PROLAB ORTHOTICS
Evidence-Based Medicine

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HOW FOOT ORTHOSES WORK – DIRECT MECHANICAL EFFECT OF FOOT ORTHOSES

As noted in my last ProLab Newsletter, the available research literature clearly demonstrates that foot orthoses can be an effective treatment for many foot and lower extremity pathologies. However, there seems to be no general consensus within the medical and/or biomechanics research community as to how foot orthoses actually work to produce their biomechanical effects. There are currently only a few biologically plausible and theoretically coherent mechanisms to explain the therapeutic effects of foot orthoses. One of these mechanisms, the *direct mechanical effect*, first described in 2009, is a mechanical principle which explains how foot orthoses may function in treating a number of mechanically-related pathologies of the foot and lower extremity (Kirby KA: Foot and Lower Extremity Biomechanics IV: Precision Intricast Newsletters, 2009-2013. Precision Intricast, Inc., Payson, AZ, 2014, pp. 53-54).

The *direct mechanical effect of foot orthoses* is defined as the kinetic effects (i.e., pertaining to forces and moments) and kinematic effects (i.e., pertaining to position and motion) acting on and within the foot and lower extremity which result from alterations in the location, magnitude, and temporal patterns of ground reaction force (GRF) acting on the plantar foot (Kirby KA, 2014). The mechanical interaction between the plantar foot and foot orthosis is known as *orthosis reaction force* (ORF) and may include a direct compression force and/or a shearing force between the plantar foot and the dorsal aspect of the orthosis (Kirby KA, Spooner SK, Scherer PR, Schuberth JM: Foot orthoses. Foot & Ankle Specialist, 5(5):334-343, 2012).

In order to better explain the principle of the direct mechanical effect of orthoses, it will be helpful to describe a clinical scenario where custom foot orthoses are commonly used to treat pronation-related pathologies such as symptomatic flexible flatfoot deformity in children and posterior tibial tendon dysfunction (PTTD) in adults. The foot orthoses used to treat these pronation-related pathologies are designed to specifically push up directly on the medial aspect of the plantar foot to limit the pronation motion and the pronated position of the foot. Typically, such "anti-pronation" foot orthoses will be made with a higher and stiffer medial longitudinal arch (MLA), a stiff rearfoot post and a medial heel skive modification (Kirby KA: The medial heel skive technique: improving pronation control in foot orthoses. JAPMA, 82: 177-188, 1992).

In the case of treating symptomatic pediatric flexible flatfeet and PTTD, the orthosis should be designed to increase the ORF medial to the subtalar joint (STJ) axis to increase the overall STJ supination moment acting on the foot (Fig. 1). The medial heel skive has been shown in research from 2012 to increase the plantar pressure acting on the medial calcaneus in flat-arched feet which supports the direct mechanical effect principle of orthoses being able to push harder on the medial calcaneus to increase the STJ supination moments to limit pronation-related symptoms (Bonanno DR et al: The effect of different depths of medial heel skive on plantar pressures. Journal Foot Ankle Research. 5(1):20, 2012).

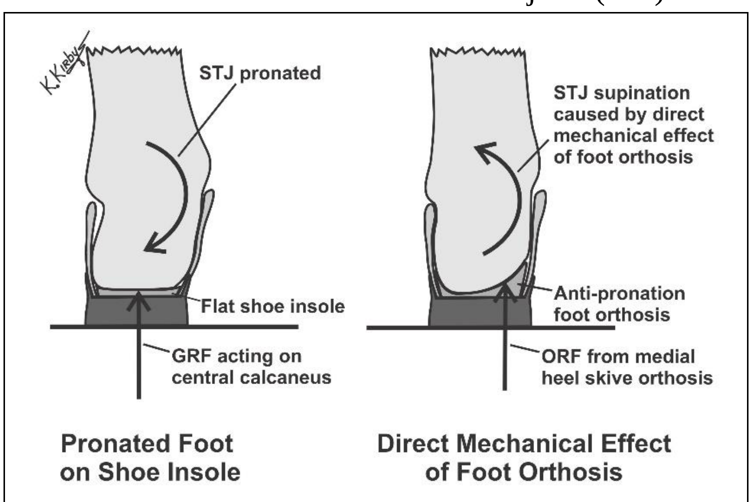

Figure 1. In a pronated foot standing on a flat shoe insole (left), the ground reaction force (GRF) acts under the central aspect of the plantar calcaneus. The direct mechanical effect of foot orthosis is based on the fact that a medial heel skive orthosis, for example, may shift orthosis reaction force (ORF) more medially on the plantar calcaneus(right) to produce a supination effect on the foot and subtalar joint (STJ).

The higher, stiffer MLA of the "anti-pronation" orthosis also functions to increase the GRF acting on the plantar aspect of the MLA of the foot so that the orthosis pushes harder under the MLA in order to limit collapse of the MLA in flatfoot deformity. In fact, recent research utilizing sophisticated motion analysis and biplane fluoroscopy technology have confirmed the long-held clinical belief that foot orthoses do effectively reduce MLA flattening of the foot during weightbearing activities (Balsdon M, Dombroski C, Bushey K, Jenkyn TR; Hard, soft and off-the-shelf foot orthoses and their effect on the angle of the medial longitudinal arch: A biplane fluoroscopy study. Prosthetics and orthotics international, 43(3):331-338, 2019).

Therefore, increasing the GRF on the medial aspect of the plantar calcaneus with the medial heel skive orthosis modification and increasing GRF on the plantar MLA of the foot with a higher, stiffer MLA built into the orthosis, will alter the magnitudes, locations and temporal patterns of GRF acting on the plantar foot during weightbearing activities and, in effect, will produce a direct mechanical "anti-pronation" effect from the orthosis. The medial shift in GRF under the plantar heel and plantar midfoot that results from this "anti-pronation" orthosis design will help supinate the STJ and/or reduce pronation of the STJ during weightbearing activities (Kirby KA, Green DR: Evaluation and Nonoperative Management of Pes Valgus, pp. 295-327, in DeValentine, S.(ed), Foot and Ankle Disorders in Children. Churchill-Livingstone, New York, 1992).

The principle of a direct mechanical effect of foot orthoses can also be used to treat patients with "over-supination" symptoms in pathologies such as peroneal tendinopathy, lateral ankle instability and lateral dorsal midfoot interosseous compression syndrome (i.e. lateral dorsal midfoot pain), where the foot and lower extremity may be experiencing "over-supination" pathologies (Kirby KA.: Foot and Lower Extremity Biomechanics: A Ten-Year Collection of Precision Intricast Newsletters. Precision Intricast, Inc., Payson, AZ, 1997, pp. 165-166). In these "over-supination" pathologies, the knowledge of a direct mechanical effect of foot orthoses is used to design foot orthoses with increased valgus-wedging to shift the GRF toward the lateral aspect of the plantar foot which will, in turn, increase STJ pronation moments and reduce the STJ supination moments acting on the foot. These specially-designed "valgus-wedged" orthosis modifications, such as lateral heel skives and valgus forefoot extensions, work to effectively reduce supination-related symptoms by directly applying more GRF on the plantar foot more lateral to the STJ axis.

Likewise, the direct mechanical effect of foot orthoses can be used to understand the function of orthoses in off-loading symptomatic or ulcerated high pressure areas of the plantar foot. Pathologies such as metatarsalgia, plantar plate tears, plantar heel pain and diabetic neuropathic ulcers can be effectively treated by custom foot orthoses which are specifically designed to reduce high plantar pressures by redistributing the plantar loading forces to less symptomatic or non-ulcerated areas of the plantar foot (Burns J, Crosbie J, Ouvrier R, Hunt A: Effective orthotic therapy for the painful cavus foot. JAPMA, 96:205-211, 2006).

Metatarsal stress reactions/stress fractures may also be treated using the direct mechanical effect by designing the orthoses to exert less GRF under the metatarsal heads and more GRF under the necks of the affected metatarsals in order to prevent excessive bending moments acting on the metatarsals during weightbearing activities (Simkin A, Leichter I, Giladi M, et al: Combined effect of foot arch structure and an orthotic device on stress fractures. Foot Ankle, 10:25-29, 1989). In addition, the direct mechanical effect of foot orthoses is evident when considering the numerous studies where custom foot orthoses have been designed to reduce the symptoms from medial knee osteoarthritis, patellofemoral pain and medial tibial stress syndrome (Kirby KA: "Evolution of Foot Orthoses in Sports", in Werd MB, Knight EL, Langer PR (eds), Athletic Footwear and Orthoses in Sports Medicine. Second Edition. Springer, New York, 2017).

Overall, the principle of the direct mechanical effect of foot orthoses relies on the fact that custom foot orthoses have the ability to be designed so that they can significantly alter the magnitudes, plantar locations and temporal patterns of GRF acting on the plantar foot during weightbearing activities. As such the direct mechanical effect of foot orthoses allows a change in the plantar pushing forces that would normally occur from weightbearing on a flat surface (e.g., ground, shoe insole) and convert them into new set of plantar pushing forces, all done with the ultimate goal of reducing the pathological external and internal forces and moments acting on and within the foot and lower extremity that are causing injury, pain and disability.

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