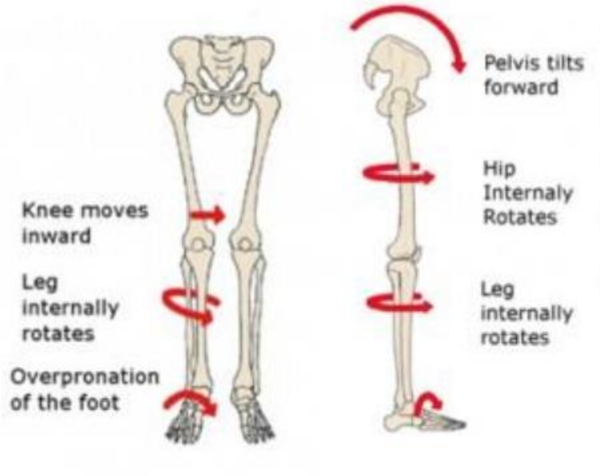
Bio mechanics of lower extremity

Basic biomechanics at the hip

We have seen how the movement of the foot into pronation and supination affect the knee joint. But what happens even further up the chain at the hip joint?

With pronation of the foot, there is internal rotation (twisting of the knee) and this results in the knee moving inwards. This movement in turn causes the hip to internally rotate and tilts the pelvis forward.

The following diagram demonstrates the flow on effect of a pronating foot further up the kinetic chain.



What effect does this have on the hip and other structures?

The excessive internal rotation of the hip can affect optimal loading of the hip cartilage during weight bearing. With increase loading of the cartilage over a prolonged period of time there can be accelerated wear and tear of the cartilage – thereby causing premature osteoarthritis of this joint – resulting in pain and stiffness.

The internal rotation of the hip also places increased load through the soft tissues around the hip (muscles, tendons and fascia). Increased load can produce problems in these structures.

The most common conditions that can result from this are:

- **Gluteus medius/minimus tendinopathy** (lateral hip pain)
- **Troachanteric bursitis** (pain on the side of the hip/thigh)
- **Anterior impingement of the hip** (pain in the groin or front of the hip)
- **Iliotibial band pain (ITB pain) –** pain on the side of the thigh anywhere from the top of the thigh to the side of the knee

Basic biomechanics at the knee

We have looked at what the foot does during walking and weight bearing in terms of pronation and supination.

With each of these movements at the foot there is movement that occurs further up the leg (the kinetic chain).

What happens during pronation?

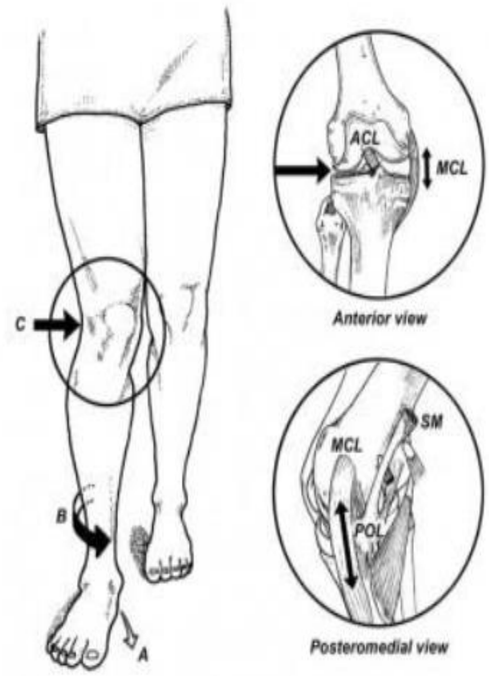
During pronation of the foot where the foot flattens out, there is a rotation movement that occurs at the knee. The knee joint internally rotates. You can test this movement yourself when sitting in a chair. If you place your feet shoulder width apart on the floor, deliberately make your foot flatten out and then make an arch with your foot. You should be able to see your shin rotating or twisting. This resultant twist is what causes rotation through the knee joint.

A certain amount of rotatory movement is normal, but what happens when the movement is excessive?

When the rotatory movement is excessive there is excessive loading of the knee cartilages and meniscus in the knee. On top of this, the optimal alignment of the bones in the knee is compromised and this can cause accelerated wear and tear of the cartilage and meniscus (which leads to accelerated or early Osteoarthrits), and places increased load on the muscles and other soft tissues around then knee which can lead to common problems such as:

- **Patello-femoral joint pain (pain under the knee cap)**
- **ITB friction syndrome**
- **Pes anserius bursitis**
- **Patellar tendinopathy**
- **Medial ligament pain**

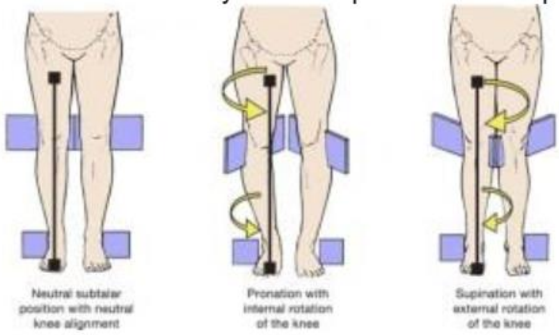
The following picture shows the effect of excessive pronation and the subsequent internal rotation of the lower leg and rotation and the knee.



What happens with a high arched or supinated foot?

With a foot that does not pronate enough (i.e. has a high arch that does not flatten out sufficiently) there is a reduced capacity in the foot for shock absorption. Weight bearing tends to focus on the outside border of the foot and the reverse kind of rotation occurs in the lower leg and knee. With a high arched foot there is external rotation of the lower limb and also external rotation of the knee.

The following picture shows the different rotatory effects of pronation and supination of the feet.



Ankle Sprain

Those with a supinated foot type are more likely to experience an ankle sprain on the outside part of the ankle. This is because of the foot positioning during weight bearing tending to be more on the lateral or outside border of the foot. An ankle sprain occurs when the ankle is forced out of its normal position due to instability while walking, tripping or falling. The ligaments, which connect bones together, on the outside of the ankle joint are injured due to over-stretching or tearing.

Peroneal Tendinopathies

Excess supination of the foot can lead to injuries that result from reduced shock absorption. This can lead to over-use injuries, such as peroneal tendinpoathy. The peroneal tendon sits behind the outside bone of the ankle joint. Its job is to turn the foot and ankle in an outwards direction. A supinated foot tends to angle in the opposite direction thereby placing a tension/load on these structures. This increased load can cause problems to develop.

Stress Fractures

Those with a supinated foot type can also suffer from recurrent stress fractures due to the reduced amount of shock absorption. A stress fracture can occur when the muscles are over-used and in the case of the legs when the feet do not absorb shock properly, transferring the forces to the bone further up the chain. The repetitive stress can cause a small crack or fracture in bones of the foot or ankle. The pain of a stress fracture appears suddenly and goes away with rest. Over time, the pain can become debilitating, requiring complete rest of the affected leg or foot including the use of crutches in order to get around.

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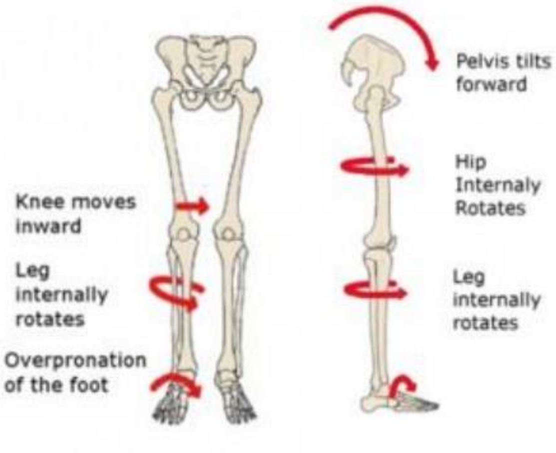

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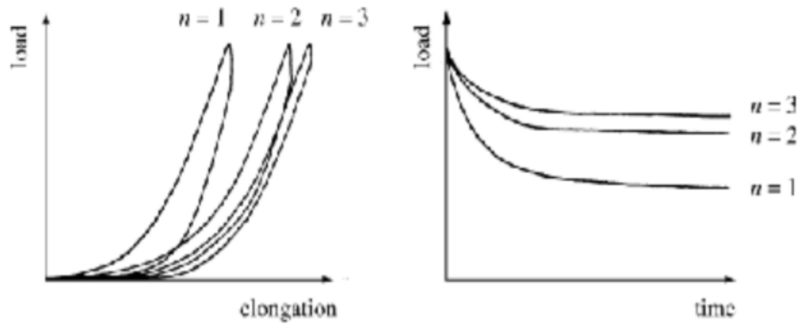
MECHANICAL PROPERTIES OF SOFT BIOLOGICAL TISSUES

The diversity of mechanical properties encountered in soft biological tissues is huge. Soft organic tissues are in general characterized by very complex mechanical behaviour. They show non-linear, anisotropic, viscoelastic and in some cases also viscoplastic behaviour. They often have a layered or an even more complicated structure. The mechanical properties are inhomogeneous, i.e. they depend on the position in the material. The perfusion of the organs and their constituting tissues also plays an important role regarding the elastic properties.

The stress strain relationship

There are mainly two sources of elasticity in soft biological tissues. The first source of elasticity is due to changes of internal energy whereas the second one is due to changes of entropy. Change of entropy occurs in tissues whenever changes of orientation or waviness of fibers during loading or unloading occur.A typical load-elongation and load-time diagram for soft tissue is shown in the figure below.



With repeated loading cycles the load-deformation curves shift to the right in a load-elongation diagram and the hysteretic effects diminish. In a load-time diagram the load-time curves shift upwards with increasing repetition number. By repeated cycling, eventually a steady state is reached at which no further change will occur unless the cycling routine is changed. In this state the tissue is said to be preconditioned. Any change of the lower or upper limits of the cycling process requires new preconditioning of the tissue. Preconditioning occurs due to internal changes in the structure of the tissue. Hysteresis, non-linearity, relaxation and preconditioning are common properties of all soft tissues, although their observed degrees vary.

The hysteresis in the stress strain relationship clearly shows the viscoelastic behaviour of soft biological tissue. In a viscoelastic material the history of strain affects the actually observed stress. As well, loading and unloading occur on different stress-strain paths. The hysteresis of most biological tissues is assumed to show only little dependence on the strain rate within several decades of strain rate variation. This insensitivity to strain rate over several decades is not compatible with simple viscoelastic models consisting e.g. of a single spring and dashpot element. With such a simple viscoelasticity approach the material model will show a maximum hysteresis loop at a certain strain rate whereas all other strain rates will show a smaller hysteresis loop. A model consisting of a discrete number of spring-dashpot elements therefore produces a discrete hysteresis spectrum with maximum dissipation at discrete strain rates. If the relaxation times of the different elements are chosen adequately a series of spring-dashpot elements might be used as an approximation to a continuous relaxation spectrum. Living tissues often show a viscoelastic behaviour as shown qualitatively in the figure below.

In the above figure the viscoelastic material properties are characterized by storage and loss modulus, which are concepts only valid for linear elasticity.

With a series of spring-dashpot elements arbitrary viscoelastic material properties can be modelled.

Sprain

A **sprain**, also known as a **torn ligament**, is the stretching or tearing of ligaments within a joint, often caused by an injury abruptly forcing the joint beyond its functional range of motion. Ligaments are tough, inelastic fibers made of collagen that connect two or more bones to form a joint and are important for joint stability and proprioception, which is the body's sense of limb position and movement. Sprains can occur at any joint but most commonly occur in the ankle, knee, or wrist. An equivalent injury to a muscle or tendon is known as a strain. The majority of sprains are mild, causing minor swelling and bruising that can be resolved with conservative treatment, typically summarized as RICE: rest, ice, compression, elevation. However, severe sprains involve complete tears, ruptures, or fractures, often leading to joint instability, severe pain, and decreased functional ability. These sprains require surgical fixation, prolonged immobilization, and physical therapy.

Signs and symptoms

- Pain
- Swelling
- Bruising
- Joint instability
- Difficulty with bearing weight
- Decreased functional ability or range of motion of the injured joint
- Ligament rupture may cause a cracking or popping sound at the time of injury

Knowing the signs and symptoms of a sprain can be helpful in differentiating the injury from a strain or fracture. Strains typically present with pain, cramping, muscle spasm, and muscle weakness, and fractures typically present with bone tenderness, especially when bearing weight.

Causes

Acute sprains typically occur when the joint is abruptly forced beyond its functional range of motion, often in the setting of trauma or sports injuries. Chronic sprains are caused by repetitive movements leading to overuse.

Mechanism

Ligaments are collagen fibers that connect bones together, providing passive stabilization to a joint. These fibers can be found in various organizational patterns (parallel, oblique, spiral, etc.) depending on the function of the joint involved. Ligaments can be extra-capsular (located outside the joint capsule), capsular (continuation of the joint capsule), or intra-articular (located within a joint capsule). The location has important implications for healing as blood flow to intra-articular ligaments is diminished compared to extra-capsular or capsular ligaments. Collagen fibers have about a 4% elastic zone where fibers stretch out with increased load on the joint. However, exceeding this elastic limit causes a rupture of fibers, leading to a sprain. It is important to recognize that ligaments adapt to training by increasing the cross-sectional area of fibers. When a ligament is immobilized, the ligament has been shown to rapidly weaken. Normal daily activity is important for maintaining about 80–90% of the mechanical properties of a ligament.

Risk factors

- Fatigue and overuse
- High-intensity contact sports
- Environmental factors
- Poor conditioning or equipment
- Age and genetic predisposition to ligament injuries
- Lack of stretching or "warming up", which when performed properly increases blood flow and joint flexibility

Diagnosis

Sprains can often be diagnosed clinically based on the patient's signs and symptoms, mechanism of injury, and physical examination. However, x-rays can be obtained to help identify fractures, especially in cases of tenderness or bone pain at the injured site. In some instances, particularly if the healing process is prolonged or a more serious injury is suspected, magnetic resonance imaging (MRI) is performed to look at the surrounding soft tissue and ligaments.

Treatment

Treatment of sprains usually involves incorporating conservative measures to reduce the signs and symptoms of sprains, surgery to repair severe tears or ruptures, and rehabilitation to restore function to the injured joint. Although most sprains can be managed without surgery, severe injuries may require tendon grafting or ligament repair based on the individual's circumstances. The amount of rehabilitation and time needed for recovery will depend on the severity of the sprain.

Other non-operative therapies including the continuous passive motion machine (moves joint without patient exertion) and cryocuff (type of cold compress that is activated similarly to a blood pressure cuff) have been effective in reducing swelling and improving range of motion.

Functional rehabilitation

The components of an effective rehabilitation program for all sprain injuries include increasing the range of motion of the affected joint and progressive muscle strengthening exercises. After implementing conservative measures to reduce swelling and pain, mobilizing the limb within 48–72 hours following injury has been shown to promote healing by stimulating growth factors in musculoskeletal tissues linked to cellular division and matrix remodelling. Prolonged immobilization can delay the healing of a sprain, as it usually leads to muscle atrophy and weakness.

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