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WHITE PAPER

Foot pronation

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Over the past decades, pronation has been discussed as a potential risk factor for injuries or as the mechanism behind impact damping. However, little is understood about pronation. The objectives of this paper were to (a) define and differentiate between the terms of pronation and eversion, (b + c) underline the importance and problematic aspects of pronation. The terms of pronation and eversion have often been used interchangeably in previous work. Both metrics describe rotations about two different axes of the foot. Due to the inaccessible location of the talus bone, mainly variables measuring eversion have been used to approximate the actual movement of pronation. However, the variety of surrogate variables does not facilitate the understanding of such particular foot movement. Since pronation is natural and it is necessary to successfully perform dynamic tasks such as running, normative values were developed for most pronation-associated variables. However, the optimal amount of pronation remains unknown. Furthermore, various aspects of pronation are widespread among researchers and clinicians. Despite their popularity, they are mis- or not well understood such as the impact damping paradigm and its link to running injuries. Especially, the exclusive causality between pronation and running injuries has been shown in neither cross-sectional nor longitudinal study designs with sufficient sample sizes. Therefore, it seems important to reconsider the topic of pronation from novel perspectives.

Keywords: pronation; sports injuries; overuse injury; eversion; foot and ankle

The objectives of this paper were to (a) define the terms of pronation/eversion and differentiate between, (b) underline the importance as well as (c) the problematic aspects of pronation.

The human foot consists of 28 bones, 33 joints, and more than 100 muscles, ligaments and tendons. The description of the movement of such a complex structure is complicated. The foot can be subdivided into rear foot, midfoot and forefoot.

In the past 40 years, biomechanical research has primarily concentrated on the rear foot. The rear foot has two major functional joints: the subtalar joint (i.e. the joint between the calcaneus and the talus), and the talocrural or ankle joint (i.e. the joint between the talus and the tibia). The ankle joint axis is close to a mediolateral axis through the ankle joint complex. The subtalar joint axis (Figure 1) is a line pointing from the ground surface on the posterior and lateral side of the foot toward the medial anterior side of the foot and inclined by about 42 degrees (Inman, 1976). The rotations about the subtalar joint axis are defined as pronation and supination:

> Pronation is the inward rotation of the rear foot about the subtalar joint axis.
>
> Supination is the outward rotation of the rear foot about the subtalar joint axis.

The quantification of pronation and supination in real-life situations, such as running, is difficult, if not impossible since the talus bone cannot be accessed from the outside. For this reason, scientists, athletes and clinicians have introduced variables with the goal to describe pronation-like movements in real-life situations. The most common ones are the rear foot angle (Areblad, Nigg, Ekstrand, Olsson, & Ekström, 1990; Hunt, Fahey, & Smith, 2000; Moseley, Smith, Hunt, & Gant, 1996) and Achilles tendon angle (Engsberg & Andrews, 1987; Reinschmidt, van Den Bogert, Murphy, Lundberg, & Nigg, 1997), which can be seen in Figure 2. Publications use these definitions inconsistently and might refer to the Achilles tendon angle as rear foot angle which appears to be the most often used term (Cheung & Ng, 2007;

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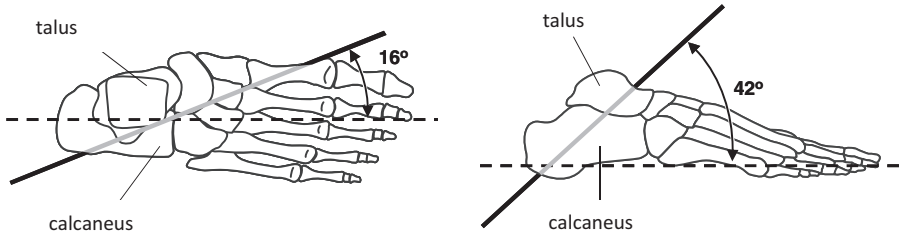

Figure 1. The subtalar joint axis is indicated by the solid line and the clinical longitudinal axis by the dotted line (adapted from Nigg (2010), with permission).

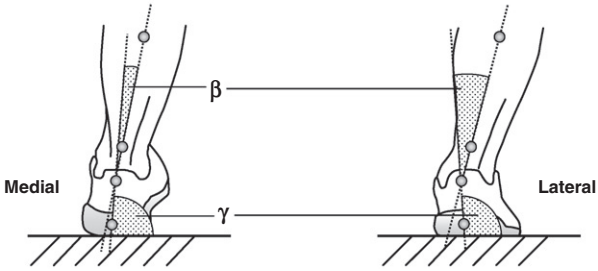

Figure 2. While the actual movement in the ankle joint complex is foot pro- and supination, the literature quantified typically rear foot eversion, γ, or the Achilles tendon angle, β, when talking about foot pronation. This is what we see when looking from behind at an athlete running (adopted from Nigg (2010), with permission).

Rossner Buchanan & Davis, 2005). Many more variables were linked to pronation, such as the longitudinal arch angle (McPoil & Cornwall, 2005) and Foot Posture Index (Redmond, Crosbie, & Ouvrier, 2006). However, these variables quantify movement about 'clinical axes' that are not the real physical anatomical axes. The most common clinical one is the longitudinal foot axis, which corresponds to the dotted line in Figure 1. Rotations about this axis were used as surrogate variables for foot pronation (= foot eversion) and supination (= foot inversion) using the following definitions:

> Eversion is an inward rotation of the foot with respect to the longitudinal foot axis.
>
> Inversion is an outward rotation of the foot with respect to the longitudinal foot axis.

Important aspects of foot pronation

Natural movement

Pronation and supination are normal and necessary components of the gait cycle to stabilize the foot during dynamic tasks (Elftman, 1960; Sarrafian, 1987; Tansey & Briggs, 2001). During locomotion, whenever the foot contacts the ground, pronation occurs during the first 40–50% of foot contact.

Is there an optimum degree of pronation?

As in any natural movement, the pronation movement should have an optimum, which is specific to each individual. There is no concrete indication, what this optimum might be. Too little or too much pronation may be a disadvantage. However, substantial movement in this area of the foot does not appear to be something of concern.

Problematic aspects of foot pronation

Surrogate variables

A recent review of the literature found a total of 62 surrogate variables that have been used in scientific publications, all claiming to quantify something like pronation (Behling, Manz, von Tscharner, & Nigg, 2018). The same study also found that these surrogate pronation-variables were not correlated with each other except for internal correlations (correlations of the same variables at different time points). Consequently, these variables describe various different aspects of foot movement and may or may not be associated with actual foot pronation.

Impact damping

Pronation of the foot has often been described as a method to damp the impact shock during walking and heel-toe running. This 'functional description' is inappropriate since the impact phase is completed at approximately 40–50 ms after heel strike, while the pronation (eversion) position has its maximum at about 150–200 ms in running and at about 250–350 ms in walking. This begs the question: How could something that happens much later during ground contact damp the impact, which happens early in the ground contact?

Running injuries

'Excessive pronation' has often been associated with running injuries particularly overuse injuries. The terms 'over-pronation', 'hyper-pronation' or 'excessive pronation' have often been used in literature when describing injury risks in running (e.g., James, Bates, & Osternig, 1978). The actual mechanisms how the injury occurs due to 'over-', 'hyper-'or 'excessive' pronation is not well

understood (Milner, Ferber, Pollard, Hamill, & Davis, 2006), although several theories have been suggested. One major problem with the term 'over-pronation' is that there is no clinical definition (Horwood & Chockalingam, 2017). The 'normal' degree of pronation is unknown: therefore, it is impossible to determine what is in excess of 'normal'. Furthermore, pronation velocity has been discussed as a potential indication of an increased injury risk (Messier & Pittala, 1988; Vtasalo & Kvist, 1983); However, the findings regarding this variable are inconsistent (Hetsroni et al., 2006; Messier & Pittala, 1988; Stefanyshyn, Stergiou, Lun, & Meeuwisse, 2001; Vtasalo & Kvist, 1983) and epidemiological evidence is missing.

One reason, pronation has been linked to the development of running injuries is the coupling between the rearfoot and the tibia. Foot pronation (eversion) produces an internal rotation of the tibia. Very high foot pronation (depending on the coupling) may result in a high internal rotation of the tibia, which may create problems at the knee of the athlete (Taunton et al., 2002; van der Worp et al., 2015; van Gent et al., 2007).

While it is appealing to associate 'over-pronation' or 'over-eversion' with an increased risk of injury, the results of the epidemiological and empirical scientific literature on this topic are inconsistent. Since it has been shown that pronation-variables are not correlated to each other, inconclusive results based on different methodologies (variables) are not surprising. The scientific support for a link between the magnitude of pronation and injury is weak. A major problem in the biomechanical studies of pronation and running injuries is that most studies have a small number of participants. Therefore, it is difficult to make generalizations about the relationship. In the past decade, more studies have refuted the association of 'over-pronation' and risk of injury (Lun, Meeuwisse, Stergiou, & Stefanyshyn, 2004; Nielsen et al., 2014; Nilstad, Andersen, Bahr, Holme, & Steffen, 2014). In fact, Hintermann and Nigg (1998) reported that between 40% and 50% of runners who 'over-pronate' are not at risk for overuse injuries. Thus, it could be that pronation may has an effect on certain injuries. However, pronation may not be the only factor influencing injury development.

Final comments

(1) Pronation is a natural movement of the foot, which corresponds to a term that is widely used, but not well understood. Pronation is often associated with running injuries; however, evidence for this association is weak.
(2) There is no clinical definition for 'over-', 'hyper-' or 'excessive' pronation. Thus, these terms should be avoided.

Many aspects of pronation are mis- or only partially understood. Therefore it seems important to reconsider the topic of pronation from different and novel perspectives to answer questions regarding injuries and their relationship with pronation.

Disclosure statement

No potential conflict of interest was reported by the authors.

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