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Pronation in Runners

Implications for Injuries

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Abstract

In spite of some significant progress in the understanding of the biomechanics of the ankle joint complex, especially the coupling mechanism between foot and leg, various mechanisms causing overuse injuries in the lower extremities are still poorly understood. Some increased pronation of the foot is often physiological, but excessive pronation is potentially harmful. Compensatory overpronation may occur for anatomical reasons. However, not only the amount of foot eversion, but also the way this eversion is transferred into tibial rotation may be crucial to the overloading stress on the knee. In other words, the individual transfer mechanism of foot eversion into internal tibial rotation may be of some predictable value for lower extremity overloading and related injuries.

Further research is necessary to improve the functional understanding of anatomical and biomechanical abnormalities and their pathological value in predicting overuse injuries.

Injuries to the lower extremities constitute the majority of injuries in running.[1-3] The risk of sustaining an injury depends on a number of extrinsic factors such as velocity, training time (frequency of training over a period), equipment and the running surface. However, intrinsic factors, such as the individual's physical and personality traits, can also influence the individual's likelihood of injury.[4] The factors most associated with foot and ankle running-related injuries include anatomical or biomechanical abnormalities, lack of flexibility, poor strength or muscular imbalance, the type of shoe and/or use of orthoses, and the type of running surface.[5] The poor alignment of the lower extremity and/or overpronation have frequently been associated with stress fractures of the lower extremity.[6,7]

The belief that runners who overpronate have an initially higher risk for sustaining a running-related injury is still widely held by runners and coaches, although there has been no reliable study supporting this.[8,9] Probably the most comprehensive study of running-related injuries, the Ontario cohort study,[10] has shown that none of the anthropometric variables, such as femoral neck anteversion, knee and patella alignment, rearfoot valgus and pes cavus/planus, were significantly related to risk. Similarly, although lower extremity injuries in dancing have been related to poor technique and malalignment,[11-13] 2 independent studies have failed to confirm such an association.[14,15]

Indeed, anatomical/biomechanical alterations appear to be casually related to injury. In running, overpronation may result in some cases of running-related overuse injuries,[16-19] but probably in no more than 10% of cases.[4] Fortunately, approximately 70% of runners with lower extremity injuries treated with orthotic devices will improve (section 2.4).[18,20-22]

In an attempt to shed some light on pronation in runners and its implication for injuries, this paper discusses first some biomechanical aspects.

1. Pronation from a Biomechanical Point of View

To understand pronation as a complex motion of the whole lower extremity, it is important to analyse the movement of the lower extremity during gait/running, the coupling mechanism between the foot and leg and forces acting on/in the human foot and ankle joint.

1.1 The Movement of the Lower Extremity During Gait/Running

During normal locomotion, rotation occurs in the sagittal, frontal and transverse planes. This motion is well documented and consistent from person to person during walking.[23-26] However, as the speed of gait increases the measurement of rotation in the transverse plane becomes much more difficult. The rapid development of technology has provided gait analysis systems that offer the possibility for 3-dimensional movement analysis.

The biomechanical events occurring in the lower limb at the time of initial ground contact include shock absorption, joint stabilisation of the hip, knee and ankle, and foot flexibility (fig. 1).[27] Shock absorption occurs through the flexion present in hip and knee joints, the dorsiflexion at the ankle joint and pronation at the subtalar joint. The electrical activity of the muscle groups at the time of ground contact provide joint stability at the ankle joint level mainly via the posterior tibial muscle. Foot flexibility results from the pronation of the subtalar joint which produces a degree of relaxation of the midtarsal joints and, subsequently, the other stabilising mechanisms of the foot arch. The tibialis posterior muscle seems, again, to play a significant role in stabilising the foot arch, and,

Fig. 1. At the time of initial ground contact, typical patterns of segmental motion can be observed including foot pronation and internal tibial rotation.

thus, in controlling the pronation movement occurring at the ankle joint complex.[28]

1.2 The Coupling Mechanism Between the Foot and Leg

In running, the calcaneus touches the ground and everts until about midstance (at about 150 to 250 milliseconds). The calcaneus eversion induces, through the talus, internal rotation of the tibia. At the same time, from initial contact to midstance, the pelvis rotates externally with respect to the supporting leg, which is initiating an external rotation of the femur. As the 2 movements are in opposite directions, the movement transfer between the 2 segments cannot be direct somewhere between calcaneus and pelvis.[29] Substantial transfer of the eversion movement of the calcaneus to the tibia may, however, be associated with potential overloading stress on the knee. It is, therefore, important to understand the transfer mechanism between calcaneus and tibia.

It has been suggested that the transformation of leg rotation into foot eversion-inversion mainly occurs in the subtalar joint.[30-33] Studies have suggested that the subtalar joint acts as an oblique hinge joint.[24,32,34,35] More recent studies,[36,37] however, have suggested that the subtalar joint may not act as a real hinge joint. The coupled motion of the subtalar and ankle joints[32] may explain why the range of motion, in any direction, of the ankle joint complex is greater than that of either ankle or subtalar joint alone.[38]

Hintermann et al.[39] and Hintermann and Nigg[40] have extensively studied the *in vitro* relationship between calcaneal and tibial rotation by mounting a foot-leg specimen in a 6-degrees-of-freedom device. They found high interindividual differences for movement transferred from calcaneal eversion into tibial rotation, and vice versa from tibial rotation into calcaneal eversion-inversion (fig. 2).[39-41] They also found that this movement transfer was not constant. In other words, the ratio between the input and output movement was not the same when calcaneal eversion-inversion or tibial rotation were applied. Aside from the input movement, movement transfer depended on the flexion position of the foot (plantar/dorsiflexion),[39,40] loading of the ankle joint complex,[39] fusion of selected joints[42,43] and integrity of the ligaments.[44,45] The significant changes in movement transfer after selective ligament transection emphasise the crucial role of the lateral and medial ankle ligaments in the coupling mechanism of foot and leg.[44,45] Finally, these studies showed that the ankle

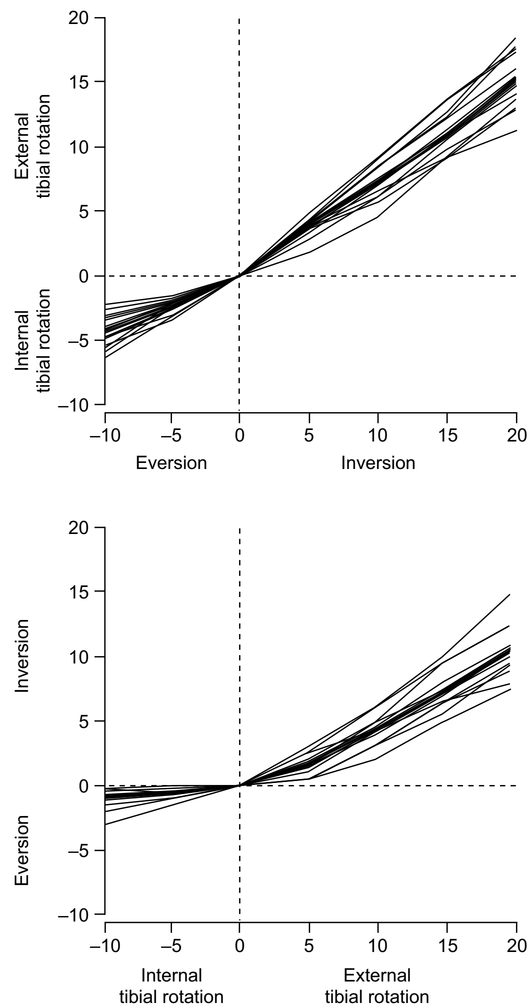

Fig. 2. High interindividual differences for the movement transferred from (**top**) calcaneal eversion into tibial rotation and (**bottom**) vice versa from tibial rotation into calcaneal eversion-inversion.[39]

(talocrural) and the subtalar (talocalcaneal) joints are not universal joints, as had been suggested in earlier studies.[31,32,46-48]

Quantification of the mechanical coupling of the calcaneus and tibia is technically much more difficult *in vivo*. One possibility is to place markers on the skin of the heel or heel of the shoe and skin of the leg, and then analyses of the movement of the skin markers relative to the bone are possible.[25] An alternative is to fix the markers by pins into the bone,[23] or to use bone markers and roentgen-stereophotogrammetry.[33] Several techniques, including methods for assessing the motion of the bones of the foot when running, have recently been developed and should be clinically available in the near future.

1.3 The Forces Acting On and In the Human Foot and Ankle Joint

Whenever the foot is in contact with the ground, forces act from the ground onto the foot and vice versa. These forces, called ground reaction forces, are resultant forces that correspond to the movement of the centre of mass and gravity. Ground reaction forces are typically subdivided into impact and active forces.[25] External forces are different for various activities and in running can easily exceed bodyweight several-fold.[49-51] In running, the internal forces at the ankle joint increase from the stance phase to take-off and may be as high as 3 to 8 times the individual's bodyweight.[52]

Another method to estimate the ground reaction forces is the measurement of foot pressure distribution. In addition to the direct measurement of pressure distribution in footwear, pressure distribution sensors have been used to estimate internal forces in the anatomical structures of the human foot.[52,53] The results of pressure distribution measurements were used as localised input into different foot structures to provide a possible means of quantifying internal forces in the joints, ligaments and tendons of the foot, an estimation that cannot be performed using the ground reaction force as force input.[25]

2. Clinical Implications for Running

These biomechanical findings suggest that pronation in running has to be analysed from different points of view, i.e. the amount of foot eversion (pronation) and the movement transferred from eversion into tibial rotation.

Therefore, the following questions should be addressed:

- if and to what extent does the shoe influence pronation?
- if and to what extent may shoe modifications and supports reduce foot pronation and, thus, help to prevent injuries?

2.1 Amount of Foot Eversion (Pronation)

Excessive pronation (ankle joint eversion) has been typically associated with the development of overuse injuries in locomotion.[16,54,55] Individuals with injuries typically have pronation movement that is about 2 to 4° greater than that of those with no injuries. However, between 40 and 50% of runners with excessive pronation do not have overuse injuries.[25,56]

2.2 Transfer of Foot Eversion into Tibial Rotation

The transfer of foot eversion into the internal rotation of the tibia has most commonly been associated with the incidence of knee pain.[16,18,56] Various studies have shown a high variation in the movement transfer between different individuals (fig. 2).[33,39,41,46,57,58] Hintermann et al.[39] found in the neutral flexion of the foot, for example, a movement transfer between 14 and 66% for eversion as the input throughout all loading conditions. Assuming that the 2 individuals with a movement transfer of 14 and 66%, respectively, show an eversion of 20° during gait, the first will experience internal tibial rotation of about 3° and the latter of about 13°. This example illustrates that not only the amount of eversion, but also the way this eversion is transferred into tibial rotation, may be crucial for the etiology of knee stress. It has been suggested that individuals with a high level of movement transfer for eversion are potential candidates for knee overloading and related injuries.[58]

It has been proposed that movement transfer between foot eversion and tibial rotation is small for individuals with low arches and high for those with high arches.[58] Consequently, individuals with high arches are more susceptible to overuse injuries than those with low arches, if they show excessive ankle joint eversion.

It has been suggested that a combination of excessive pronation and substantial movement transfer of foot eversion into internal tibial rotation is a better predictor of the development of overuse injuries, especially of the knee joint.[39,56,59]

2.3 Influence of Pronation by the Shoe

Pronation has been shown to be substantially influenced by the shoe.[18,22] Differences in pronation for the same person using different running shoes are considerable. It is easily possible that the maximal ankle joint eversion movement is 31° for one and 12° for another running shoe.[25,59]

2.4 Influence of Medial Support on Foot Pronation

Medial support in a shoe may provide increased stability to the foot and leg and may reduce the maximal foot pronation (fig. 3). However, at the same time, medial support may increase external rotation of the tibia. It is assumed that this change is associated with increased inclination of the subtalar axis.[58]

Fig. 3. Orthotic devices can be adjusted to meet the needs of the individual in order to correct malalignment and to support the medial foot arch. Determination of the (**top**) rearfoot angle and (**bottom**) the amount of medial support are needed for realignment.

Corrective running orthotic devices have been successfully used in the treatment of lower extremity overuse injuries to control compensatory overpronation, and have been postulated to alter the amount of tibial rotation occurring during the stance phase.[18,60,61] Pronation and knee flexion both impart obligatory internal rotation of the tibia, while supination and knee extension generate external tibial rotatory forces. It has been speculated that, when maximum pronation and maximum knee flexion do not occur simultaneously during the stance phase, conflicting rotatory forces will be generated through the tibia, rendering the ankle and knee joints functionally antagonistic and predisposing to injury.[18,60,61] Corrective running orthotic devices reduce the potential of this by reducing the amount of pronation which occurs during the stance phase, allowing maximum pronation and maximum knee flexion to occur simultaneously.

3. Discussion and Conclusions

Some increased pronation of the foot is often physiological, but excessive pronation is potentially harmful. Compensatory overpronation may occur for anatomical reasons, such as a tibia vara of 10° or more, forefoot varus, leg length discrepancy, ligamentous laxity, or because of muscular weakness or tightness in the gastrocnemius and soleus muscles. Excessive pronation will have secondary effects on the lower extremities, such as an increased compensatory internal rotation of the tibia resulting in lower leg and knee problems (fig. 4). The degree of calcaneal eversion, and, therefore, pronation, determines the degree of compensatory internal tibia rotation. This increased rotation of the tibia may also give more proximal effects through the femur and the pelvis. In other words, the lower extremity should be regarded as a functional unit when carrying out clinical examination.

Recent biomechanical work has brought some light into the pronation mechanism of the ankle joint complex, in particular, the mechanism of movement transfer between foot and leg. However, there is still a lack of knowledge in the clinical assessment of these variables and thus the recognition of individuals who have a potentially higher risk of becoming symptomatic when overpronation is present. In other words, despite the increased knowledge, it remains tremendously difficult to identify individuals at a higher risk, which of course would be very helpful in preventing injury. In fact, there is no evidence that medial supports or shoe modification is necessary in every case of overpronation. To the contrary, in some cases such orthotic devices may even initiate additional stress and overload by making the ankle joint complex more rigid.[59] Nevertheless, approximately 70% of runners with lower extremity injuries treated with orthotic devices will show an improvement.

Excessive pronation, however, will predispose individuals to injury on the medial aspects of the lower extremities (fig. 4). Increased pronation is associated with injuries such as medial tibial stress syndrome,[62] tibialis posterior tendinitis,[63] Achilles bursitis or tendinitis,[17,62,64] patellofemoral disorders,[18,20] iliotibial friction syndrome[20,62] and lower extremity stress fractures.[6] However, it can not be emphasised enough that specific anatomic abnormalities and abnormal biomechanics of the lower extremity are not correlated with specific injuries on a predictable basis.[65]

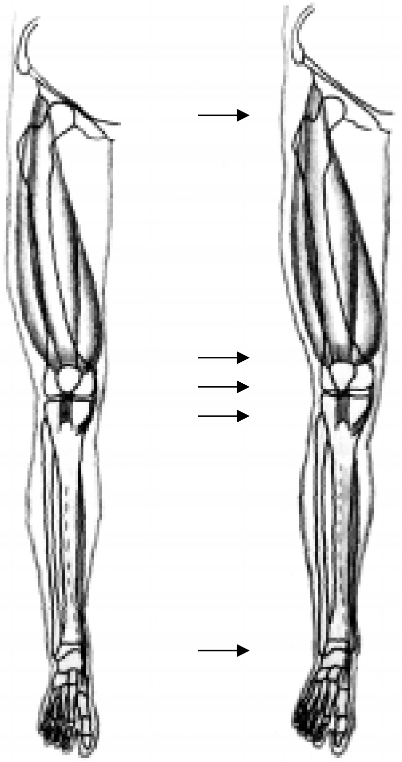

Fig. 4. Excessive pronation induces an increased compensatory internal rotation of the tibia (**right**) that may result in overloading stress on the knee. This increased rotation of the tibia may also lead to more proximal effects through the femur and pelvis. The normal (neutral) position of the leg (**left**) is also shown.

In conclusion, despite some progress in the understanding of the biomechanics of the ankle joint complex, especially the coupling mechanism between foot and leg, various mechanisms causing overuse injuries to the lower extremities are still not well understood. Therefore, further research is needed to improve the functional understanding of anatomical and biomechanical abnormalities and their pathological value in predicting overuse injuries.

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