Anatomy/Biomechanics

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Bones

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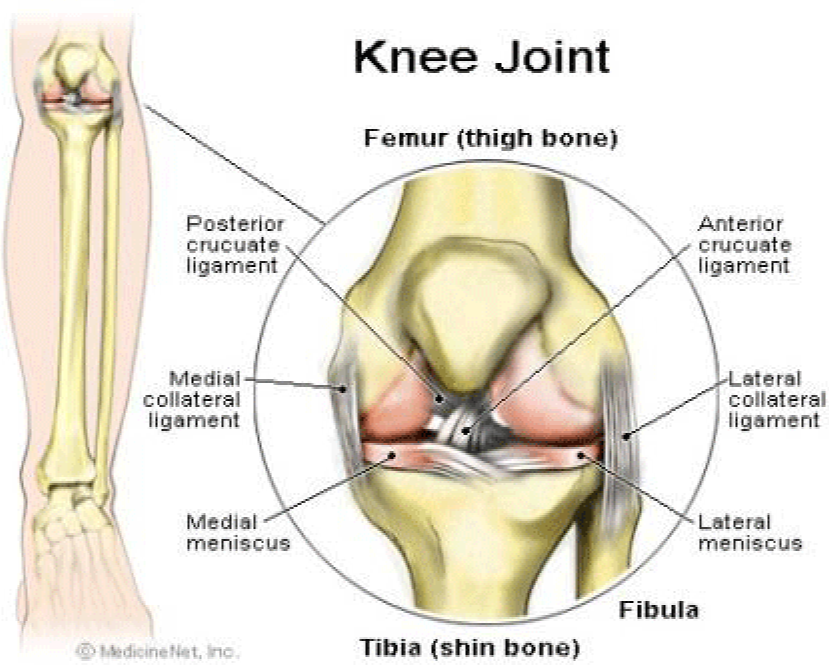

Femur

The femur is the longest and strongest bone in the body. The shaft of the femur is nearly cylindrical, fairly uniform in calibre and the shaft has a bow with the apex anteriorily progressing from proximal to distal.

The distal aspect of the femur broadens into the medial and lateral condyles with all but the sides of these condyles being articular and involved in the knee joint. The inferior, posterior oblong portions of the condyles articulate smoothly with the tibial plateau, whereas the central anterior surface between the condyles articulates with the facets of the patella. The inferior, oblong surfaces of the condyles are separated by the intercondylar fossa which houses the cruciate ligaments.

In shape and dimensions the femoral condyles are asymmetric; the larger medial condyle has a more symmetrical curvature. The lateral condyle viewed from the side has a sharply increasing radius of curvature posteriorily. The lateral condyle is slightly shorter than the medial. The long axis of the lateral condyle is slightly longer and is placed more sagittal than the long axis of the medial condyle. The lateral condyle is slightly wider than the medial condyle at the centre of the intercondylar notch. Anteriorily the condyles are separated by a groove, the femoral trochlea. The sulcus represents the deepest point in the trochlea relative the mid plane between the condyles, the sulcus lies slightly laterally. The lateral condyle has a greater posterior excursion than the medial. The contact surface of the patella is derived mostly from the lateral condyle. The anterior extensions of both condyles form a fossa for the patella to sit in extension. The lateral extension is the greatest.

The intercondylar notch separates the two condyles distally and posteriorily. The lateral wall of the notch has a flat impression where the proximal origin of the anterior cruciate ligament (ACL) arises. On the medial wall of the notch is a larger site where the posterior cruciate ligament (PCL) originates.

The lateral condyle has a short groove just proximal to the articular margin, in which lies the tendinous origin of the popliteus muscle. The groove separates the lateral epicondyle from the joint line. The lateral epicondyle is a small but distinct prominence which attaches the lateral (fibula) collateral ligament (LCL). On the medial condyle the prominent adductor tubercle is the insertion of the site of the adductor magnus. The medial epicondyle lies anterior and distal to the adductor tubercle and is C shaped with a central depression or sulcus. The epicondylar axis passes through the centre of the sulcus of the medial epicondyle and the prominence of the lateral epicondyle. This line serves as an important reference line in total knee replacements. The medial epicondyle is more prominent and provides attachment for the medial (tibial) collateral ligament (MCL)

Tibia

The proximal tibia is expanded to receive the condyles of the femur. The shaft of the bone flares out into lateral or medial buttresses which form the medial and lateral condyles. The tibia is the weight bearing bone of the leg whereas the fibula serves the muscular attachments and for completion of the ankle joint. The superior articular surface of the tibia presents two facets. The larger medial facet is oval in shape and has a slight concavity. The lateral facet is nearly round and although concave from side to side, it is convex in front. The rims of the facets are in contact with the medial and lateral menisci but the central portions receive the condyles of the femur. Both tibial facets have a posterior inclination with respect of the shaft of the tibia of approximately 10°. On inspection of the tibial plateau, it would appear as though the femoral and tibial surfaces do not conform. However, this is more apparent than real. In the intact knee the menisci enlarge the contact area considerably and increase conformity of the joint surfaces.

The medial portion of the tibia between the articular facets is occupied by an intercondylar eminence with two tubercles. The articular surface of the tibia continues onto the adjacent sides of the medial and lateral intercondylar eminences. Anterior to the intercondylar eminence is a depression, the anterior intercondylar fossa to which, from anterior to posterior, the anterior horn of the medial meniscus, the ACL and the anterior horn of the lateral meniscus are attached. Behind this region are two elevations, the medial and lateral tubercles. They are divided by a gutter-like depression, the intertubecular sulcus. On an antero-posterior radiograph the medial tubercle usually projects more superior than the lateral tubercle. On the lateral radiograph the medial tubercle is located anterior to the lateral tubercle. The tubercles do not function as attachment sites for the cruciate ligaments or the menisci but may act as side to side stabilisers by projecting towards the inner sides of the femoral condyles. In the posterior intercondylar fossa, behind the tubercles, the lateral then the medial menisci are attached anterior to posterior. Most posterior, the posterior cruciate ligaments inserts on the margin of the tibia between the condyles. From its origin, the posterior cruciate ligament travels anterior and slightly medial where it is joined by one or two cords from the lateral meniscus (the anterior and posterior menisco-femoral ligaments (or the ligament of Humphrey and the ligament of Riesburg respectively)) to attach the medial condyle of the femur in the intercondylar notch.

On the anterior aspect of the proximal tibia, the tibial tuberosity is the most prominent feature and is the attachment site of the patellar tendon. Approximately 2 to 3 cm lateral to the tibial tubercle is Gurdy's tubercle, which is the insertion site of the ilio-tibial band (ITB). Posterior to Gurdy's tubercle, the lateral condyle has a nearly circular facet on its postero-inferior surface for articulation with the head of the fibula.

At its upper medial portion the tibia provides the attachment for the medial collateral ligament, both the deep and superficial bands of the medial collateral ligament. The medial surface of the body of the tibia is smooth and convex. Its upper one third receives the insertion of the sartorius, gracilis and semitendinosus tendons (medial hamstrings).

Fibula

The fibula is a long slender bone that lies parallel and lateral to the tibia. It does not participate in weight bearing but rather serves the muscle and tendon attachments. The head of the fibula is knob-like, and superiorly slanted towards the tibia, is the almost circular articular surface which participates in tibio-fibular articulation. At the postero-lateral limit of the articular facet the apex of the head projects upwards and provides attachment for the lateral (fibula) collateral ligament (LCL) of the knee joint. The tendon of biceps femoris muscle attaches to the lateral aspect of the head of the fibula.

Tibiofibular Joint

The joint between the circular facet of the head of the fibula and a similarly shaped surface on the postero-lateral aspect of the under surface of the lateral condyle of the tibia is a plane joint. The articular surface of the head of the fibula is directed superiorly and slightly antero-medially to articulate with the postero-lateral part of the tibial metaphysis. The head of the fibula in addition to the insertional site for the LCL and the biceps femoris tendon also acts as insertion for the fabello-fibular ligament and the arcuate ligament.

The superior tibio-fibula joint is a synovial joint lined by synovial membrane possessing a capsular ligament that is strengthened by anterior and posterior ligaments.

In contrast, the inferior tibio-fibula joint is a syndesmosis and the bones are joined by strong interosseus ligament. Movement at the superior tibio-fibula joint is slight at best but is nevertheless important.

There are a number of nerves and arteries that run in close proximity to the proximal end of the fibula. The anterior tibial artery, the terminal branch of the popliteal artery, enters the anterior compartment of the leg through the opening in the interosseus membrane two finger breadths below the superior tibio-fibula joint. The anterior tibial nerve and a terminal branch from the common peroneal nerve also pierces the anterior interosseus ligament and comes to lie lateral to the artery. The superficial peroneal nerve arises from the common peroneal nerve on the lateral side of the neck of the fibula and runs distally forward in the substance of the peroneus longus muscle.

Patella

The patella is the largest sesamoid bone in the body and is situated in the tendon of the quadriceps femoris muscle. It articulates against the anterior articular surface of the distal femur. It holds the patellar tendon off the distal femur thus improving the angle of approach of the tendon to its distal insertion on the tibial tuberosity, so increasing the power generation of the quadriceps mechanism by 30%. The anterior surface of the patella is convex. The superior border is thick and gives attachment to the tendinous fibres of the rectus femoris and vastus intermedius muscles. The lateral and medial borders are thinner and receive the tendinous fibres of the vastus lateralis and vastus medialis muscles respectively. These two borders converge inferiorly to the pointed lower pole of the patella which gives attachment to the patellar ligament.

The articulation between the patella and femoral trochlea forms the patello-femoral knee joint compartment. The articular surface of the patella is described as possessing seven facets. Both the medial and lateral facets are divided vertically into approximately equal thirds, whereas a seventh or odd facet lies along the extreme medial border of the patella. Overall the medial facet is smaller and slightly convex, the lateral facet which consists of roughly two thirds of the patella has both sagittal convexity and coronal concavity.

Six variants of the patella have been described. Types one and two are stable whereas the other variants are more likely to result in lateral subluxation as a result of unbalanced forces. The facets of the patella are covered by the thickest hyaline cartilage in the body which may measure up to 6.5mm in thickness.

The patella fits in the trochlea of the femur imperfectly with the contact area between the patella and femur varying with position of flexion. The area of contact never exceeds about one third of the total patella articular surface. At 10 to 20° of flexion at the distal pole the patella first contacts the trochlea in a narrow band across the medial and lateral facet. As flexion increases the contact area moves proximally and laterally. The most extensive contact is made at about 45° where the contact area is an elipse across the central portion of the medial and lateral facet. By 90° the contact area is shifted to the upper part of the medial and lateral facets. With further flexion the contact area separates into two distinct medial and lateral patches. Because the odd facet only makes contact with the femur in extreme flexion (such as in the act of squatting) this facet is habitually a non contact zone in humans in Western countries.

The main biomechanical function of the patella is to increase the momentum of the quadriceps mechanism. The load across the joint rises as flexion increases but because the contact area also increases, higher forces are dissipated over a larger area. However, if extension against resistance is performed, the force increases while the contact area shrinks. Straight leg raises eliminate forced transmission across the patello-femoral joint because in full extension the patella has not yet engaged the trochlea.

Cruciate Ligaments

The cruciate ligaments consist of a highly organised collagen matrix which accounts for approximately three fourths of their dry weight. The majority of the collagen is type 1 (same as in bone) (90%) and the remainder is type 3 (10%). Water constitutes 60% of the net weight under physiological conditions.

The cruciate ligaments are named based on their attachments on the tibia and their relationships to the intercondylar eminence of the proximal tibia. They are essential to the function of the knee joint. The cruciate ligaments act to stabilise the knee joint and prevent antero-posterior displacement of the tibia and the femur. They also contain numerous sensory endings implying an important role in proprioceptive function. These ligaments are intra-articular but because they are covered by synovium they are considered extra-synovial. They receive their blood supply from branches of the middle genicular and both inferior genicular arteries.

ACL - Anterior Cruciate Ligament

The ACL originates from the medial surface of the lateral femoral condyle posteriorily in the intercondylar notch in the form of a segment of a circle. The ligament courses anteriorily, distally and medially towards the tibia. Over the length of its course the fibres of the ligament undergo a slight external rotation. The average length of the ligament is 38mm and the average width 11mm. The tibial attachment is a wide depressed area anterior and lateral to the medial tibial tubercle in the intercondylar fossa. The tibial attachment is more robust than the femoral attachment. There is a well marked slip to the anterior horn of the lateral meniscus. Morphologically it is felt that the ACL is composed of two bands, the anteromedial band and the posterolateral band.

In extension the posterolateral band of the ACL is taut and the anteromedial band is lax, whereas in flexion the anteromedial band is tight and the posterolateral band is relatively relaxed.

The ACL is a prime static which stabilises against anterior translation of the tibia on the femur accounting for up to 86% of the total force resisting anterior draw. The ACL also plays a lesser role in resisting internal and external rotation.

The maximum tensile strength of the ACL is approximately 1725 +/- 270 newtons. This is less than the peak forces that occur in vigorous athletic activity. Stability is enhanced by dynamic stabilisers such as muscles that exert a force across the knee joint. The ACL plays an important proprioceptive function because of the variety of receptors in the anterior cruciate ligament. In people with ACL deficient knees, a significantly higher threshold for detecting passive motion of the involved knee has been reported.

Posterior Cruciate Ligament

The posterior cruciate ligament originates from the posterior part of the lateral surface of the medial femoral condyle in the intercondylar notch. The PCL has an average length of 38mm and an average width of 13mm. It is narrowest in its mid portion and fans out to a greater extent superiorly and inferiorly. The fibres are attached to the tibial insertion which occurs in a depression posterior to the intra-articular upper surface of the tibia. This is therefore outside the knee joint per se. The attachment extends for up to 1cm distally onto the adjoining posterior surface of the tibia. Immediately proximal to the tibial attachment the PCL has slips that blend with the posterior horn of the lateral meniscus. These slips variably pass anterior to the PCL (ligament of Humphrey) and/or posterior to the PCL (ligament of Riesburg).

The normal PCL has a uniformly low signal intensity on MRI studies with a hockey stick shape (MRI image of PCL). Tears of the ligament appear as bright signal intensity within the ligament substance or with discontinuity of the fibres. (

The PCL is considered to be the primary stabiliser of the knee because it is located close to the central axis rotation of the joint is almost twice as strong as the ACL. The PCL has been shown to provide approximately 95% of the total restraint to posterior translation of the tibia on the femur. The PCL is maximally taught at full flexion and also becomes tighter with internal rotation. Two inseparable components of the PCL have been identified. The anterior fibres form the bulk of the ligament and are believed to be taut in flexion and lax in extension. The opposite applies to the thinner posterior portion which is taut in extension and lax in flexion. The PCL appears to function in concert with the LCL and popliteus tendons to stabilise the knee

Injuries to the PCL are less common than the ACL and usually result from hyperextension or anterior blows to the flexed knee. Rarely do these injuries result in symptomatic instability but they may be associated with chronic pain. Significant degenerative changes that involve the medial compartment in 90% of cases have been associated with chronic PCL injuries as well as degenerative changes within the patello-femoral compartment.

Synovial Membrane and Cavity

The articular cavity of the knee joint is the largest joint space of the body. The cavity includes a space between and around the tibial and femoral condyles but also extend upwards behind the patella to include the patello-femoral articulation and further into the supra-patellar bursa which lies between the tendon of the quadriceps femoris muscle and the femur.

The synovial membrane lines the articular capsule and reflects onto the bone as far as the edges of the articular cartilage. It also lines the supra-patellar bursa and may also line any other bursas that communicate with the knee joint. The synovial membrane also covers the cruciate ligament except where the PCL is attached to the back of the capsule. The anterior cruciate ligament is therefore an intra-articular structure which is within the synovial cavity of the knee joint whereas the posterior cruciate ligament is an intra-articular structure which is outside the synovial cavity of the knee joint.

The infra-patellar fat pad which lies below the patella represents an anterior section of the median septum of tissues with the cruciate ligaments separating the two tibio-femoral articulations into medial and lateral compartments. From the synovial surface of the infra-patellar fat pad, a vertical fold frequently passes towards the cruciate ligament and attaches to the intercondylar fossa of the femur, anterior to the ACL and lateral to the PCL. This is called a ligamentum mucosum.

The numerous folds and recesses within the knee are potential sites for collection of wear debris, loose bodies and bacterial contamination. All these recesses need to be assessed arthroscopically in these situations.

Capsule

The capsule of the knee joint is a fibrous membrane containing areas of thickening that may be referred to as discreet ligaments. The anterior capsule is thin and directly anterior it is replaced by the patellar ligament. Proximally the capsule of the knee joint attaches to the femur approximately three to four finger breadths above the patella. Distally it attaches circumferentially to the tibial margin except where the popliteal tendon enters the joint through the hiatus. Posteriorily the capsule consists of vertical fibres that arise from the condyles and from the walls of the intercondylar fossa of the femur. In this region the capsule is augmented by the fibres of the oblique popliteal ligament, which is derived from the semi-membranous tendon. This broad flat band is attached proximally to the margin of the intercondylar fossa and posterior surface of the femur close to the articular margins of the condyles. The oblique popliteal ligament forms part of the floor of the popliteal fossa and the popliteal artery rests on it.

Knee Flexors

Seven muscles flex the knee: a) semi-tendinosis b) semi-membranosis c) biceps femoris d) sartorius e) gracilis f) popliteus g) gastrocnemius.

The semi-tendinosis, semi-membranosis and biceps femoris muscles are collectively known as the hamstrings and all originate from the ischial tuberosity of the pelvis. All the knee flexors except for the short head of biceps femoris and the popliteus are two joint muscles (ie crossing the hip and knee joint). Four of the flexors (popliteus, gracilis, semi-membranosis and semi-tendinosis) medially (or internally) rotate the tibia on the fixed femur, whereas the biceps femoris is a lateral rotator of the tibia. The semi-tendinosis, semi-membranous and biceps femoris muscles (hamstrings) flex the knee and extend the thigh. Because the muscles used reproduce a combined maximal excursion at one joint (eg extension of the thigh) they will limit movement at the other joint to less than maximal. Therefore they work most effectively at the knee joint if they are lengthened over a flexed hip.

Except for the plantaris muscle, the gastrocnemius is the only muscle at the knee that crosses both the ankle and knee joint. The gastrocnemius makes a relatively small contribution to knee flexion but is effective in preventing knee joint hyperextension thus the gastrocnemius appears to be more a dynamic stabiliser and less a mobility muscle at the knee joint.

The tendon of the gracilis muscle in addition to the sartorius and semi-tendinosis insert into the medial tibia to form part of the pes anserinus (goose's foot). These muscles collectively insert anterior and proximal to the insertion of the superficial medial collateral ligament (SMCL). The gracilis flexes the knee joint and produces slight medial rotation of the tibia. The three muscles of the pes anserinus appear to function effectively as a group to stabilise the medial aspect of the knee joint.

The popliteus muscle is a one joint knee flexor (in addition to the short head of biceps femoris). The popliteus flexes the knee and rotates it medially serving as a medial rotator of the tibia and the femur. The popliteus muscle may play a role in initiating unlocking of the knee because it reverses the direction of automatic external rotation that occurs in the final stages of knee extension (screw home mechanism).

Knee Extensors

The four extensors of the knee are collectively known as the quadriceps femoris muscles. The only portion of the quadriceps that crosses two joints is the rectus femoris which originates on the anterior inferior iliac spine. The vastus intermedius, vastus lateralis and vastus medialis muscles originate from the femur and merge into a common quadriceps tendon.

The fibres of the quadriceps tendon continue distally as the patellar ligament. The patellar ligament runs from the apex of the patella, across the anterior surface of the patella to insert into the proximal portion of the tibial tubercle. The vastus medialis and vastus lateralis also insert directly into the medial and lateral aspects of the patella by way of the retinacular fibres of the joint capsule.

The vastus medialis obliquis (VMO) serves as an important dynamic stabiliser of the patella. The VMO portion of the vastus medialis overlies the superior aspect of the medial patello-femoral ligament (MPFL) in layer two of the medial knee and is therefore not part of the medial retinacular complex. However, above the MPFL the VMO tapers into aponeurosis which fuses with layer two of the medial retinacular complex near its insertion into the superior medial patella.

The quadriceps tendon is a tri-laminate structure. The anterior layer is formed by the rectus femoris, the intermediate layer by the vastus medialis and the lateralis and the deep layer by the tendon of vastus intermedius.

Because there is an inclination to the shaft of the femur from the hip, the quadriceps muscle does not pull in direct line with the patellar tendon. The angle formed is always valgus (pointing outwards) and the average is 14° in the male and 17° in the female. This angle, called a quadriceps (Q) angle, is accentuated by internal rotation of the femur. The resulting tendency towards lateral patella displacement is resisted by the lateral lip of the femoral trochlea, the horizontal fibres of the VMO, and the medial patella retinaculum of which the most important structure is the MPFL.

Action of Muscles

The movements of the knee are flexion, extension and rotation. Flexion is performed by the hamstrings and biceps femoris and to a lesser extent the gastrocnemius and popliteus.

Flexion is limited by the soft tissues at the back of the knee.

Extension is performed by the quadriceps and because of the shape of the articulation and ligament attachments, the femur rotates medially on the tibia in terminal extension, the screw home mechanism that locks the joint. This movement is purely passive as are other rotatory movements occurring during flexion/extension and is due to articular geometry and static stabilisers.

The exception is lateral rotation of the femur that proceeds flexion by unlocking the joint. This movement is performed by the popliteus muscle. The sartorius, gracilis and hamstrings are weak rotators of the knee but probably do not act as such primarily.

Knee Joint Stabilisation

The stability of the knee joint is dependent upon static and dynamic factors. The static stabiliser includes passive structures such as the knee joint capsule and the various ligaments and other associated structures such as the menisci, the coronary ligaments, the menisco-patella and patello-femoral ligaments. The ligaments which all act as static stabilisers include the medial collateral ligament, the lateral collateral ligament, the ACL, PCL, the oblique popliteal and arcuate ligaments. The ilio-tibial band is also considered a static stabiliser in spite of its muscular connections.

The bony geometry also contributes to the static stability of the knee. The contribution is variable but can be made worse by certain anatomic variants such as a flat lateral femoral trochlea which will predispose to lateral instability of the patella.

The dynamic stabilisers of the knee are all the muscles and their aponeuroses including: 1. quadriceps femoris and extensor retinaculum, 2. pes anserinus, 3. popliteus, 4. biceps femoris, 5. semi-membranosis. The structures on the medial, antero-medial and postero-medial side of the knee are medial compartment structures and stabilisers and structures on the respective lateral side are lateral compartment stabilisers.

The contribution that both muscles and ligaments make to stability is dependent on joint position of the knee and the surrounding joints, the magnitude and direction of the force and the availability of reinforcing structures to resist forces if the primary restraints become incompetent.

Knee Motion

The knee joint is a modified hinge joint (ginglymus). The active movements of the knee joint are described as flexion, extension, medial rotation and lateral rotation.

The flexion and extension at this joint differ from those of a true hinge as the axis about which the movement occurs is not fixed, but translates upwards and forwards during extension and backwards and downwards during flexion. The knee joint possesses limited inherent stability from the bony architecture. The lack of conformity between bony surfaces allow 6° of freedom of motion about the knee including translation in 3 planes (medio-lateral, antero-posterior, proximo-distal) and rotation in 3 planes (flexion/extension, internal/external, varus/valgus).

With the foot fixed on the ground the last 30° of extension is associated with medial rotation of the femur. Compared with the medial femoral condyle, the articular surface of the smaller lateral femoral condyle is a rounder and flattens more rapidly anteriorily. Consequently, it approaches a more fully congruent relationship with its opposed tibial meniscal surface, some 30° before full extension has been obtained. To achieve full extension, the lagging medial compartment must medially rotate about a fixed vertical axis while moving backwards in an arc.

There is progressive increase in passive mechanism that resists further extension. In full extension parts of both cruciate ligaments, the collateral ligaments the posterior capsular and oblique posterior ligament complex and the skin and fascia are all taught. There is also passive or active tension in the hamstrings, gastrocnemius muscles and the ITB. In addition the anterior parts of the menisci compress between the femoral condyles and the tibia.

At the beginning of flexion, the knee "unlocks" with an external rotation of the femur on the tibia. This is partly related to the opposite interplay of the meniscal articular and ligamentous structures involved but is also brought about by the contraction of the popliteus muscles. It pulls downwards and posterior on its attachment to the lateral condyle of the femur helping the greater roll back in this compartment which occurs with flexion. Via its meniscal attachment the popliteus pulls on the posterior horn of the lateral meniscus. In this way, while rolling back, the posterior motion of the menisci occurs in both compartments, the greater motions laterally can be facilitated. The menisci which are squeezed between the joint surface in extension are moved posteriorily with the femur in flexion, the lateral more so than the medial. With terminal extension achieved and the knee locked by the femur rotating internally on the tibia, this is called the screw home mechanism.

Flexion is checked by the quadriceps mechanism, the anterior parts of the capsule and the PCL and by the compression of the soft tissue structures in the popliteal fossa.