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Lower Limb – Hip and Knee

1. Hip Joint

1.1 Muscular control of the hip joint

The position and movements of the femoral head within the hip joint are controlled by muscles arising from the pelvis, the spine, and the lower limb.
Because these muscles are asymmetrically distributed and have different vector potential, if they enter into excessive tension they may initially make the joint muscularly rigid and, if the excess tension persists over time, determine articular misalignment.

1.2 Functional classification of the hip muscles

Stabilizing muscles: monoarticular muscles, with a short force line, have vectors that favour articular stabilization.
Their excess tension is expressed above all in compaction of the femoral head within the acetabulum.

Dynamic muscles: polyarticular muscles and monoarticular muscles with an important force line, for example the adductors, have vectors favourable for movement and positioning of the femur.

1.3 Flexor-extensor dominance

With respect to flexion and extension, dominance is expressed differently depending on whether the femur is the mobile point, unloaded, or the fixed point, loaded.

Flexion	Extension	Vector dominance
Iliopsoas; quadriceps femoris; sartorius; femoral adductors; gracilis; tensor fasciae latae; pectineus	Hamstrings; gluteals; piriformis	With the femur as the mobile point, vector dominance is in hip flexion. With the femur as the fixed point, under load, dominance is in anterior pelvic tilt and lumbar hyperlordosis.

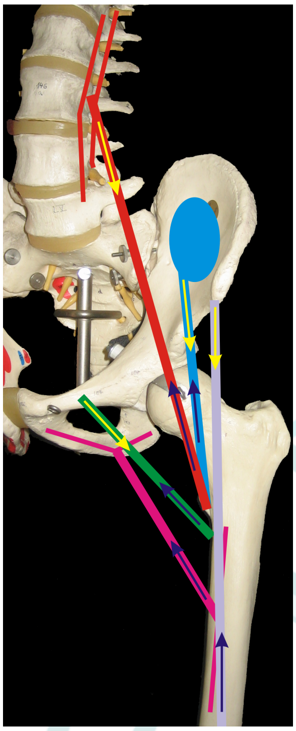


Figure 1: Flexor-extensor dominance
Psoas: red; iliacus: blue; rectus femoris: light purple; pectineus: green; adductors: magenta. Femur as the mobile point: dominance of the hip flexors, blue arrows. Femur as the fixed point, under load: dominance in anterior pelvic tilt and anterior projection of the lumbar spine, yellow arrows.

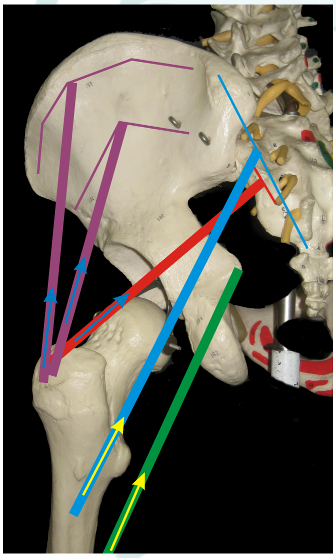


Figure 2: Hip extensors
Piriformis: red; gluteus maximus: blue; gluteus medius and minimus: purple; hamstrings: green. The only vectors with good extensor capacity are the hamstrings, with secondary support from the gluteus maximus, yellow arrows. Piriformis, gluteus medius, and gluteus minimus have vectors oriented mainly toward articular stability.

Mechanism of dominance under load
The difference in dominance between the mobile femur and the fixed femur derives from the change in the point of application of the forces.
With the femur as the mobile point, when the limb is lifted, the hip flexors bring the femur toward the pelvis, producing flexion.
With the femur as the fixed point, foot in stance, the same muscles change the direction of their action: instead of bringing the femur toward the pelvis, they bring the pelvis toward the femur.
The iliopsoas and the rectus femoris, by pulling through their pelvic insertions, determine anterior pelvic tilt, which drags the lumbar vertebrae with it and increases lordosis.
The hip extensors, hamstrings and gluteals, although opposing this action, are subdominant when axial loading increases the stabilization required of the joint.
Under load, therefore, the resultant vector dominance favours anterior pelvic tilt and lumbar hyperlordosis.

1.4 Adductor-abductor dominance

Adduction	Abduction	Vector dominance
Femoral adductors; gracilis; gluteus maximus, through its insertion onto the gluteal tuberosity; pectineus; quadratus femoris; obturator externus	Tensor fasciae latae; gluteus medius and minimus; gluteus maximus, through its insertion into the fascia lata; piriformis; obturator internus	Adduction

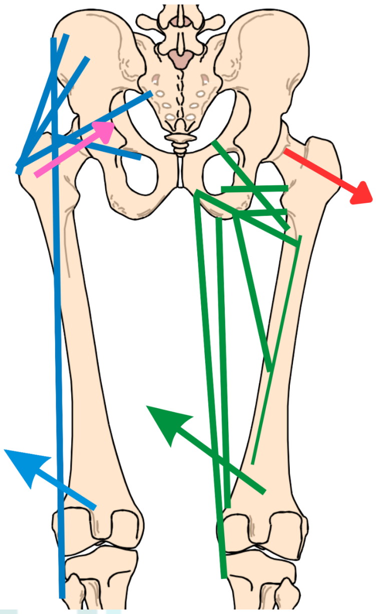


Figure 3: Mechanism of adductor dominance
Blue: abductors; green: adductors. The adductor vector dominance, expressed mainly at the distal portion of the femur, green arrow, determines displacement toward dislocation of the femoral head, red arrow. By contrast, the abductors, more than expressing themselves at the distal portion, blue arrow, act at the proximal portion, pink arrow, behaving as dynamic ligaments capable of adapting to intra-articular stresses.

1.5 Rotatory dominance

Internal rotation	External rotation	Vector dominance
Semitendinosus; semimembranosus; adductor magnus; gracilis; gluteus medius and minimus through their anterior fibres; tensor fasciae latae	Adductors; biceps femoris; sartorius; gluteus maximus; gluteus medius and minimus through their posterior fibres; iliopsoas; quadratus femoris; obturator internus; piriformis	Numerically, the external rotators are more numerous and are dominant when the femur is not under load, for example in supine or during the swing phase of gait. In upright stance and with the foot in contact with the ground, considering force length and Power, force per displacement per unit time, the dominant vectors are semitendinosus and semimembranosus and, as co-agonists, adductor magnus and gracilis. The resulting vector dominance is therefore expressed as internal rotation.

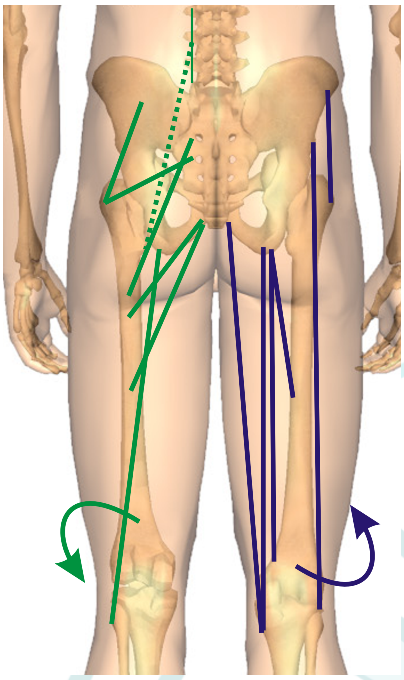


Figure 4
Femoral internal rotators: blue; femoral external rotators: green. In upright stance with the feet in contact with the ground, vector dominance is in favour of the internal rotators.

1.6 Articular equilibrium and muscular compensations

With regard to stresses within the coxo-femoral joint, muscles with long vectors, that is, those which, with modest intrinsic shortening, alter the articular axis, must be balanced by monoarticular muscles which, behaving as true dynamic ligaments, raise their basal tone.
This increase in tone may determine local symptoms.

Piriformis syndrome: a clinical example
One example is piriformis syndrome, which may manifest in two opposite scenarios.

Scenario 1 – Internal rotation and abduction of the femur:
If muscular dominance carries the femoral head into internal rotation and abduction, through adduction at its distal part, for example in knee valgus, the piriformis must activate at high intensity in order to contain the joint.

Scenario 2 – Knee varus:
In the opposite problem, knee varus, the femoral head is "pushed" into the acetabulum.
In this case, the piriformis, with its insertions approximated, must work with increased basal tone in order to be effective in its role as an active ligament.

In both cases, the piriformis is overloaded.
In terms of the Resistant Force/Working Force relationship, in the first scenario the piriformis increases Resistant Force in order to maintain containment tension, and in the second it increases Resistant Force in order to compensate for shortening of the insertions.
In both cases, the increase in Resistant Force reduces available Working Force, producing mechanical inefficiency and overload that may compress the sciatic nerve.

1.7 Neural connections and vertebral correlations

In hip disorders, the dermatomal connection with L5-S1 must also be considered.
In arthrotic phenomena, as a concomitant finding, horizontalization of the sacrum with involvement of the L5-S1 transition is often observed.
It is necessary to assess whether this vertebral alteration represents the primary cause of the hip problem or merely a simple association.

2. Knee

2.1 Reference positioning

In upright stance and posterior view, with the axis from the centre of the heel to the second toe oriented forward, the four femoral condyles should lie on the same horizontal line.

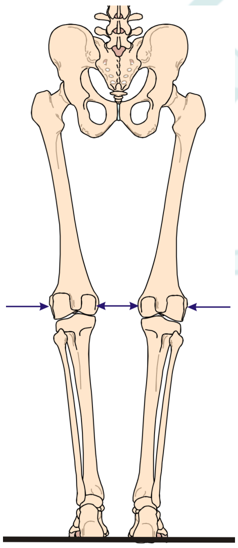


Figure 5: Physiological positioning
In upright stance, with the axis from the centre of the heel to the second toe oriented forward, the four femoral condyles should lie on the same horizontal line.

The dominant vectors produce different patterns, variably associated with one another.

2.2 Hyperextension

Excluding hyperextension due to ligamentous laxity, that is, severe systemic collagen disease, and after carrying out the differential evaluation that will be discussed later, hyperextension is seen to present a specific mechanism.

Mechanism of hyperextension with the foot as the fixed point
In upright stance, with the feet on the ground as the fixed point, the hamstrings and triceps surae do not "change" their action, but the direction of their traction produces an opposite mechanical effect.
The hamstrings, maintaining their force line between the ischium and the tibia, pull the tibia posteriorly when the foot is the fixed point.
Since the tibia cannot move backward, because the foot is fixed in stance, the traction is translated into a push of the knee toward extension.
Similarly, the triceps surae, with femoral insertion anterior relative to the heel as the fixed point, pulls the femur posteriorly.
This traction also becomes knee extension when the foot is fixed.
The rectus femoris, with the foot fixed, expresses its extensor component only in the portion between the patella and the tibial tuberosity, a minimal fraction of its total length.

Its action is therefore one of participation in extension, not that of a primary motor.
The true motors of extension under load are the hamstrings and triceps surae pair.
The hamstrings and triceps do not invert their action: they continue to pull through their insertions.
The different fixed point, however, converts traction into extension instead of flexion.
It is the physics of the points of application of the forces that determines the resultant effect, not a change in muscular function.

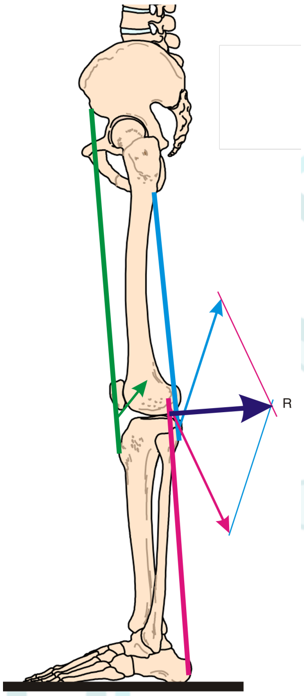


Figure 6: Extensor mechanism
In upright stance, with the foot as the fixed point, the hamstrings, blue, having tibial insertion anterior relative to the posterior superior iliac spine, pull the tibia backward and upward. The triceps surae, magenta, having femoral insertion anterior relative to the insertion on the heel, pull the femur backward and downward. The resultant carries the knee into extension, an action in which the rectus femoris participates only modestly through the portion between the patella and the tibial insertion, green arrow.

This dynamic is even more evident in the action of standing up from a chair, walking uphill, or climbing stairs.
Knee extension is produced by the hamstrings-triceps surae pair, while the rectus femoris is occupied mainly in stabilizing the pelvis. It is the patella, functioning as a force multiplier, that enables it to balance the hamstrings, which would otherwise make the dynamic action impossible by producing pelvic retroversion.

Recurvatum also produces alterations at the hip and tibio-tarsal joints, detectable through study of the behaviour of the G and R forces.
In particular, the global force of the trunk applied to the hip joint cannot be distributed along the whole femur when the latter is in hyperextension.
Consequently, the G and R forces are concentrated within the acetabular cavity, determining potential mechanical conflicts.
Potential mechanical conflicts may also be found at the knee and tibio-tarsal joints, where force moments may be generated.

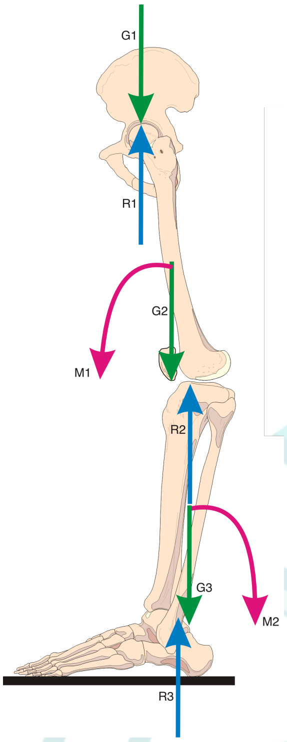


Figure 7: Distribution of forces in recurvatum
Knee recurvatum in upright stance. The global G and R forces applied to the individual centres of gravity determine, through their g and r components, localized intra-articular compressions. Force G1 is balanced by force R1 but, since it does not meet the body of the femur on its own axis, instead of distributing along the whole femur, it remains localized within the acetabular cavity. Forces G2 and G3 determine moments of force M1 and M2 and, through forces R2 and R3, mechanical compression at the anterior portion of the knee joint and the posterior portion of the tibio-tarsal joint.

2.3 Internal rotation

Under load, the dominant vectors are those of semitendinosus and semimembranosus, associated with the femoral adductors that possess an internal rotation component.

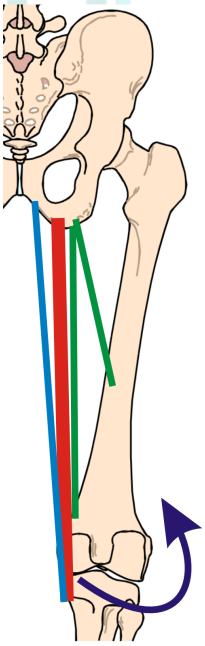


Figure 8: Internal rotator muscles
Semitendinosus and semimembranosus: red; gracilis: blue; adductor magnus: green.

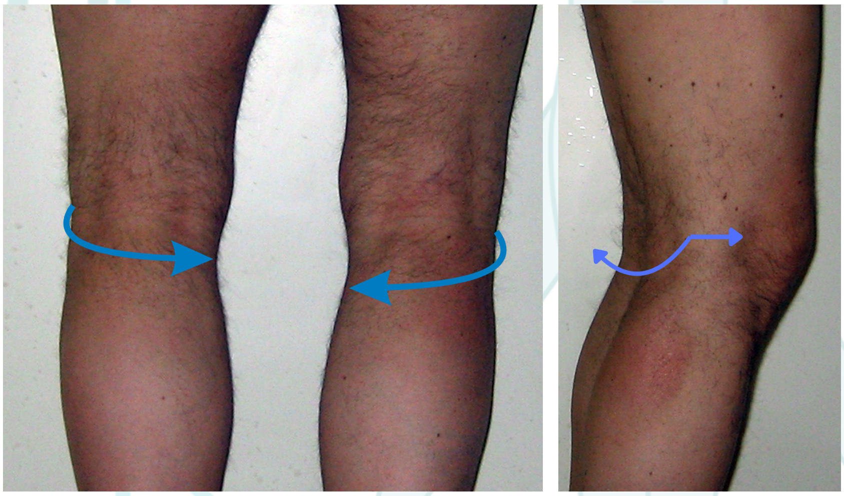
Associated pattern: hyperextension and internal rotation often constitute an associated pattern.

Differential test for recurvatum
To differentiate recurvatum induced by muscular shortening from that induced by ligamentous

laxity, among the many possible investigations, it is possible simply to correct femoral internal rotation by externally rotating the knees, actively or passively.

- In recurvatum due to ligamentous laxity: derotation does not modify hyperextension
- In recurvatum induced by muscular shortening: derotation produces flexion of the knees, since lengthening of one part produces the reaction of shortening in the other

Figures 9 and 10: Knees in hyperextension and internal rotation



Figures 11 and 12: Differentiation test
By actively requesting correction of the internal rotation, or by performing it passively, it is possible to differentiate recurvatum due to ligamentous laxity from recurvatum due to muscular tension. In the image, active external rotation of the knees determines flexion. In this case, it may be hypothesized that the load-bearing position of the lower limb is due to excessive tension of the internal rotators and knee extensors.

2.4 Flexion

The hyperextensor action of the hamstrings-triceps surae pair is limited by the femoro-tibial joint itself.
Once this maximum limit is reached, if shortening of the two muscular groups progresses, the final

resultant force line will determine knee flexion.
The tibial insertions of the hamstrings, in fact, come to lie posterior relative to the posterior superior iliac spine, just as the femoral insertions of the triceps surae become posterior relative to the heel.

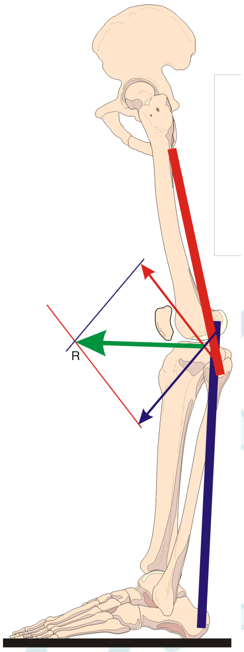


Figure 13: Inversion of action Triceps surae: blue; hamstrings: red. Once the articular limit of hyperextension is reached, they enter into inversion of action and flex the knee.

Mechanism of rigid flexion
When shortening of the hamstrings-triceps surae pair is such that the knee is taken from hyperextension into flexion, the two groups again become knee extensors.
In this case, however, their vertical vector components act at such intensity as to prevent extension itself.
The sum of the horizontal and vertical vector components cannot extend the knee in upright stance, but can, together with the quadriceps, oppose collapse to the ground.
This action requires high energy expenditure, with consequent articular stiffening.

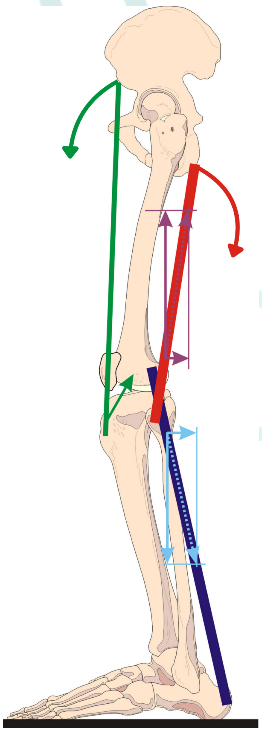


Figure 14: Rigid flexion Triceps surae: blue; hamstrings: red; rectus femoris: green. If shortening of the hamstrings-triceps surae pair is such that the knee is brought into flexion, the two muscular groups become extensors of the knee once again. In this case, however, their reciprocal shortening does not permit extension of the knee, but only, and with great energy expenditure, prevention of collapse to the ground in association with the rectus femoris. In addition, shortening of the hamstrings determines a traction force at the posterior superior iliac spine, red arrow, that would take the pelvis into retroversion if not balanced by the rectus femoris, green arrow. The vertical vector components, dominant over the horizontal ones, in addition to preventing extension, may determine mechanical compressive phenomena at the posterior portion of the joint.

Note: in this chapter, the vectors of the lower limb are being analysed.
The pelvic retroversion induced by the hamstrings may also be balanced by the iliacus and latissimus dorsi. If the latter intervenes, it will produce compression at the thoracolumbar spine.

Distribution of forces in flexion
The global forces G2, G3 and R2, R3 and their g and r components may determine localized compressive phenomena at the posterior portion of the knee joint and the anterior portion of the tibio-tarsal joint.
The global force G1, coming from the trunk, being unable to distribute itself uniformly along the whole femur, is balanced by the global force R1 within the acetabular cavity, giving rise to potential intra-articular mechanical conflicts.

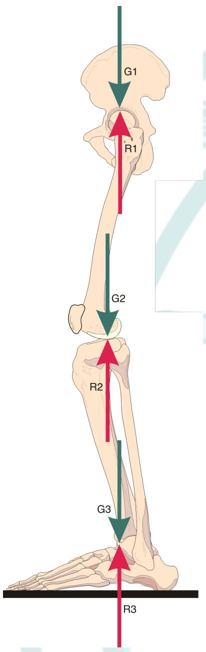


Figure 15: Distribution of forces in flexion
The global force G1, coming from the trunk, is not distributed along the whole femur and the G1-R1 force pair determines mechanical compression within the acetabular cavity. The forces G2, G3, R2 and R3 determine mechanical compression at the posterior portion of the knee joint and the anterior portion of the tibio-tarsal joint.

2.5 External rotation

Internal rotation is limited by the joint itself.
If, once this limit is reached, the hamstrings shorten further, the external rotation component of the biceps femoris will prevail, joined by the adductors that have an external rotation action.

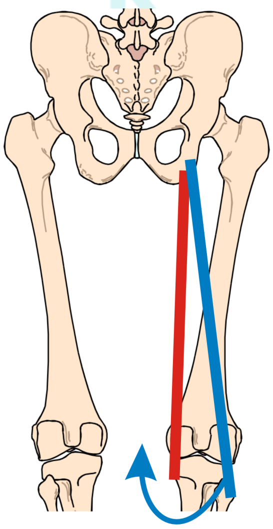


Figure 16: Mechanism of external rotation
Semitendinosus and semimembranosus: red; biceps femoris: blue. Semitendinosus and semimembranosus prevail vectorially over biceps femoris, and global shortening of the hamstrings initially determines internal rotation of the knee. Once the articular limit is reached, if these muscles shorten further, the external rotation component induced by the biceps femoris prevails, supported by the long and short adductors, not shown in the figure.

2.6 Progression of pathological patterns

The four patterns are associated with one another and represent a progression of worsening: initially internal rotation and hyperextension, then flexion and external rotation.
A knee that appears well positioned may therefore truly be so, but it may also have exhausted the first two directions of movement and entered the following two.
The two patterns have as their extremes internal rotation and recurvatum on the one hand, and external rotation and flexion on the other.
In the transition from one pattern to the other, the components may determine intermediate patterns variably associated with each other: for example, the knee may present as internally rotated and flexed.
The transition from one pattern to another, expression of further muscular shortening, progressively makes the knee joint more rigid, increasing intra-articular compressive components.

2.7 Lateral patellar deviation

During gait, the patellae must be oriented forward, and this is ensured by the quadriceps femoris through the vasti.
When, through the action of the hamstrings, the femur is in internal or external rotation, the quadriceps may reposition the patella, thereby creating a femoro-patellar dissociation.
The action of the quadriceps vasti is secondary and aimed at preserving function.
Patellar deviation is therefore caused directly by the vastus medialis or lateralis, but as a consequence of lower-limb rotation induced predominantly by the hamstrings.

Clinical assessment of patellar deviation
In observation of the knees, the posterior view provides the effective axial position of the femoro-tibial relationship and of the femur.
The anterior view makes it possible to assess patellar position and its synchrony with femoral rotation.
To evaluate the true position of the patellae, therefore, they must be observed frontally after the axis of the femur has been corrected.


Figures 17 and 18: Femoro-patellar dissociation
On posterior observation, the femur appears internally rotated. On anterior observation, the patellae appear globally oriented forward. In this case, femoro-patellar dissociation is present, caused by the action of the internal rotators on the femur and of the vastus lateralis on the patella.

2.8 Valgus

In the absence of skeletal alterations, congenital or acquired, the forces that, in shortening, can determine valgus arise from the pelvis, adductors and tensor fasciae latae, and, with the foot in stance as the fixed point, from the heel supinators, triceps surae, and the foot, tibialis posterior.

Muscles determining valgus

Adductors: by adducing the distal portion of the femur, they create a force pair that valgizes the knee and at the same time destabilizes the femoral head, activating high-intensity balancing by the monoarticular muscles of the hip.

Tensor fasciae latae: when the knee is aligned, its action shifts the tibia outward and, together with the gracilis, which does the opposite, stabilizes the knee laterally.
Once valgus is established, the tensor fasciae latae inverts its action and contributes to fixation of the valgus, although it is never the primary cause.

Triceps surae: it is a strong supinator of the heel.
When the heel is in contact with the ground, its shortening is expressed by deviating inward the distal portion of the femur.

Tibialis posterior: again, with the foot in contact with the ground, its shortening is expressed by deviating inward the proximal portion of the tibia.

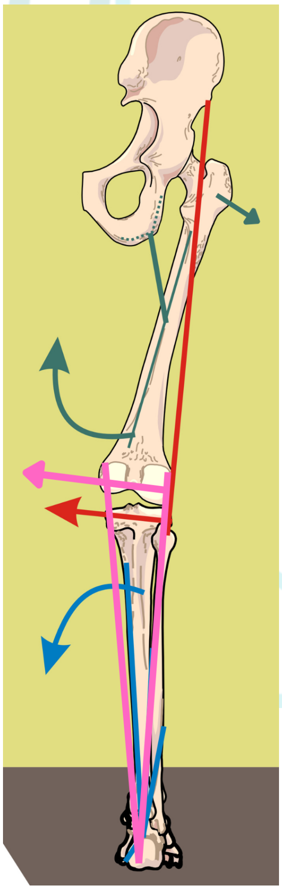


Figure 19: Valgizing muscles
Tensor fasciae latae: red; adductors: green; triceps surae: violet; tibialis posterior: blue.

2.9 Varus

Again in the absence of congenital or acquired skeletal alterations, varus is determined vectorially by shortening of the muscles arising from the foot when the latter is the fixed point: tibialis anterior and fibularis, peroneus, longus and brevis.

Considerations on the hip muscles

The abductor component of the hip muscles, expressed at the proximal level of the femur, is of limited significance.

In the introductory chapters of the text, it was shown how maximal efficiency of muscular contraction occurs with approximation of the articular ends by 10% of the total muscle length, and it was also emphasized that residual shortening within muscular fibres is of small magnitude, 2-3%.

If one imagines a global shortening of less than 2-3%, it becomes clear how the hip abductors, monoarticular muscles, can only minimally influence the femoro-tibial relationship, in contrast to longer vectors such as those of the tibial and fibular muscles.

They are, however, very effective in stabilizing the femoral head within the acetabulum.

Behaviour of the gracilis

The gracilis behaves like the tensor fasciae latae on the opposite side.

When the knee is aligned, the gracilis adducts the tibia and thereby balances the tensor fasciae latae, with which it forms a force pair for lateral stabilization of the knee.

Once the knee is in varus, the gracilis inverts its action and contributes to stabilization of the varus.

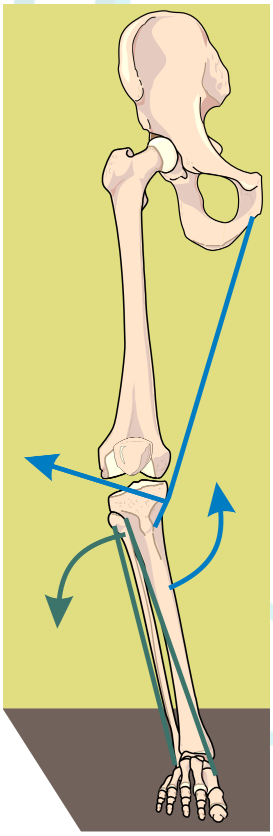


Figure 20: Varizing muscles
Tibialis anterior and fibularis muscles: green; gracilis: blue.

2.10 Differential assessment of varus and valgus

On the basis of what has been described, the vectors that lead to valgus are numerically more numerous than the varizing ones.
Differential assessment must exclude interference caused by rotation of the lower limbs.

Assessment methodology
In upright stance and with the feet in contact, the medial femoral condyles should be in slight contact.

- In the case of valgus: contact is excessive
- In the case of varus: contact is absent

Varus and valgus are malalignments expressed in the frontal plane, and femoral rotational components may disguise the real varus or valgus by exaggerating or reducing it.

Derotation test

1. Initial position: patient in upright stance, spontaneous position.
2. Observation: assess apparent varus or valgus and the presence of femoral rotations.
3. Execution: ask the patient to derotate the femurs while keeping the feet parallel and the knees extended, or guide the movement passively.
4. Evaluation: observe how the distance between the medial condyles changes.

Derotation eliminates interference of the rotational component on the frontal plane, revealing the true varus-valgus relationship of the joint, and the variation observed guides identification of the primary components of the alteration: whether predominantly rotatory, predominantly varus-valgus, or mixed.

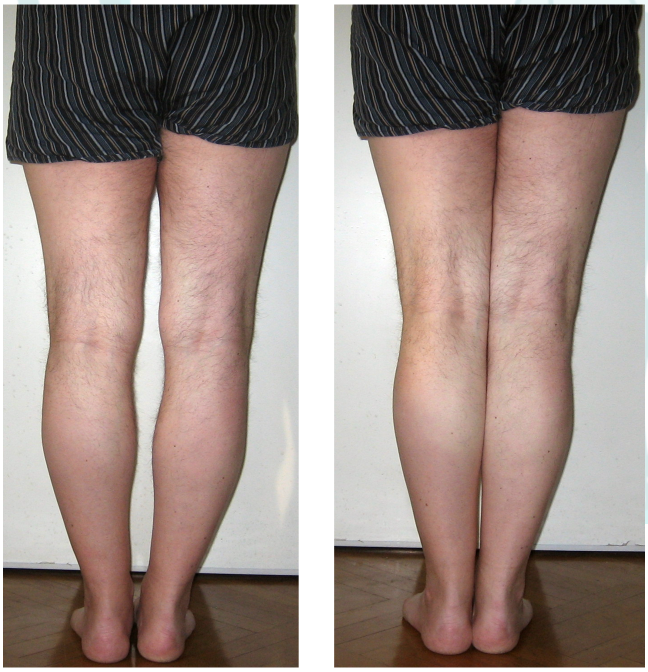


Figure 21: Derotation test
Left photograph: position spontaneously assumed by the patient. The knees appear in varus, but marked internal rotation of the lower limbs is also present. Right photograph: with active derotation in knee extension, the medial condyles approach and come into hyper-contact. In this case, internal rotation of the femurs makes the knee appear varus whereas, in reality, the tendency of the knee is toward valgus.

Conclusions of the knee section

Analysis of the knee shows how this joint represents the point of convergence of forces arising from the hip and the foot.
The pathological patterns follow a logical progression determined by intensification of muscular shortening, with manifestations ranging from initial hyperextension and internal rotation to flexion and external rotation in the more advanced phases.
Understanding this progression, the mechanisms of patellar compensation, and axial deviation provides the tools to identify the primary causes of the alterations and distinguish them from the secondary manifestations.
Alterations of the knee and foot influence one another reciprocally through the kinematic chain of the lower limb.
A supinated foot may compel the knee toward rotatory compensations in order to permit plantar support, just as an axial deviation of the knee may determine distal adaptations.
Analysis must therefore consider the bidirectionality of mechanical influences in order to identify the primary origin of the alteration.

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