**Biomechanics of the human body while running**

From faulty movement patterns injuries arise. Here we go back to basic principles in running.

*Running is both a very popular competitive sport in its own right and a fitness activity used at all levels, from recreational gym routines to elite sports training programmes. But running requires the body to absorb continues repeated impact forces, and running-related injuries are a common presentation in any physiotherapy or sports medicine clinic. At the extreme, elite endurance runners will probably require a weekly physiotherapy treatment, all year round, to keep their bodies healthy.*

There is complicated and highly individual interaction between intrinsic (personal) and extrinsic (environmental) factors that may contribute to a running injury. Specifically, the research suggests that the biggest predictors of injury are the following two extrinsic factors:

* Total volume of running undertaken;
* Sudden changes in volume or intensity of running.

By contrast, research is equivocal when it comes to pinpointing specific biomechanical patterns (intrinsic factors) that cause injury. That said, it is probably safe to assume that, for a given amount of weekly running, an individual with an abnormal or inefficient running action is more likely to suffer injury than someone with good mechanics.

It is impossible to stay, for instance, that all runners who over-pronate (tilt heavily inwards) at the foot will definitely suffer injury. Every runner will have their own threshold of tolerance to the stresses of running, and it will take a unique combination of factors to tip that runner’s body over the threshold and cause injury.

This article describes the biomechanics of running, focusing for each body part on what is considered ‘normal’ mechanics and then discussing how deviations from that norm way increase stress on the body, and lead to injury. We are confining our scope to distance running, and therefore research from the analysis of running speeds between 12 and 16kph (about 8 – 6 minutes per mile). The sprint action (9-10 metres per second or faster) is distinct from running at these more moderate speeds.

**The running cycle**

Running can be seen as a series of alternating hops from left to right leg. The ankle, knee and hip provide almost all the propulsive forces during running (apart from some upward lift from the arms). The running cycle comprises a stance phase, where one foot is in contact with the ground while the other leg is winging, followed by a float phase where both legs are off the ground.

The other leg then makes contact with the ground while the first leg continues to swing, followed by a second float phase. At running speeds about 6min/mile, a single running cycle will take approx0.7 sec, out of which each leg is only in contact with the ground for 0.22sec.

It is, not surprisingly, during the stance phase that the greatest risk of injury arises, as forces are acting on the body, muscles are active to control these forces, and joints are being loaded.

**Two sub-phases of stance**

The first sub-phase is between ‘initial contact’ (IC) and ‘midstance’ (MS). IC is when the foot makes the first touch with the ground. MS is when the ankle and knee are at their maximum flexion angle. This sub-phase is called the ‘absorption’ or sometimes the ‘braking’ phase. The body is going through a controlled landing; the knee and ankle flex and the foot rolls in to absorb impact forces. At this point the leg is storing elastic energy in the tendons and connective tissue within the muscles.

The second-sub phase is between MS and ‘toe-off’ (TO). TO is the point where the foot leaves the ground. The period between MS and TO is known as the ‘propulsion’ phase. The ankle, knee and hip all extend to push the body up and forward, using the recoiled elastic energy stored during the absorption phase.

This is an efficient way for the body to work. The more ‘free’ recoil energy it can get from the bounce of the tendons the less it has to make or to draw on from its muscle stores. Research shows that at least half of the elastic energy comes from the Achilles and foot tendons – a reminder of how important the lower leg is to running efficiency.

**Ankle, knee, hip mechanics**

The ankle, knee and hip motion are described in the side view (sagittal plane). At IC the ankle will be slightly dorsiflexed, around 10 degrees; the knee will be flexed at 30-40 degrees and the hip flexed at about 50 degrees relative to the trunk (a fully extended hip is at 0 degrees when the midline of the thigh and the midline of the body form a straight line through the centre of the pelvis). The further forward trunk leans, the greater the hip flexion. Prior to the IC the hip is already extended (the leg is moving backwards) and the foot at IC is moving back towards the hips. If the gluteal-hamstrings are not actively pulling the foot backwards prior to IC, then the foot contact will be too far ahead of the hips and the braking forces on the leg are increased.

During the absorption phase the angle change. By MS the ankle dorsiflexion angle has increased to around 20 degrees and the knee has also flexed to 50-60 degrees. This ankle and knee flexion is coordinated to absorb the vertical landing forces on the body, which is distance running speeds are in the order of two to three times bodyweight.

This is where eccentric strength in the calf and quadriceps muscles is required to control the knee and ankle joints; otherwise the knee and ankle would collapse or rotate inwards. In fact, the quadriceps and calf muscles are active prior to IC, and at their most active between IC and MS to help control the braking forces. The hip continues to extend through the absorption phase of stance, reaching around 20 degrees of flexion by MS.

During the propulsion phase the ankle and knee motion is reversed. By TO the ankle is plantarflexed to around 25 degrees and the knee has re-extended to 30-40 degrees. The hip continues to move to 10 degrees of extension by TO.

Thus, during the second half of the stance phase the ankle, knee and hip combine in a triple extension movement to provide propulsion upwards and forwards. The calf, quadriceps, hamstring and gluteal activity during the propulsion phase is less than during the absorption phase, because the propulsion energy comes mainly from the recoil of elastic energy stored during the first half of stance.

The role of the muscle therefore is to control the joint positions, creating stiffness in the leg system that allows the tendons to lengthen and then recoil. During the swing phase between TO and IC the knee and hip flex to maximum flexion angles of 130 degrees and 60 degrees respectively and then re-extend prior to IC, with the ankle dorsiflexing throughout swing to 10 degrees at IC.

Good runners will follow these movement patterns. It is essential that the ankle and knee can quickly control the braking forces and create a stable leg system to allow the tendons to maximise their recoil power. This is where good technique is vital. Too much upward bounce will increase the landing forces, putting greater stress on their joints and requiring more muscle force to control. Runners need to learn to bounce along and not up, by quick, light steps.

It is also important to bring the foot back prior to IC using active hip extension as this reduces braking forces and time needed for the absorption phase. The benefits of a ‘quick contact’ and a ‘horizontal’ running style will be discussed in the next chapter, ‘Beginner’s guide to pose’. Good strength in the gluteals, hamstrings, quadriceps and calf muscle will help runners achieve this.

In summary, excessive braking forces can contribute to injury. The correct movement patterns of the hip, knee and ankle combined with correct activation and strength of the major leg muscles will help control braking forces during running and result in a more efficient action using tendon elastic energy and minimising landing forces.

**Pelvis and trunk mechanics**

The motion of the pelvis and trunk are described in side and rear views (sagittal and frontal planes). The angle of the pelvis from the side view is called the anterior-posterior tilt (A-P tilt), with a positive angle describing a tilt down towards the front. The trunk angle from the side is described relative to the horizontal.

At IC the trunk will be flexed forward between 5 and 10 degrees and the A-P tilt will be 15-20 degrees. During the absorption phase from IC to MS, trunk flexion increases by 2-5 degrees while the A-P tilt remains stable. This slight forward flexing of the trunk during the braking phase helps to maintain the body’s forward-horizontal momentum. Gluteal-hamstrings, abdominals and erector spinae are all active to control the trunk and pelvis during the absorption phase.

During the propulsion phase the trunk re-extends to the initial position, so the trunk angle at TO will be similar to that at IC. The A-P tilt however will increase by 5-7 degrees in concert with the extensions. This slight shift in the anterior tilt of the pelvis helps to direct the propulsion forces of the leg horizontally. If the pelvis were in neutral than the triple extension of ankle, knee and hip would be directed more vertically.

A slight forward lean and anterior pelvic tilt is though efficient for running. Too much forward lean may suggest that the posterior chain muscles (hamstrings-gluteal-erector spinae) are not strong enough and this may increase the strain on the hamstrings and back during the running action. Too upright a posture may encourage vertical movement which will increase landing forces. Too much A-P tilt between IC and MS suggests that the gluteals and abdominals do not have the strength to control the pelvis adequately during landing and/or may indicate incorrect quadriceps activation and reduced hip flexibility. Excessive A-P tilt during the propulsion phases is normally associated with tight hip flexors and inadequate range of motion during hip extension. This will reduce the power of the drive from the hip and encourage a compensatory reliance on lumbar extension.

In general, a poor trunk position or lack of pelvic stability is likely to reduce the efficiency of the running action, creating extra load on the leg muscles or increasing stress through the lumbar spine and pelvis. Any of these negative factors can increase the likelihood of injury.

From the rear view the pelvic angle is described as a lateral tilting, with a negative angle meaning the pelvis is tilt down towards the swing leg side. The trunk is described as lateral flexion with a positive angle meaning the trunk is leaning down towards the stance leg side. At IC the lateral pelvic tilt is around – 5 degrees *(i.e. a small tilt downwards on the contact side).* This position may increase slightly (up to 5 degrees) during the absorption phase, although ideally very little movement will occur. At fast running speeds, the lateral tilt will be bigger.

Trunk lateral flexion is about 2 degrees at IC, which increases to 5 degrees at MS. This lateral flexion counterbalances the pelvic tilting. Between MS and TO the pelvic lateral tilt should revert to +5 degrees by TO and trunk flexion should return to 0 degrees (*i.e.* vertical spine alignment). This balanced spine position allows the propulsion forces to be directed forwards at TO and the positive lateral hip angle supports the knee lift of the swing leg.

The aim of the pelvis and trunk in the frontal plane during stance phase is to be stable and provide balance. The gluteus medium muscles (abductors) are of primary importance in providing lateral stability: their contraction prior to and during the absorption phase prevents the hip from dropping down too far to the swing leg side. The muscles will be acting eccentrically, or even isometrically, to prevent this movement.

An excessive or uncontrolled pelvic tilt increases the forces through the lumbar and sacroiliac joints, and forces the knee of the stance leg to internally rotate, which in turn may increase the pronation forces on the ankle. It is possible to observe a correlation between excessive pronation and excessive pelvic tilting in runners, and it is good illustration of how one unstable link in the biomechanical chain can have an adverse knock-on effect and increase the risk of injury.

**Foot mechanics**

The outwards and inwards rolls of the foot during running, as seen from the rear view, are called supination and pronation. This rolling action is normal and healthy. It is only excessive pronation or supination that leads to injury.

At IC the foot is in a supinated position, with the rear foot inverted. During the absorption phase between IC and MS, the ankle is dorsiflexing which – because of the way the subtalar joint works – also causes the foot to pronate. Pronation combines rear foot eversion with tibial internal rotation, and allows the foot to be flexible and absorb the impact forces of landing.

At around midstance the foot begins to re-supinate. This inverts the rear foot and externally rotates the tibia, moving the foot into a more rigid position to allow for a stronger push-off and more efficient recoil through the foot and Achilles tendon. You can feel the difference for yourself: roll your heel and ankle inwards and your foot will feel soft and flat. Then roll your heel and ankle out, and your foot should feel strong with an arch.

Pronation and supination both involve three-dimensional movements (heel eversion/inversion, ankle dorsi/plantar flexion and tibial internal/external rotation), which makes them very difficult to measure. The most commonly used approach is to measure the inversion and eversion range of motion of the rear foot during the stance phase, representing the pronation and supination movement patterns. Inversion and eversion angles are calculated by the angle made between the middle of the calcaneus and the midline of the tibia, view from the rear. In normal movement, at IC the rear foot is inverted by 5-10 degrees. The maximum pronation angle will occur around MS and will be an everted position of around 10 degrees.

However, foot mechanics are highly complex and these values must be read as simply one part of the picture. Similarly, you should interpret with caution any qualitative video analysis you make of a runner’s rear foot motion. Don’t rush to judgement about the need for orthotics based solely on a visual reading of rear foot movement.

An excessive supinator will typically land in the inverted position and then remain inverted during the stance phase. This means that they will lose out on the shock-absorbing benefits of the normal pronation movements. Excessive supinator’s tend to suffer from injuries to the lateral knee and hip, and can also be prone to stress fractures, because of the higher repetitive impact forces they incur.

Excessive pronators come in three types:

* Those who land inverted as normal but rotate across into an excessively everted position (such as 20 degrees);
* Those who may pronate normally on landing but then stay everted throughout the stance phase;
* Those who seem to pronate through a normal range but do it very rapidly.

We do not know which of these three faulty movement patterns it most likely to lead to injury, but logically all three can be problematic. If a runner spends too long in pronation, the foot will not be in a strong position to assist push-off during the propulsion phase, so the slower leg muscle will have to work harder. If the runner pronates too far or too quickly, the rotation forces acting on the tibia and knee joints may lead to problems. Excessive pronators tend to suffer from anterior knee pain, medial tibial stress syndrome, Achilles and foot soft-tissue injuries.

**Upper body and arm mechanics**

The main function of the upper bod and arm action is to provide balance and promote efficient movement. In the forward horizontal plane, the arms and trunk move to oppose the forward horizontal plane the arms and trunk move to oppose the forward drive of the legs. During the braking phase (from IC to MS), the arms and trunk combine to produce a braking force. This may seem a little weird, but in fact it is an advantage: the out-of-phase actions of the arms and trunk reduce the braking effect on the body and so converse forward momentum.

In the vertical plane around the centre, the arms and upper trunk also oppose the motion of the pelvis and legs. For example, as the right knee drives up and through in front of the body – producing an anti-clockwise angular momentum – the left arm and shoulder move forwards – creating a clockwise angular momentum and counteracting the knee motion, thereby helping to reduce rotation forces through the body during the whole gait cycle. Although the legs are much heavier than the arms, the shoulders much wider than the hips, so the arms are well positioned for their job of counterbalancing the leg rotation. This may explain why female runners use a slightly wider or rotating arm action to compensate for their narrower shoulders and lighter upper body.

The normal arm action during distance running involves shoulder extensions to pull the elbow straight back; then, as the arm comes forward, the hand will move slightly across the body.

The arm action has more to do with running efficiency than with injury prevention directly. A good arm action needs to be encouraged to counterbalance lower-limb forces and angular momentum, which may in turn help reduce injury. The arm action also contributes a little to the vertical lift during the propulsion phase which may help the runner to be more efficient, reducing the work done by the legs.

The relationship between biomechanics and injury is specific to each body part. Overall though, poor mechanics of any body part will either increase the landing forces acting on the body or increase the work to be done by the muscles. Both increase the stress, which – depending on the individual and the amount of running – can become excessive and cause injury.