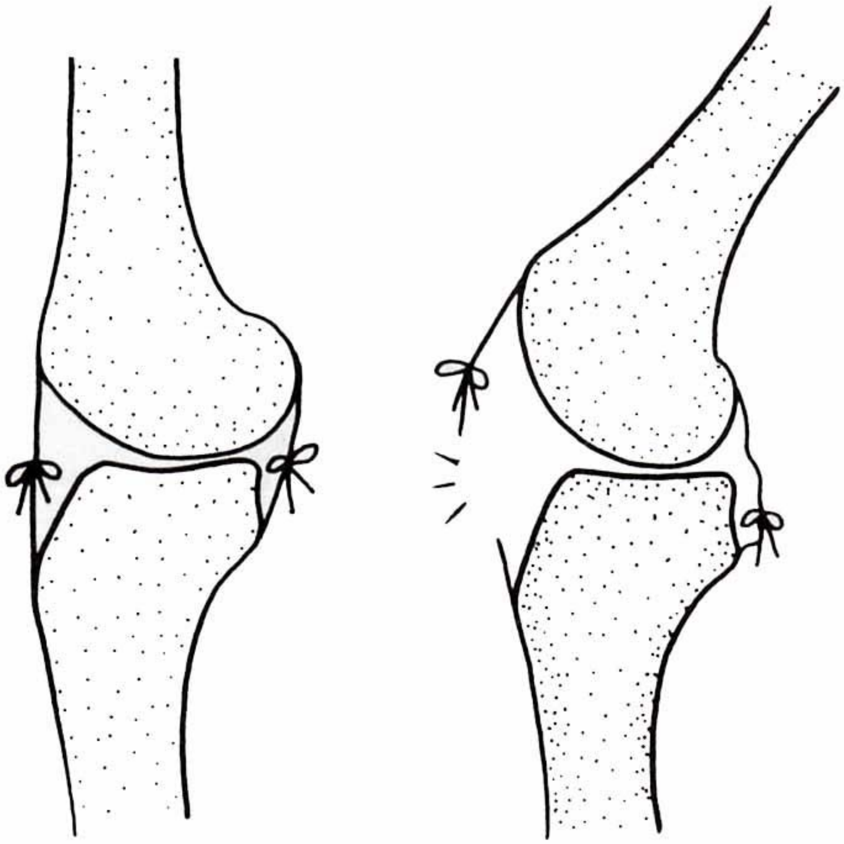
Like the hip joint, the distal femur, proximal tibia, and the patella (discussed below) are all contained within a joint capsule, which keeps synovial fluid within, as well as provides stability. To accommodate flexion, the capsule is slack, relative to the posterior aspect. However, it is much tauter to the rear, which again explains the greater range of motion during flexion vs. extension movements.

The patella is the largest sesamoid bone in the body ( ). A sesamoid is a bone which forms within a tendon (15, 5, 8). You know it commonly as the knee cap, and it articulates with the condyles of the femur, but not with the tibia. The tendon in which the patella forms is none other than that of the quadriceps femoris. It is extremely strong, and the fibers cross over each other at the knee to reinforce this strength.

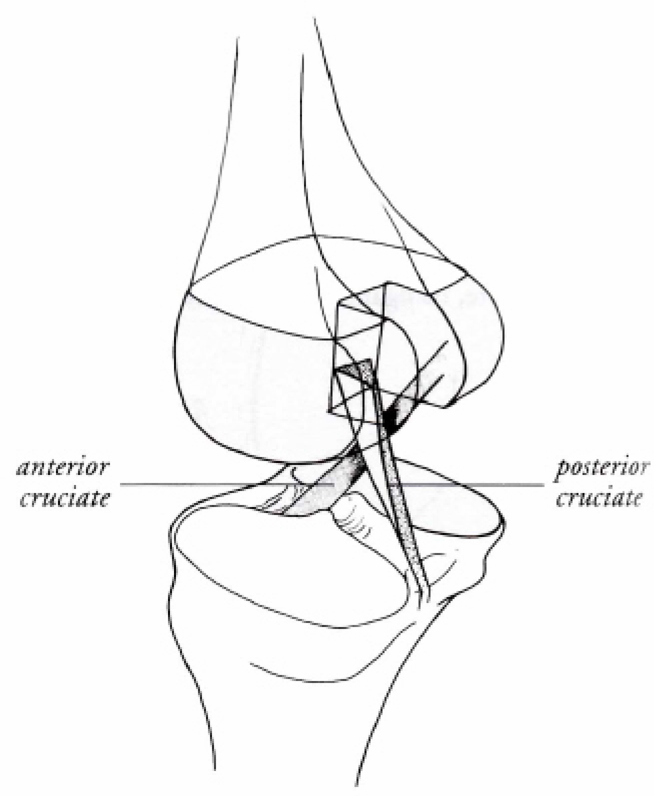


If you have ever banged your knee, and I have no doubt that you have, you realize one of the functions of this bone. You may not realize its other function, however. You see, the patella has two articular surfaces, one for the medial condyle of the femur, and one for the lateral. However, there is a depression or groove between these. The tendon slides through this groove like a rope through a pulley! It is so effective that it increases the moment arm of the quadriceps up to 70 percent (9)! The patella also lengthens the quadriceps, which subsequently increases their length tension strength curve.

Another issue in designing the knee joint, is the need for flexion and extension, accommodated by a source which maintains structural integrity. If one were to place ligaments directly outside the joint, anteriorly and posteriorly, they would have to snap if such movements took place.



To address this, God placed two cruciate ligaments within this particular articulation. Cruciate refers to any ligament which crosses another ligament. The anterior cruciate ligament attaches distally to the intercondylar region of the tibia on its anterior aspect. It then travels backward and up to attach to the medial aspect of the medial section of the lateral condyle on the femur. The posterior ligament has opposite attachment points. The anterior ligament maintains integrity anteriorly, while the posterior ligament resists separation of the posterior aspect of the joint.



To further stitch the knee in place, medial and lateral collateral ligaments have been put in place. The medial originates on the medial epicondyle of the femur, and inserts on the medial condyle of the tibia. For this reason, it is also known as the tibial collateral ligament.

The leg is made up of two bones. The tibia and fibula. The latter has its proximal attachment to the lateral condyle of the tibia (slightly posterior as well). Do you see the lateral bump on your ankle? That is the distal aspect of the fibula, known as the lateral malleolus. You can palpate the head of the fibula laterally on the leg. The lateral collateral ligament, also known as the fibular collateral ligament, originates on the lateral epicondyle of the femur, and inserts on the head of the fibula. Together, these resist extensive lateral and medial rotation of the knee joint.

In order to test medial and lateral rotation, it is best to place the tip of your finger on the tibial tuberocity. This is the bump just below your knee cap, and marks the insertion point of the quadriceps femoris. Now, lie down in a supine position (on your back) and bend your knees. From here, rotate the knee outward. You should see that the tibial tuberocity move laterally as well. This is the best way to view rotation at the knee, because it can easily be confused with movement at the ankle joint.

The Kinetic Chain System of the Lower Extremity

It would serve you well to view the lower extremity as a kinetic chain. That is, a chain in which the links are comprised of each joint mentioned today. These include the sacroiliac, hip, and knee articulations. From a biomechanical basis, each segment in the chain directly affects all other segments.

To understand such a concept, we will need to delve further into the pelvis. Recall that this bowl-like structure is made up of two coxal bones, the sacrum and coccyx. The sacrum is part of the axial skeleton, and the coxae serves as a girdle of the appendicular aspect of the human body. The pelvis can move in several directions. For the purposes of this article, our focus will be on anterior and posterior tilting of the pelvic region.
When the pelvis is tilted forward, it is technically called an anteverted pelvis, and when backward it is referred to as a retroverted pelvis (3).

In review, flexion of the thigh occurs when the angle between the femur and pelvis/trunk decreases, and extension is the opposite. When the pelvis is retroverted, flexion of the hip joint occurs, and the curvature in the lumbar region flattens out--that is, it flexes (3, 10). This is due to the fact that the hip bones are connected to the vertebral column, via the sacroiliac joint. When anteversion occurs, the angle between the anterior femur and the trunk decreases, and the back becomes extended and a notable arch occurs in the lower back (3, 10).

To test this, simply lie down on the ground in a supine position with the knees bent. Now, keeping the pelvis still, flex the hip joint until you can no longer do so. From here, continue to draw the knees closer to the chest. Note that you have to use the pelvis to do so and, while this occurs, you lose the arch in your lumbar region. Finally, drop your feet back to the ground, and regain the strong arch in the lumbar region with a notable anterior tilt of the pelvis.

From a clinical standpoint, if an athlete has a lowered ability to flex at the hip joint, such as in a squat, they will tend to continue flexing the hip with the pelvis. You can already formulate the problem with this. In doing so, they round the back and place excessive stress on the posterior, longitudal ligaments in the spine, as well as lower the load-bearing capabilities of the individual vertebrae. Moreover, when the opposite occurs, if further extension is needed, then hyperlordosis can occur, which can also unevenly distribute forces on the vertebral column. Recall that a lordodic curve takes place in the neck and lower back region. It is curved in posteriorly. Hyper refers to excessive, or past normal.

You might have noticed overuse of pelvic tilt in the out-of-shape or impaired population. For example, when someone with limited flexion ability stands, they lean forward (flex the spine) overtly when getting off of the couch. Such a movement becomes necessary to compensate for their lack of mobility at the hip. However, it also leads to deleterious effects, such as lower back pain. We will delve further into the muscular applications of this within this series. Realize, however, why Adam Knowldens article on flexibility is so important (11). By creating mobile imperfections in the lower chain, you are subjecting yourself to potential injuries.

The knee and hip joints also have a unique relationship. For example, when the knee is flexed, the hamstrings become slack, and they resist hip flexion to a lower degree than when the knee is extended. This is to say that you have a fuller range of hip flexion when the knee is bent, than extended. Additionally, as Mr. Knowlden pointed out, tight posterior muscles will naturally prohibit flexion of the hip (11). Conversely, if the hip is flexed, the knee cannot extend as easily. This is due to the fact that the hamstrings are tightened during hip flexion, and resist knee extension.

When the hip is extended, the rectus femoris is tightened, and knee flexion cannot occur to the degree that it could if the hip were flexed and the rectus was slack. Finally, when the knee is flexed, extension of the hip is limited because the rectus femoris again becomes tensed (it is a two joint muscle).

Conclusion

The mechanics of the lower extremity is not only complex, but wonderfully designed. Through a greater structural understanding, we can obtain a greater appreciation for the Creator (Romans 1:20) and his unlimited ability. Moreover, as an athlete you are prepared to realize a clearer and more profound picture of lower extremity development, and injury prevention. Concepts such as the length tension curve, moment arm, and optimal motor unit recruitment will not make sense without knowledge of the kinetic chain which the extensors, flexors, and other muscles of the hip/knee joint work through.

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Sources Cited and References/Research Credited:

1. Ateshian GAm Siskiwsjt LJ, Mow VC: Quantification of articular surface topography and cartilage thickness in knee joints using stereophogrammetry. J Biomech 1991; 24: 761-766
2. Boone DC, Azen SP: Normal range of motion in Joints in male subjects. J Bone Joint Surg: 61-A: 756-759
3. Daniel P. Regan, RN, ATC, CSCS Implications of Hip Rotators in Lumbar Spine Injuries Strength and Conditioning Journal: Vol. 22, No. 6, pp. 7–13.
4. Fithian DC, Kelly MA, Mow VC. Material properties and structure-function relationships in the menisci. Clin Orthop. 1990 Mar;(252):19-31.
5. Gray, Henry. Gray's Anatomy, Descriptive and Surgical (15th edition), Barnes and Nobles Inc. 1995
6. Greis PE, Bardana DD, Holmstrom MC, Burks RT. Meniscal injury: I. Basic science and evaluation. J Am Acad Orthop Surg. 2002 May-Jun;10(3):168-76.
7. Hislop HJ, Montgomery J: Daniel's and Worthington's Muscle Testing Techniques of Manual Examination. Philidelphia: WB Saunders, 1995
8. Hamill, Joseph Biomechanics Basics of Human Movement
9. KATZ L. Quadriceps femoris strength following patellectomy. Phys Ther Rev. 1952 Aug;32(8):401-4.
10. Kisner, C., and L. Coby. *Therapeutic Exercise: Foundation and Techniques.* (2nd ed.). Philadelphia: F.A. Davis Company. 1990. pp. 319–323. 438–44
11. Knowlden, Adam: Mobility Training and the Application of Proper Warm-up for Body Builders. The Journal of HYPERplasia Research. October 2003
12. K. Wilson, Jacob: The Mechanics Of Bone Tissue Part III - The Journal of HYPERplasia Research. July, 2003
13. Kobayashi M, Toguchida J, Oka M. Development of an artificial meniscus using polyvinyl alcohol-hydrogel for early return to, and continuance of, athletic life in sportspersons with severe meniscus injury. II: animal experiments. Knee. 2003 Mar;10(1):53.

14. Messner K, Gao J: The meniscui of the knee joint. Anatomical and functional characteristics, and a rationale for clinical treatment. J Anat 1998; 193: 161-178
15. Marrieb, E.: Human Anatomy (5th edition), Redwood City, Ca: Benhamin / Cummings (2001)
16. Roass A, Andersson GB: Normal range of motion of the hip, knee, and ankle joints in male subjects, 30-40 years of age. Acta Orthop Scand 1982, 53: 2-5-208
17. Roach KE, Miles TP: Normal hip and knee active range of motion: the relationship to age. Phy Ther 1991: 71: 656
18. Van Dillen L, McDonnell M, Fleming D, Sahrmann S: Effect of knee and hip position on hip extension range of motion in individuals with and without low back pain. J Orthop Sports Phys Ther 2000: 30: 3-7-316
19. WIlson, Jacob Pressurization As Applied To Spinal Stability The Journal of HYPERplasia Research. November 2003
20. Wilson, Jacob An Unmatched Analysis of The Elbow Joint & Its Surrounding Musculature Part I The Journal of HYPERplasia Research. October 2003
21. Wilson, Jacob: The Mechanics Of Bone Tissue Part II - The Journal of HYPERplasia Research. July, 2003