Chapter 8

The Biomechanics of the Human Lower Extremity

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Structure of the Hip

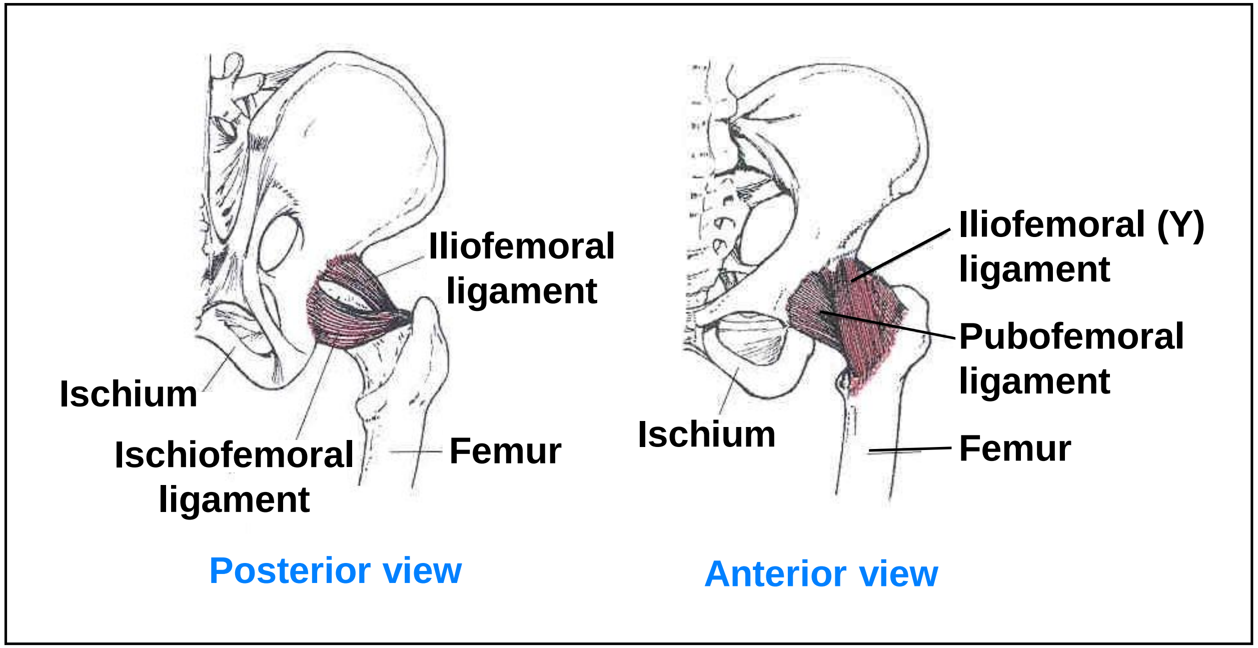
What is the hip joint?

Åa ball and socket joint

Åwhere the head of the femur articulates with the concave acetabulum

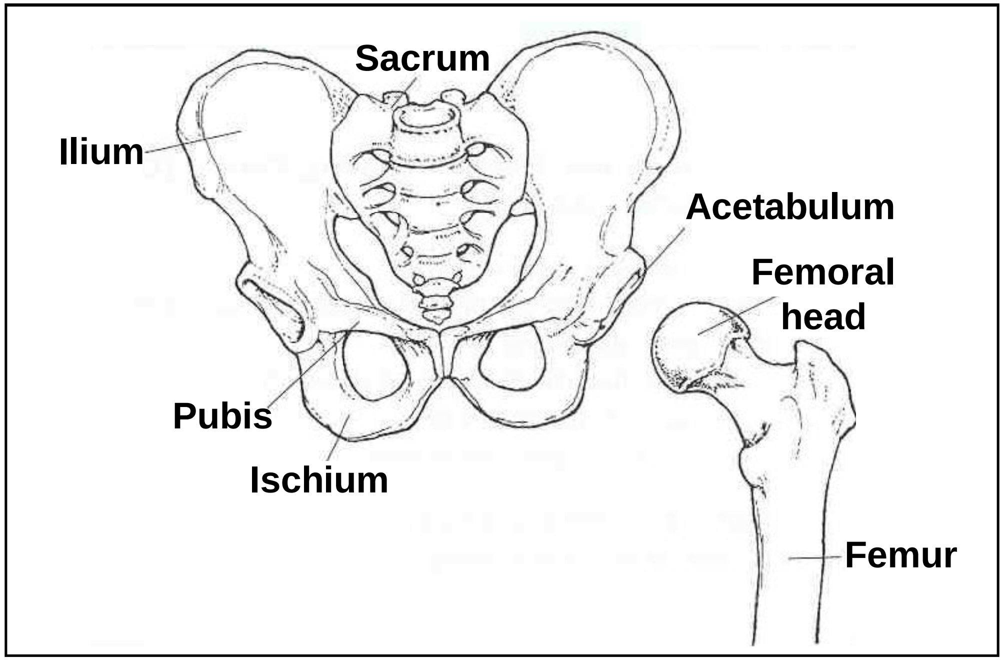
Åa more stable joint than the shoulder because of bone structure and the number and strength of the muscles and ligaments crossing the joint

Structure of the Hip



The integrity of the hip is enhanced by the strong ligaments crossing the joint.

Structure of the Hip



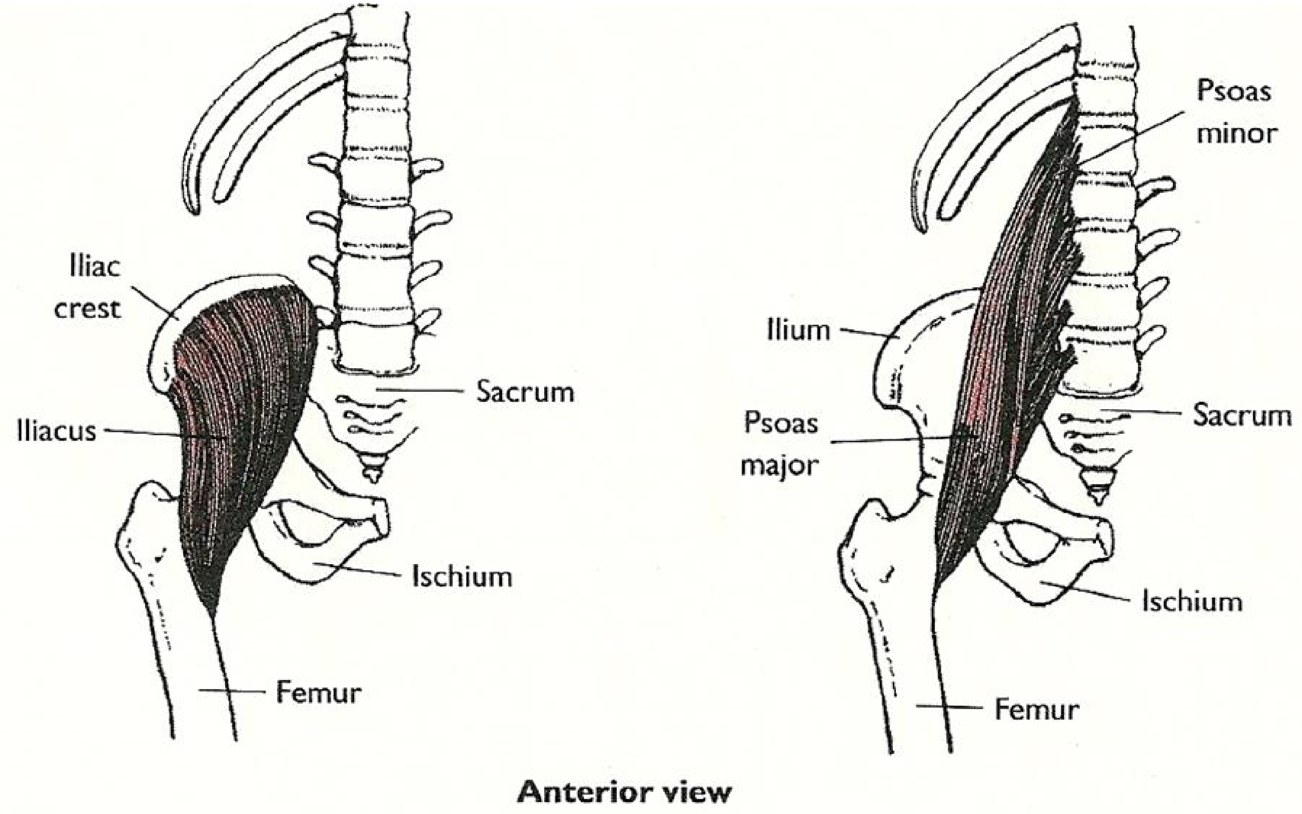
The pelvic girdle includes the two ilia and the sacrum. It can be rotated forward, backward, and laterally to optimize positioning of the hip.

Movements at the Hip

What movements of the femur are facilitated by pelvic tilt?

Pelvic tilt direction	Femoral movement
posterior	flexion
anterior	extension
lateral (to opposite side)	abduction

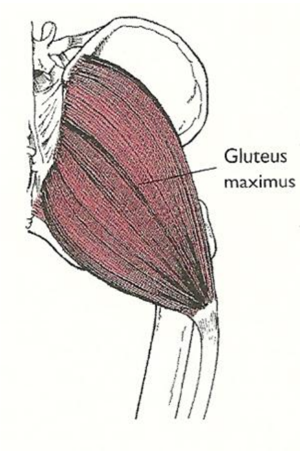
Movements at the Hip

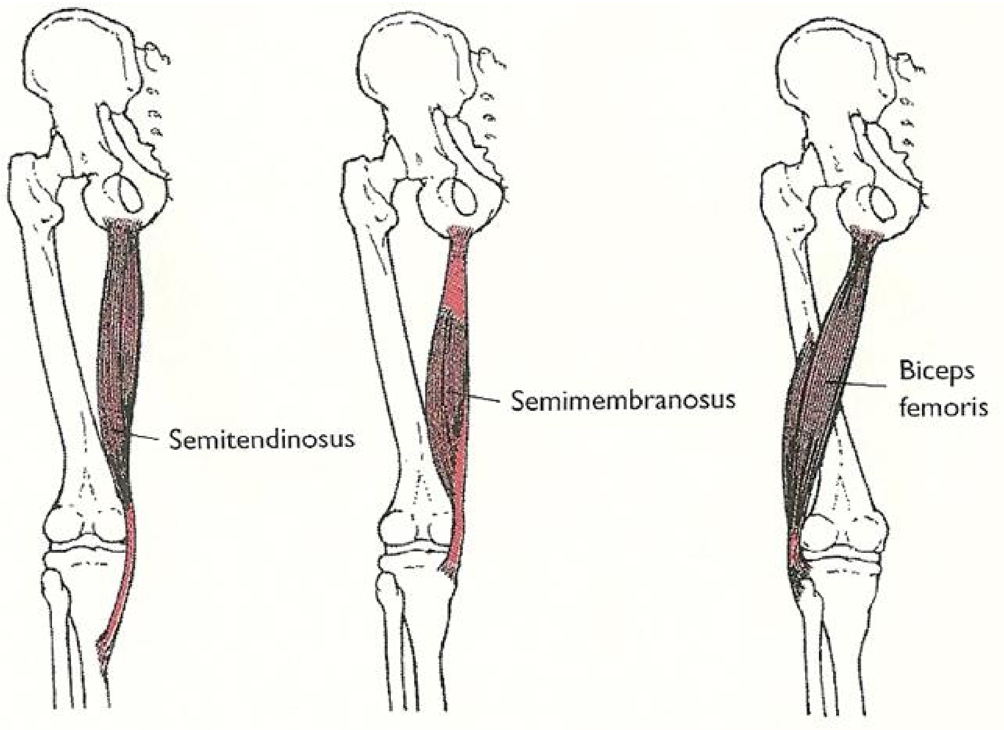


Flexor muscles at the hip are iliacus and psoas major, assisted by pectineus, rectus femoris, sartorius, and tensor fascia latae.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Movements at the Hip

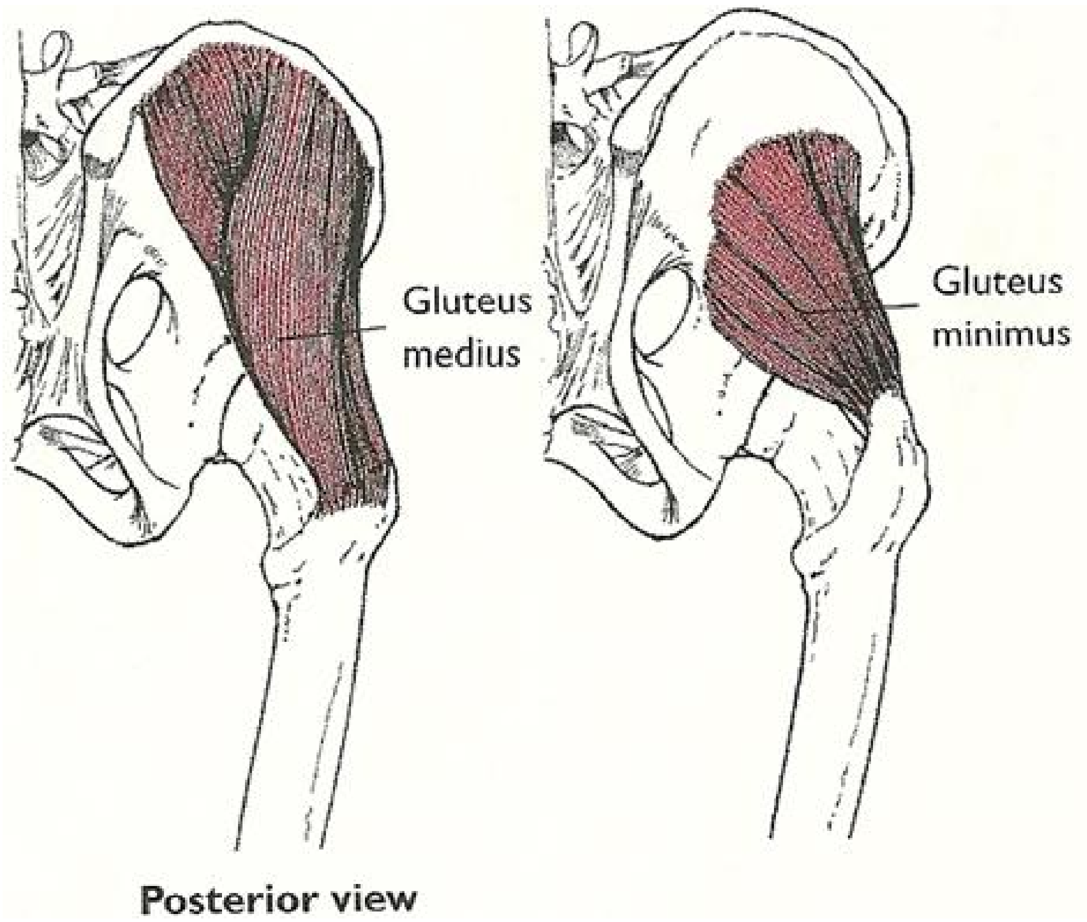




Extensor muscles at the hip are gluteus maximus and the hamstrings: biceps femoris, semimembranosus, and semitendinosus.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

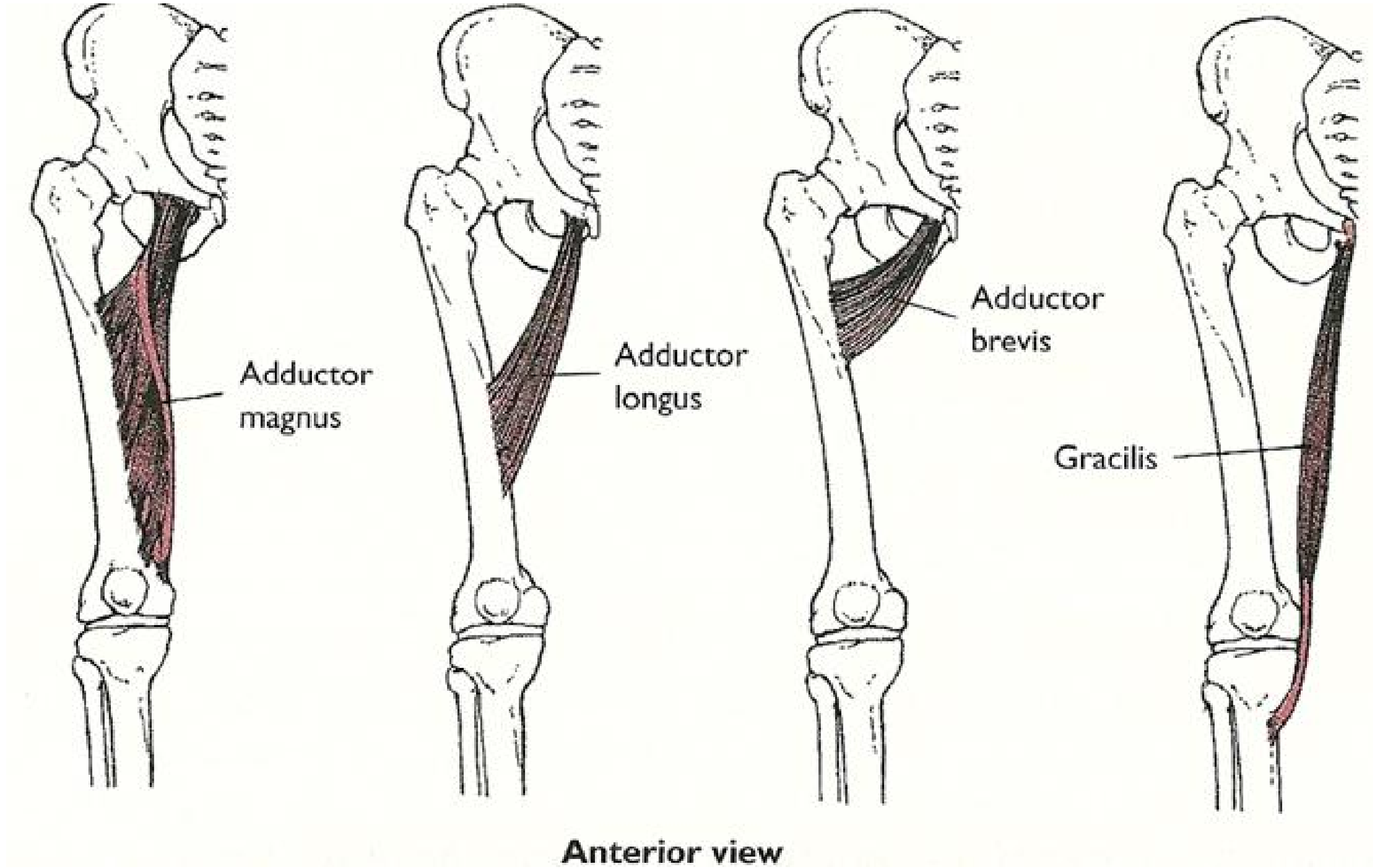
Movements at the Hip



The abductor muscle at the hip is the gluteus medius, assisted by gulteus minimus.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

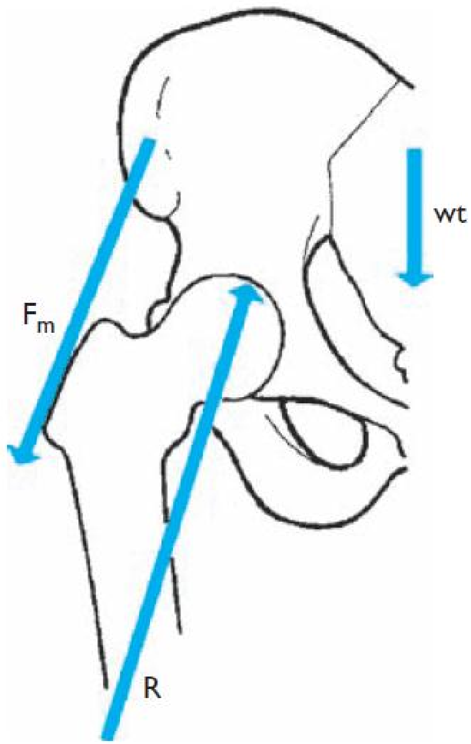
Movements at the Hip



The adductor muscles at the hip are adductor magnus, adductor longus, and adductor brevis, assisted by gracilis.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Loads on The Hip



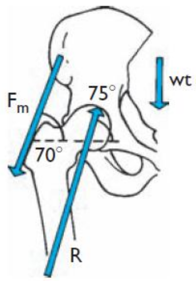
Loads on The Hip

SAMPLE PROBLEM 8.1

How much compression acts on the hip during two-legged standing, given that the joint supports 250 N of body weight and the abductor muscles are producing 600 N of tension?

Known

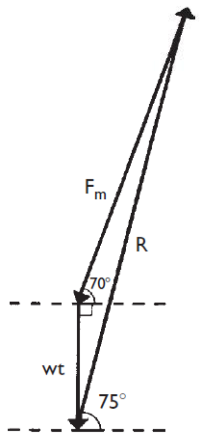
$$wt = 250\ N$$
$$F_m = 600\ N$$



Graphic Solution

Since the body is motionless, all vertical force components must sum to zero and all horizontal force components must sum to zero. Graphically, this means that all acting forces can be transposed to form a closed force polygon (in this case, a triangle). The forces from the diagram of the hip above can be reconfigured to form a triangle.

If the triangle is drawn to scale (perhaps 1 cm = 100 N), the amount of joint compression can be approximated by measuring the length of the joint reaction force (R).



$$R \approx 840\ N$$

Mathematical Solution

The law of cosines can be used with the same triangle to calculate the length of R.

$$R^2 = F_m{}^2 + wt^2 - 2(F_m)(wt)\cos 160°$$
$$R^2 = 600\ N^2 + 250\ N^2 - 2(600\ N)(250\ N)\cos 160°$$
$$R = 839.3\ N$$

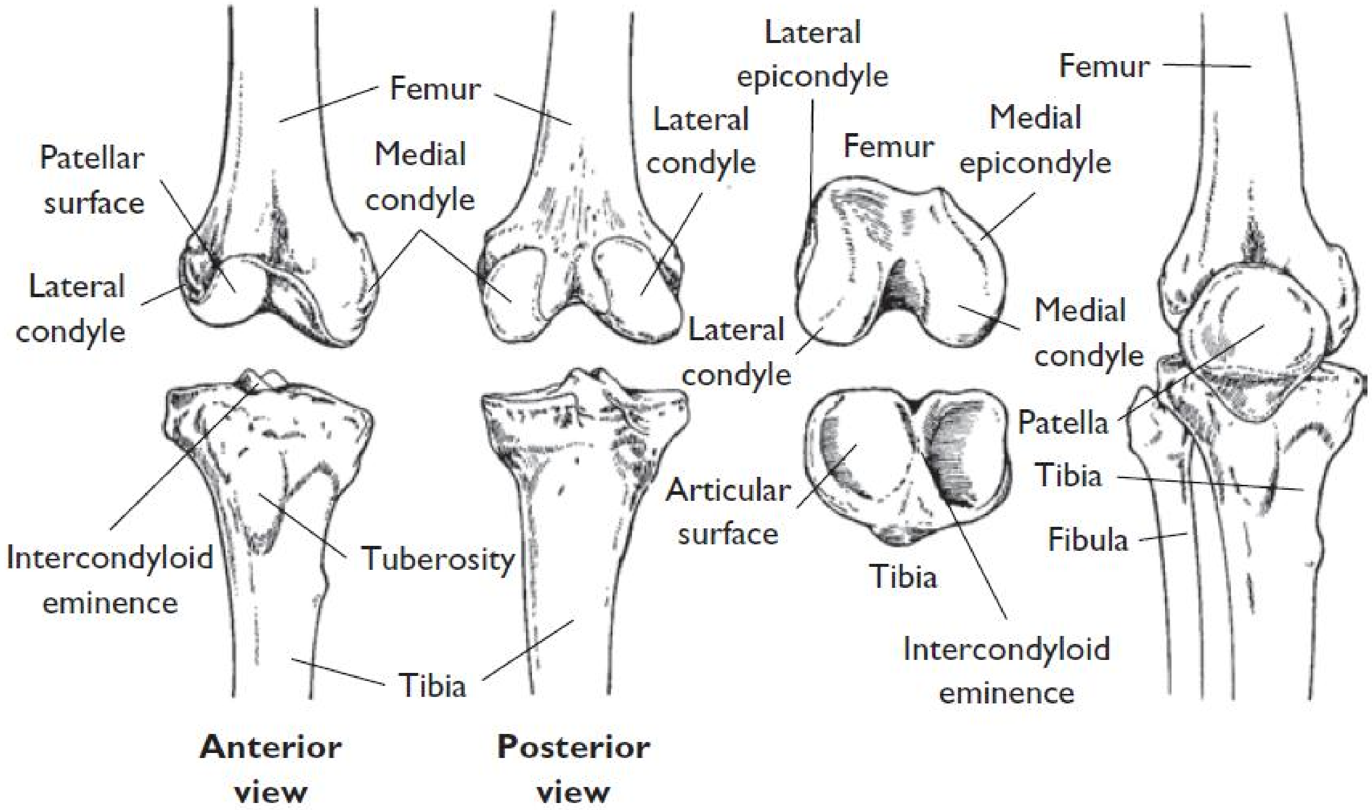
Structure of the Knee

What is the tibiofemoral joint?

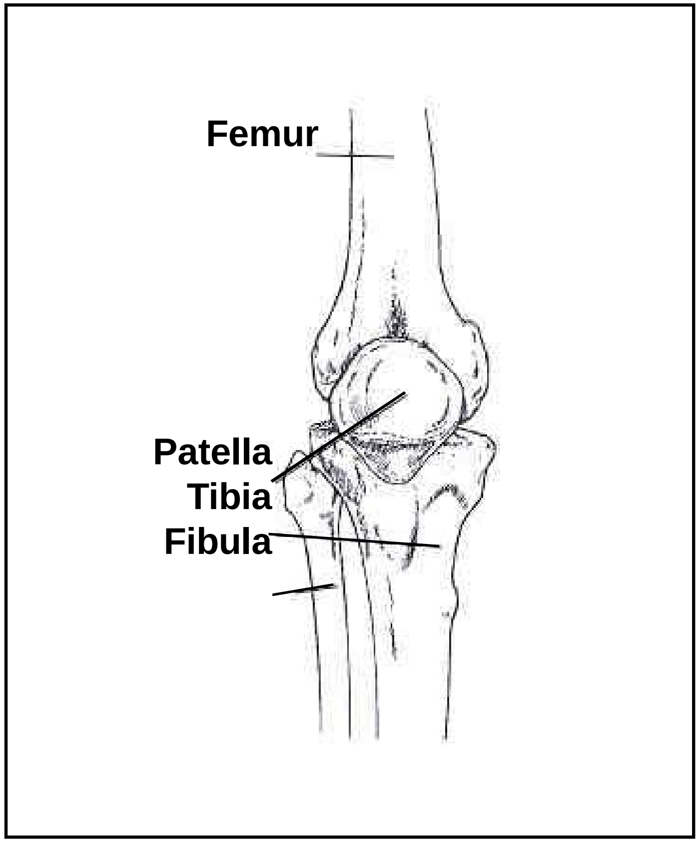
Ådual condyloid articulations between the medial and lateral condyles of the tibia and the femur; composing the main hinge joint of the knee

Åconsidered to be *the* knee joint

Structure of the Knee



Structure of the Knee



Bony structure of the tibiofemoral joint.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Structure of the Knee

What is the patellofemoral joint?

Åarticulation between the patella and the femur

Å(the patella improves the mechanical advantage of the knee extensors by as much as 50%)

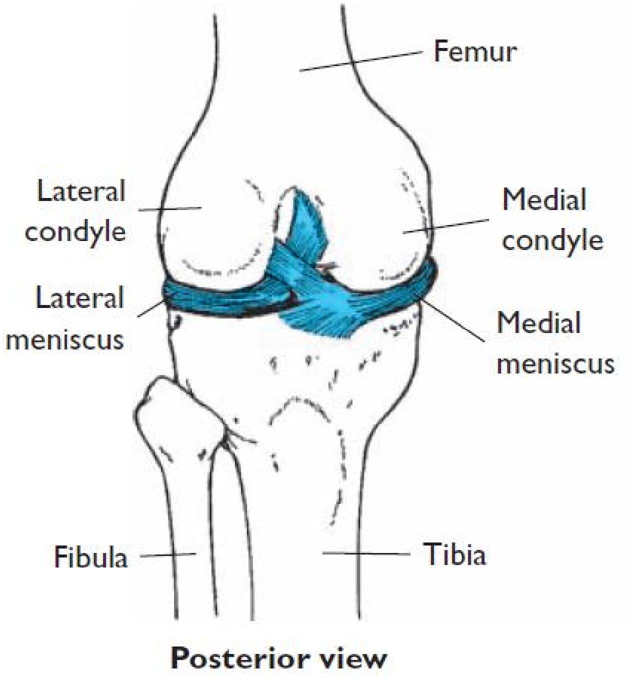
Structure of the Knee

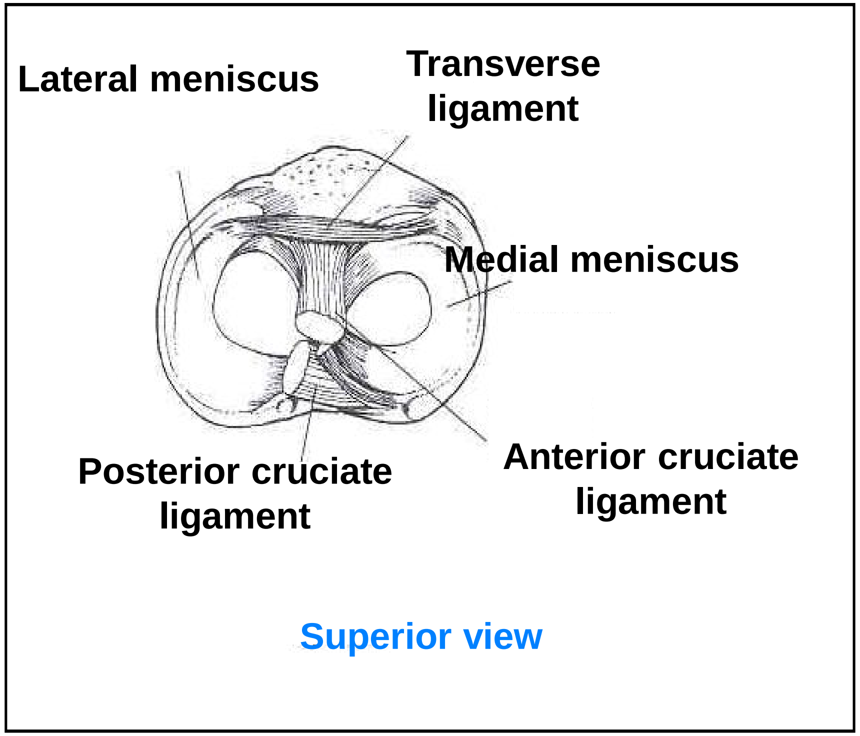
What are the menisci?

Åcartilaginous discs located between the tibial and femoral condyles

Åstructures that distribute the load at the knee over a large surface area and also help absorb shock

Structure of the Knee





The menisci of the knee.

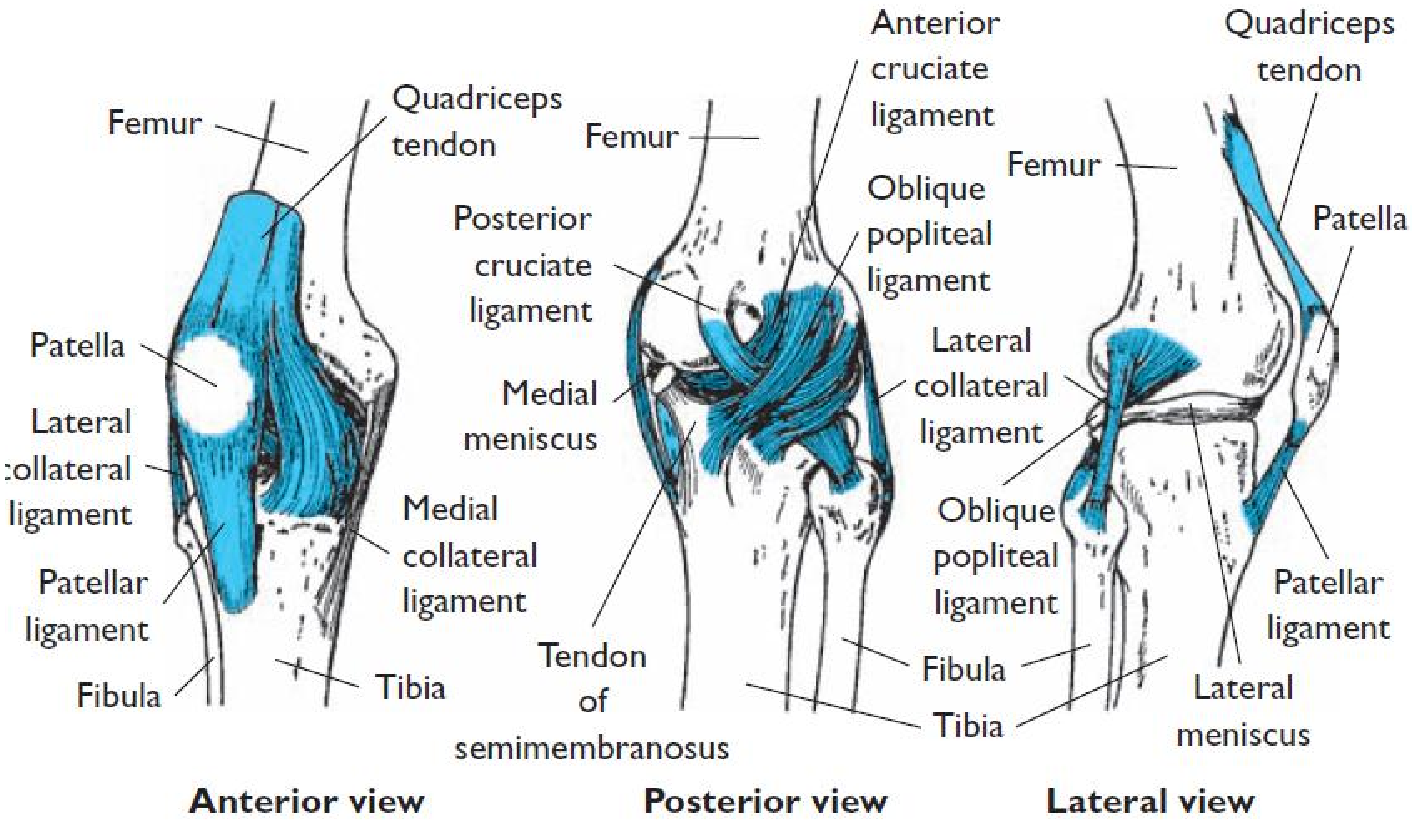
Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Structure of the Knee

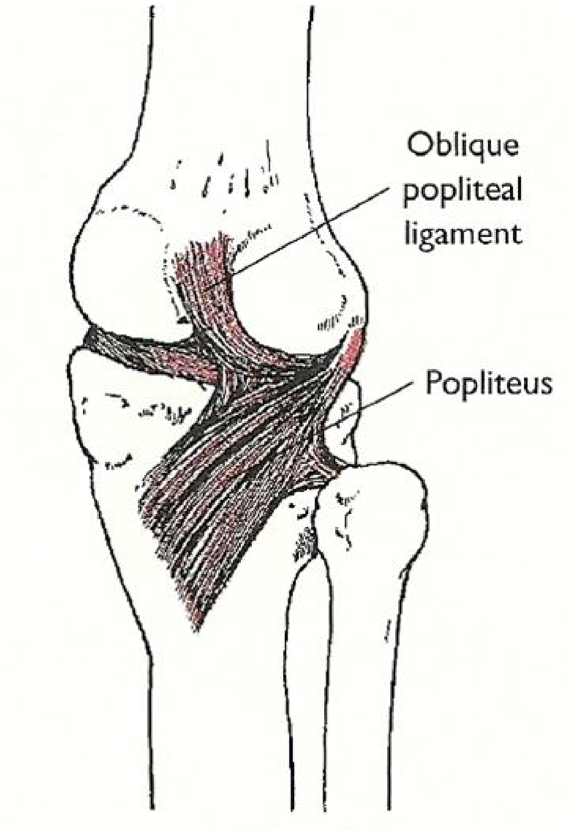
What major ligaments cross the knee?

- collateral ligaments - cross the medial and lateral aspects of the knee
- cruciate ligaments - cross each other in connecting the anterior and posterior aspects of the knee

Structure of the Knee



Movements at the Knee



The popliteus ñunlocksòthe fully extended knee by laterally rotating the femur with respect to the tibia to allow flexion to proceed.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Movements at the Knee

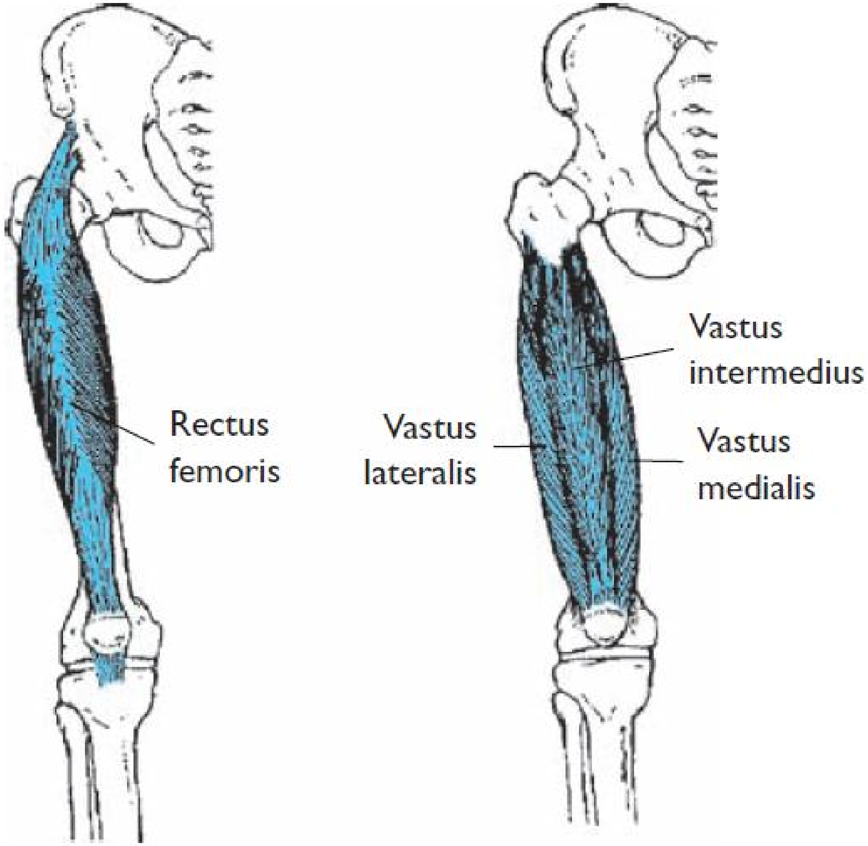
What muscles contribute to flexion at the knee?

Åhamstrings

Åassisted by:

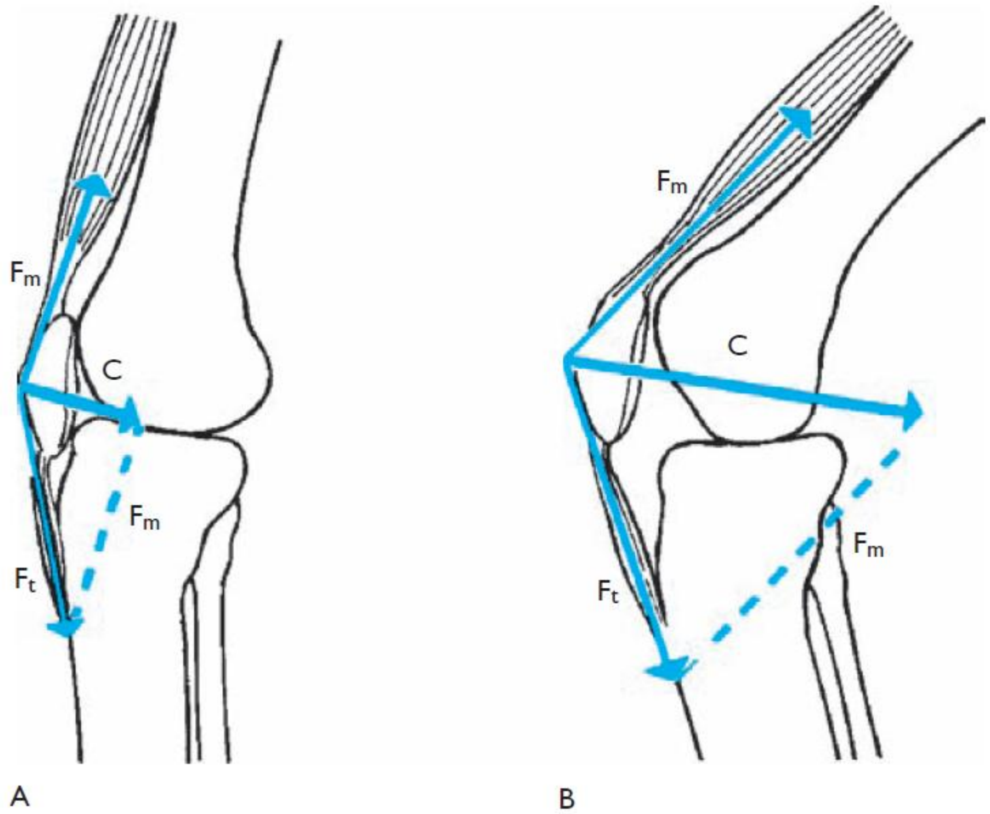
- Ågracilis
- Åsartorius
- Åpopliteus
- Ågastrocnemius

Movements at the Knee



Anterior view

Loads on The Knee



Loads on The Knee

SAMPLE PROBLEM 8.2

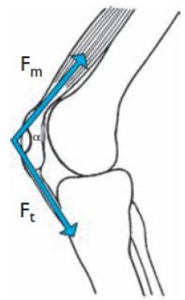
How much compression acts on the patellofemoral joint when the quadriceps exerts 300 N of tension and the angle between the quadriceps and the patellar tendon is (a) 160° and (b) 90°?

Known

$$F_m = 300 \text{ N}$$

Angle between F_m and F_t:

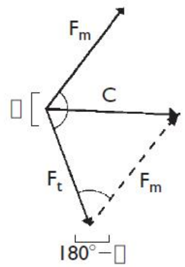
1. 160°
2. 90°



Graphic Solution

Vectors for F_m and F_t are drawn to scale (perhaps 1 cm: 100 N), with the angle between them first at 160° and then at 90°. The tip-to-tail method of vector composition is then used (see Chapter 3) to translate one of the vectors so that its tail is positioned on the tip of the other vector. The compression force is the resultant of F_m and F_t and is constructed with its tail on the tail of the original vector and its tip on the tip of the transposed vector.

The amount of joint compression can be approximated by measuring the length of vector C.



1. C ≈ 100 N
2. C ≈ 420 N

Mathematical Solution

The angle between F_t and transposed vector F_m is 180° minus the size of the angle between the two original vectors, or (a) 20° and (b) 90°. The law of cosines can be used to calculate the length of C.

1. $C^2 = F_m{}^2 + F_t{}^2 - 2(F_m)(F_t) \cos 20$

   $C^2 = 300 \text{ N}^2 + 300 \text{ N}^2 - 2(300 \text{ N})(300 \text{ N}) \cos 20$

   C = 104 N

2. $C^2 = F_m{}^2 + F_t{}^2 - 2(F_m)(F_t) \cos 90$

   $C^2 = 300 \text{ N}^2 + 300 \text{ N}^2 - 2(300 \text{ N})(300 \text{ N}) \cos 90$

   C = 424 N

Note: This problem illustrates the extent to which patellofemoral compression can increase due solely to changes in knee flexion.

Normally, there is also increased quadriceps force with increased knee flexion.

Structure of the Ankle

What is the tibiotalar joint?

Åhinge joint where the convex surface of the superior talus articulates with the concave surface of the distal tibia

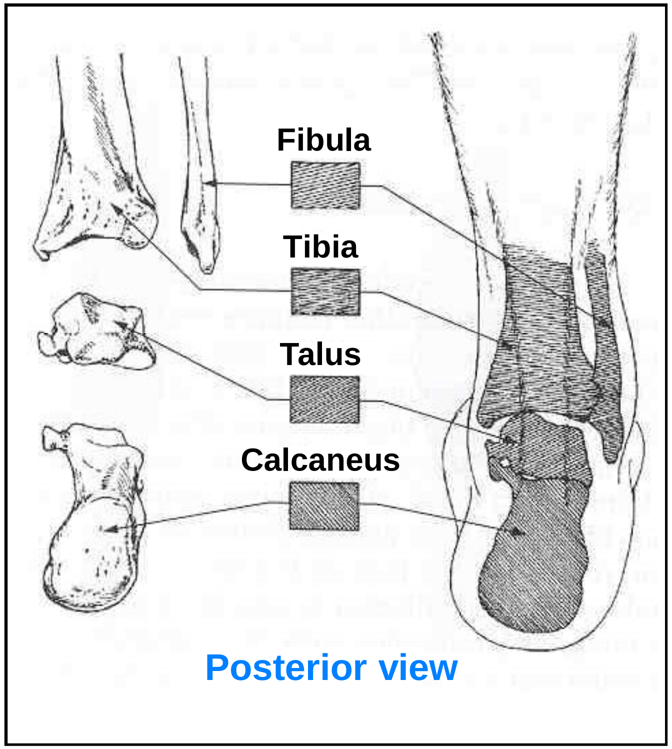
Åconsidered to be *the* ankle joint

Structure of the Ankle

What is the distal tibiofibular joint?

(a syndesmosis where dense, fibrous tissue binds the distal tibia and fibula together)

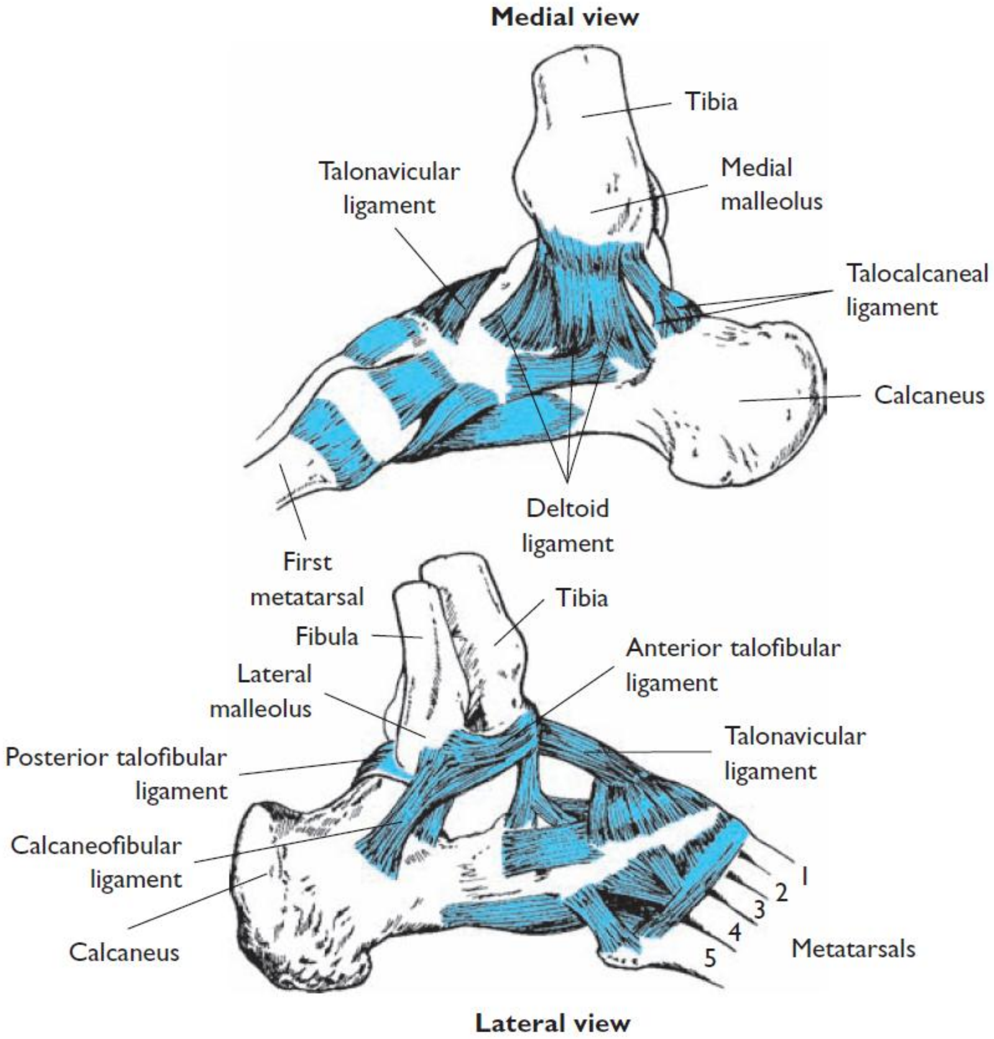
Structure of the Ankle



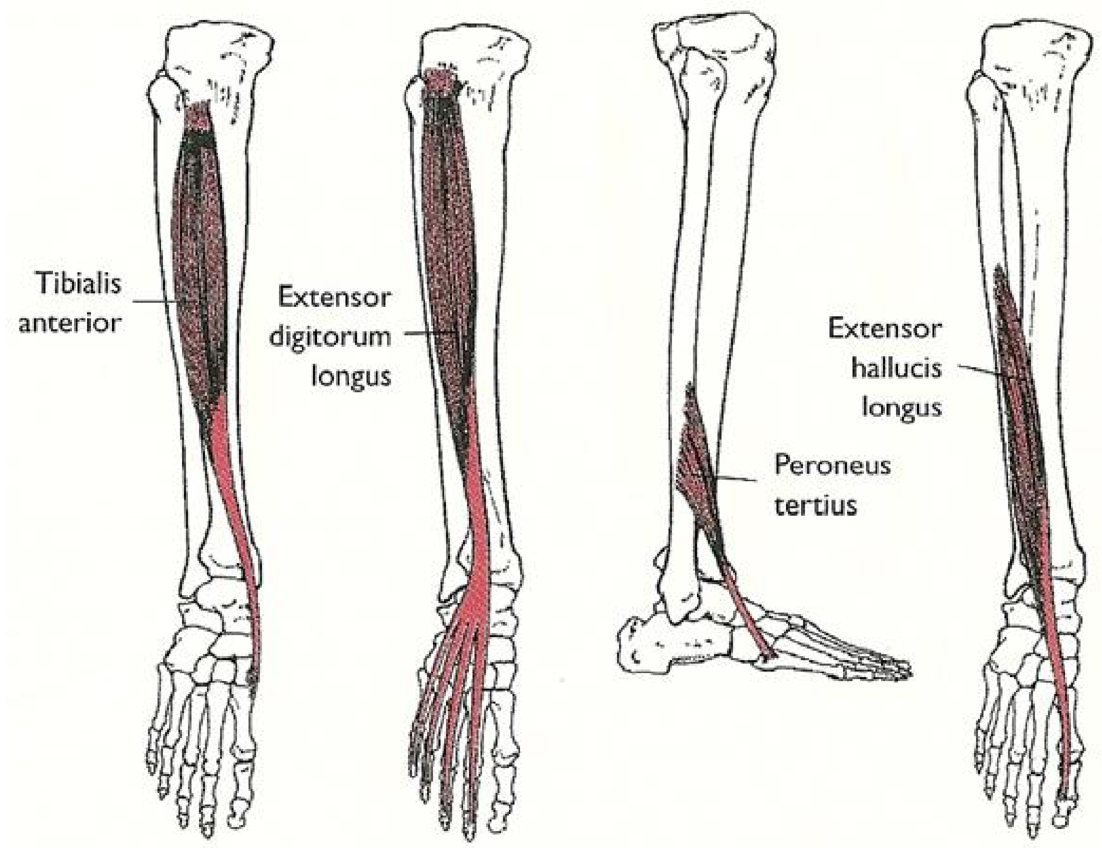
The bony structure of the ankle.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Structure of the Ankle

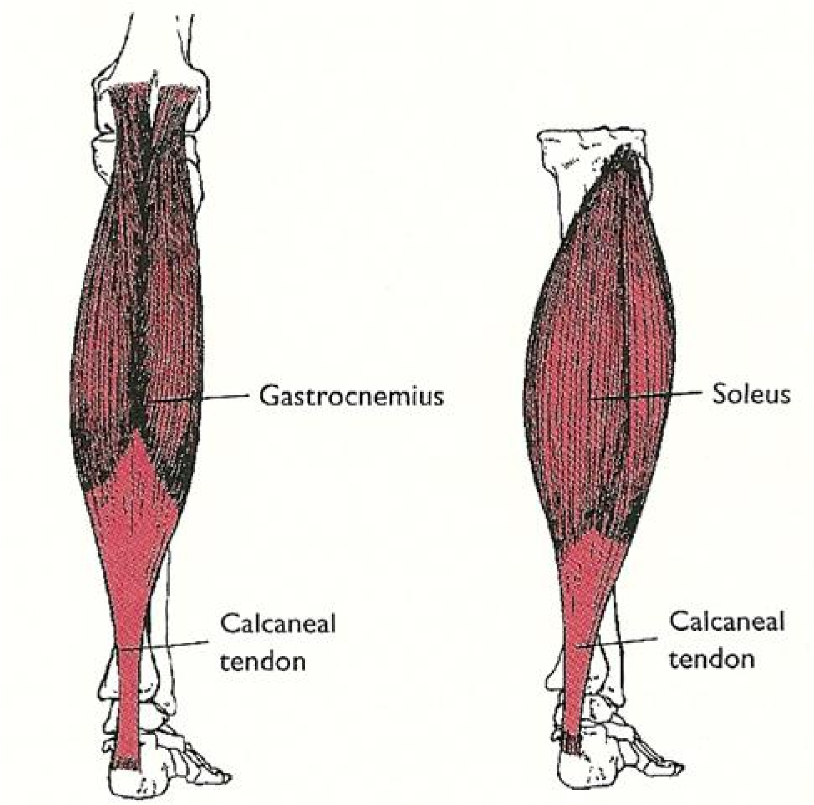


Movements at the Ankle



Dorsiflexors at the ankle include tibialis anterior, extensor digitorum longus, and peroneus tertius, assisted by extensor hallucis longus.

Movements at the Ankle



Plantar flexors at the ankle are gastrocnemius and soleus, assisted by tibialis posterior, plantaris, peroneus longus, flexor hallucis longus, peroneus brevis, and flexor digitorum longus.

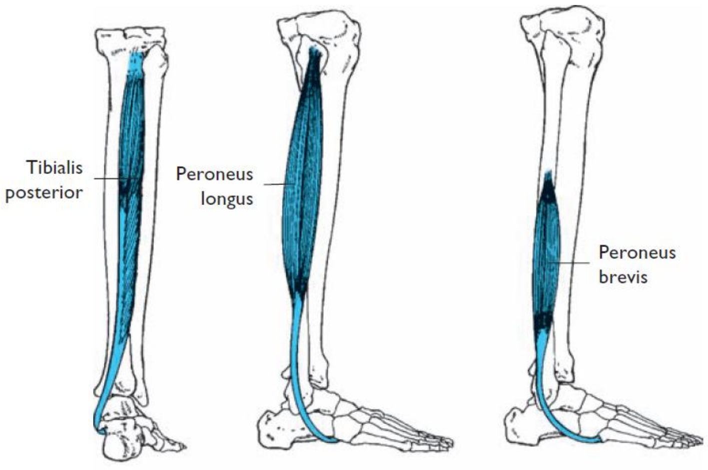
Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

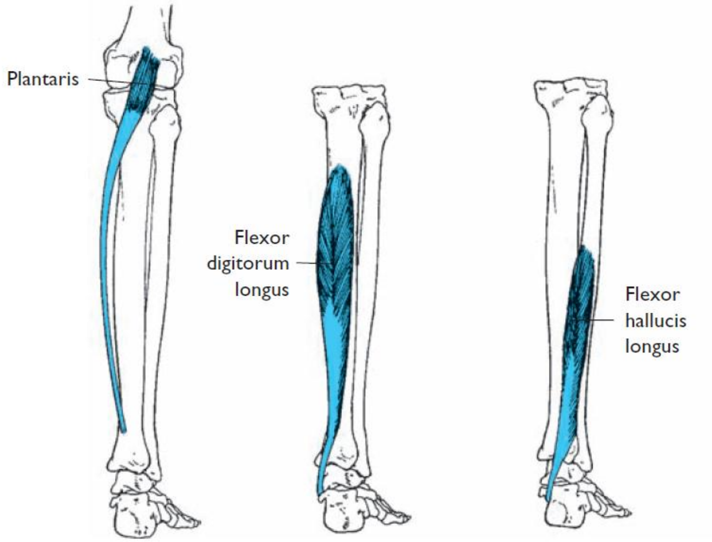
Structure of the Foot

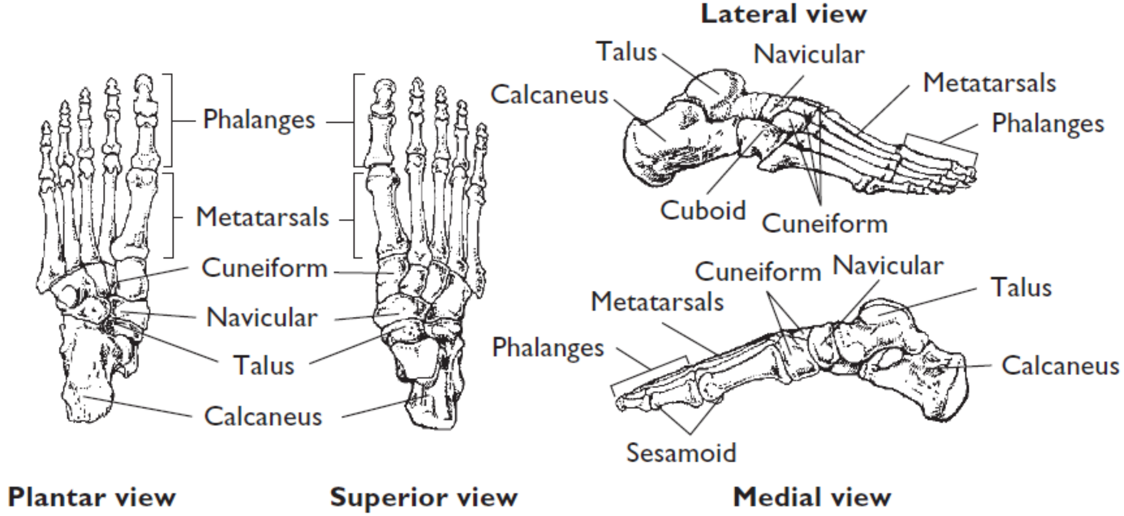
What is the subtalar joint?

(the anterior and posterior facets of the talus articulate with the superior calcaneus)

Structure of the Foot







Structure of the Foot

What are the tarsometatarsal and intermetatarsal joints?

Ånonaxial joints that permit only gliding movements

Åenable the foot to function as a semirigid unit and to adapt flexibly to uneven surfaces during weight bearing

Structure of the Foot

What are the metatarsophalangeal and interphalangeal joints?

Åcondyloid and hinge joints, respectively

Åthe toes function to smooth the weight shift to the opposite foot during walking and help maintain stability during weight bearing by pressing against the ground when necessary

Structure of the Foot

What are the plantar arches?

Åthe medial and lateral longitudinal arches stretch form the calcaneus to the metatarsals and tarsals

Åthe transverse arch is formed by the bases of the metatarsal bones

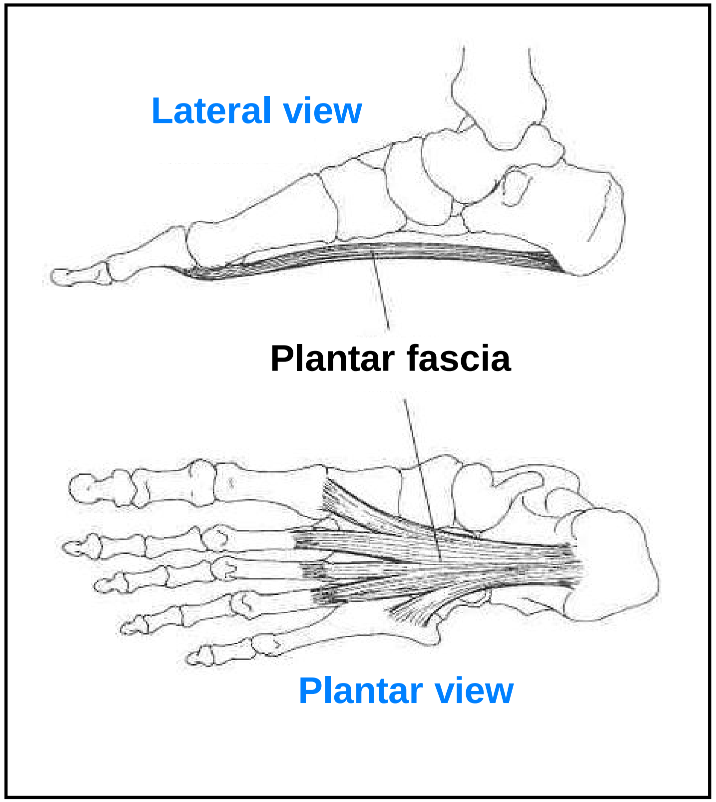
Structure of the Foot

What are the plantar fascia?

Åthick bands of fascia that cover the plantar aspects of the foot

ÅDuring weight bearing, mechanical energy is stored in the stretched ligaments, tendons, and plantar fascia of the foot. This energy is released to assist with push-off of the foot from the surface.

Structure of the Foot



The plantar fascia.

Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

Movements of the Foot

What muscles are responsible for toe flexion and extension?

Åflexion - flexor digitorum longus, flexor digitorum brevis, quadratus plantae, lumbricals, interossei

Åextension - extensor hallucis longus, extensor digitorum longus, extensor digitorum brevis

Movements of the Foot

What muscles are responsible for inversion and eversion?

Åinversion - tibialis posterior, tibialis anterior

Åeversion - peroneus longus, peroneus brevis, assisted by peroneus tertius