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Foot orthoses in rehabilitation—what's new

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Overuse injuries are common sequelae of exercise and sporting activities in general, and of running in particular. As a means of treatment and prevention of further injury, foot orthoses and shoe modifications are widely prescribed, with the primary goal of altering lower extremity joint alignment and patterns of movement. From a biomechanical perspective, if foot orthoses place the foot and lower extremity in a more advantageous position, applied stresses to the active and passive soft tissues of the foot and lower limb may be minimized [1–3]. Ample evidence exists, based on subjective pain relief, symptom resolution, and patient satisfaction [4–6], to support the continued use of these devices, particularly in runners. The biomechanical mechanisms through which we believe the clinical benefits are derived, however, are comparatively limited and not fully understood.

This article presents the evidence that may support or refute the use of orthotic intervention as an adjunct to the athlete's rehabilitation program. Alternative mechanisms of foot orthoses action that may be linked to their effectiveness, as well as the direction for future investigations, are discussed. Options for orthotic intervention for specific sports-related injuries complete the article.

Evidence and contradictions

Advances in motion analysis technology have improved our understanding of foot orthoses and shoe design effects on foot and lower extremity movement. Comparative studies of orthotic effectiveness are often confusing, however: it appears that for every investigation showing a positive response for some bio-

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mechanical parameter, another study may show no change. Discrepancies among the studies may be due to a number of factors, including the anatomical variability in the subjects' foot structures, differences in orthotic fabrication, materials, and posting locations, variations in footwear and testing conditions, and lack of statistical power.

It is also important to recognize that there may be various solutions or movement strategies with respect to the magnitude of rotations and peak moments between the segments of the lower extremity that an individual may adopt for a given activity [7,8]. Changes in rotation patterns as a result of the orthotic intervention may be subtle, and not large enough to demonstrate statistical differences, particularly when considering the sample sizes of many studies. Few investigations have shown consistent systematic trends with foot orthoses; rather, changes were highly subject-specific, and frequently correlated with a reduction in symptoms [3,8]. Nevertheless, even a small change in angular or kinetic variables may reduce the risk of injury [9–14]. It is not presently known how large such a difference needs to be to have a positive outcome.

Although their use extends across various sporting activities, orthotic effectiveness has been primarily assessed in runners. Several factors have been suggested to increase a runner's risk for injuries, including excessive pronation or rearfoot eversion, high eversion velocity, increase internal tibial rotation, increased impact and loading rate of vertical ground reaction force, increased ankle inversion moments, and increased knee abduction and external rotation moments [7,8,15–17]. To date, the majority of studies have focused on kinematic alterations; foot orthoses have been used to reduce symptoms by purportedly affecting these factors. Kinematic changes are often small and not consistently significant [10]. Recent investigations have speculated that modifications in the maximal vertical loading rate and vertical force impact peak [18] and reduction of ankle or knee joint moments [3,7,17] may be equally important functions of foot orthoses.

Alternative mechanisms of foot orthoses action

To date, the majority of clinical studies have assessed orthotic effectiveness on changing the biomechanical parameters of lower extremity movement patterns. The multifactorial nature of many athletic injuries, and intrinsic biomechanical abnormalities (training techniques, training terrain, equipment, footwear, previous injury history, etc) make it difficult to draw clear conclusions on the specific etiological factors contributing to a particular injury. Orthotic intervention may be appropriate for those injuries resulting from identifiable abnormal biomechanics, however.

Orthoses may also derive their benefit by altering muscle activation [19] and proprioceptive mechanisms involved in regulating muscle function [8,20]. Investigators have proposed that foot orthoses may increase the afferent feedback from cutaneous receptors, which may positively alter the muscle's response to stabilize joint motion [8,12,17,20]. A positive response would be classified as a

reduction in muscle activation and fatigue. Damping soft-tissue vibrations through various material properties of the orthoses has also been proposed as a strategy for reducing muscle activity [20]. Based on these assumptions, performance should improve with an optimal orthotic. Further experimental work is needed to support this concept.

In summary, subject responses to orthotic intervention have been highly variable and individualized. Kinematic studies have reported small changes in foot and lower extremity rotation patterns that may initially seem inconsequential, but when considered over time and repetition, even these small changes may have a positive impact. Continued investigations to explore afferent feedback changes through orthotic intervention and its impact on muscle activation, as well as alterations in joint moments, are needed to understand and validate the recommended use of orthoses.

Specific sports-related injuries and orthotic applications

Though not exhaustive, the following section provides examples of common conditions of the forefoot, midfoot, and rearfoot that may benefit from foot orthoses and external shoe modifications [21]. In many cases, premade or generic over-the-counter orthoses are adequate and are significantly less expensive than custom-made designs. The over-the-counter orthoses are available in a variety of materials and, in general, are designed to provide shock absorption, increased support, or both in specific areas of the foot, or across the entire foot. Examples include heel cushions, arch supports, or full-length insoles.

For the athlete with more complicated foot problems, a custom made orthosis may be necessary. The total contact orthoses (TCO) is a custom-made orthosis that is fabricated from a model or impression of the patient's foot, thereby achieving "total contact" with the plantar aspect of the foot. The TCO consists of a shell, the layer of material that is next to the foot and in total contact with the plantar surface; and the posting, or the material that fills the space between the shell and the shoe. The specific designs and materials vary according to the needs of the patient. To provide more control or shock absorption/cushioning, the TCO can be further customized by adding small amounts of additional materials to specific areas of the orthoses, such as viscoelastic polymer under the metatarsal heads or heel.

Though the focus is on the orthoses, it is essential that footwear be considered concurrently with the orthotic recommendation. Shoes are the essential foundation for effective orthotic intervention. Outsole, midsole, and insole features, as well as heel counter and shoe toe box/upper design can all be used to maximize the benefits of foot orthoses. In many situations, choosing a shoe that has been designed for the athlete's particular sport, that is appropriate for that individual's foot alignment, and that fits properly may be the only adaptation that is necessary; this should be the *first* consideration in the management of foot-related musculoskeletal problems.

Fitness footwear can also be modified to accommodate various patient diagnoses and various foot structures. External shoe modifications most commonly prescribed for the athlete include rocker soles, extended steel shanks, solid ankle cushion heels (or SACH), and flares. The reader is referred to resources available in the literature that describe these external shoe modifications in detail [21–23].

In the following section, solutions for specific sports-related injuries and conditions of the forefoot, midfoot, and rearfoot are presented. Each condition is presented by the clinical diagnosis, followed by the desired goal or function of the orthoses, and the specific footwear modification or recommendation. Many of the modifications have been derived through an understanding of the biomechanical mechanisms underlying the specific pathology, in combination with knowledge of the athlete's foot structure and the requirements of the sporting activity. Specific modifications and control will differ in each person's case and alterations may be needed during the course of treatment.

Forefoot

Turf toe and hallux rigidus

The objectives for treating turf toe or hallux rigidus are to limit dorsiflexion of the great toe, relieve dorsal or plantar pressures that may be present at the first metatarsophalangeal joint, and decrease abnormal pronation of the foot, if it is present.

A TCO with a built-in plate made of lightweight carbon fiber material may be effective in limiting hallux dorsiflexion. Footwear may need to be modified with a

Fig. 1. Shoe with extended steel shank and an example of a carbon fiber plate.

rocker sole and an extended steel shank placed between the layers of the shoe sole. This footwear design allows a smooth transition, or "rocking," between heel contact and toe off, while at the same time limiting hallux dorsiflexion (Fig. 1).

Morton's toe (elongated second metatarsal)

The goal of orthotic intervention for Morton's toe is to relieve excessive plantar pressure beneath the second metatarsal head. It may be necessary to transfer some of the pressure onto the first metatarsal head. A TCO with a metatarsal pad placed proximal to the second and possibly the third metatarsal head can help to relieve pressure in this region. It may also be necessary to increase the pressure on the first metatarsal head. A Morton's extension that consists of posting material placed under the first metatarsal shaft and head may increase the pressure on the first metatarsal head, thereby relieving the second and third metatarsal heads (Fig. 2). It is important to remember that with any type of shoe selection, with or without insoles modification, the shoes need to fit properly. In many cases, shoes are fit to length of the great toe when the second toe should be used as the reference.

Bunion deformity

Any excessive pressure created by the medial prominence associated with a bunion deformity must be relieved. This includes relief of dorsal pressure over the first metatarsal as well. Adequate shoe room, especially in the toe box of the shoe, is essential with a bunion deformity. Shoes may need to be stretched to accommodate the medial prominence. If excessive foot pronation accompanies the deformity, a TCO with medial posting may be helpful in minimizing the

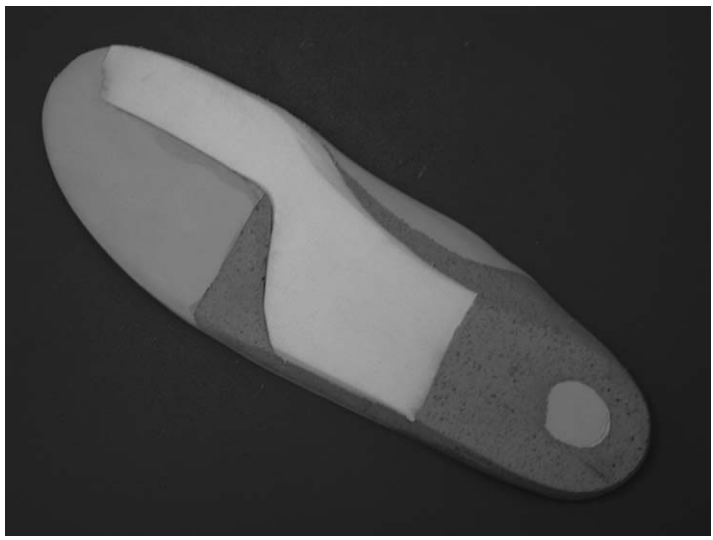

Fig. 2. Total contact orthosis (TCO) with Morton's extension.

abnormal mechanics associated with the excessive pronation [8,10,11,13,14,16,24].

Interdigital neuroma (Morton's neuroma) and sesamoiditis

The goals of orthotic intervention are to increase shock absorption and relieve plantar pressure on the metatarsal heads, sesamoids, or both. A built-in metatarsal relief or metatarsal pad can be applied to over-the-counter orthoses just proximal to the involved web space. In more severe cases, or in the presence of an underlying biomechanical foot deviation, a custom molded TCO with an added metatarsal pad may be helpful. For Morton's neuroma, the metatarsal pad may increase dorsiflexion of the metatarsals, resulting in relative plantarflexion of the proximal phalanx. This in turn may decrease the angulation of the digital nerves as they course underneath the intermetatarsal ligament. At highly sensitive areas, viscoelastic polymer may be added to the TCO under the sesamoids.

Shoe modification with a full-length steel shank and anterior rocker bottom may also be helpful in minimizing the bending moment at the metatarsophalangeal joints [25].

Metatarsal stress fracture

The primary function of orthoses and footwear after a metatarsal stress fracture are to promote healing by limiting motion. A TCO reinforced with firm posting material, such as cork, can provide support and limit excessive foot motion. Foot motion can be further limited with the use of a rocker sole shoe with an extended steel shank.

Midfoot and rearfoot

Pes cavus

This high-arch or supinated foot type tends to be a more rigid foot structure. The objectives for orthotic intervention are to provide shock absorption, especially at heel strike, and plantar pressure relief under the prominent metatarsal heads. Over-the-counter insoles with good shock absorption, together with added metatarsal relief under the first, fifth, or both metatarsal heads may be adequate. In cases that do not respond to the inexpensive approaches, an accommodative, shock-absorbing TCO that is molded from an impression of the foot may be required. Additional posting on the lateral aspect of the forefoot (in cases of a forefoot valgus) may help prevent excessive heel varus and subtalar joint supination. Curved-last footwear with good shock absorption may be modified with a lateral flare to decrease excessive supination.

Pes planus

The majority of investigations on orthotic effectiveness have focused on the pes planus, or excessively pronated foot type (the reader is referred to selected references at the end of this article for a comprehensive review of the literature on orthotic effectiveness in clinical trials [26–28]). This foot type tends to be more

flexible, and orthoses and footwear need to focus on support or control of excessive pronation. Over-the-counter, full-length insoles with added medial support under rearfoot and arch areas or medial rearfoot and forefoot regions may be adequate for most athletes. If custom orthoses are prescribed, they should consist of firmer, more rigid materials that are posted medially to help minimize excessive pronation. Straight-last footwear with motion control features such as a reinforced heel counter and medial midsole reinforcement should be recommended for this foot type.

Posterior tibial tendinitis

The primary objective for posterior tibial tendinitis is to minimize the excessive pronation that frequently precipitates and exacerbates this condition. Over-the-counter full length insoles modified with medial posting in rearfoot, arch, or forefoot locations, or in some cases just an arch support, may help to minimize tendon stress due to excessive subtalar or midtarsal pronation. Pressure relief for any associated tenderness in the area of the navicular tuberosity may also be necessary. More severe cases may require a TCO with firm posting material in the medial rearfoot, arch, or forefoot. Viscoelastic polymer material, silicon, or polyurethane may be added to the TCO along the course of the posterior tibial tendon and under the navicular. The shoe recommendation for the pes planus foot type is also appropriate for posterior tibial tendinitis, and should include a reinforced heel counter and medial midsole; a medial flare may also be added.

Peroneal tendinitis

With peroneal tendinitis, the objectives are to balance the foot to decrease pressure on the affected tendon and, in most cases, to relieve excessive supination. Pressure relief may also be necessary for any tenderness at the base of the fifth metatarsal. An over-the-counter insole with lateral support in the midfoot and rearfoot may be helpful. As stated previously, if the premade insole is not effective, a TCO posted laterally in the heel and possibly the forefoot can be used. Viscoelastic polymer, silicon, or polyurethane can also be added to the TCO for extra pressure relief along the course of the tendon and under the fifth metatarsal. The addition of a lateral flare to a shoe with a strong lateral heel counter may assist in further reduction of supination (Fig. 3).

In some cases, peroneal tendinitis and associated tenderness at the tip of the lateral malleolus may be a result of the tendons being pinched between the lateral calcaneus and tip of the fibula as a result of rearfoot valgus or excessive pronation. Orthoses and footwear management would be similar to that described previously for a pes planus foot.

Plantar fasciitis

The primary objective when treating plantar fasciitis is to minimize the abnormal mechanical factors associated with irritation of the plantar fascia, particularly in the region of the medial calcaneal tubercle. Because plantar fasciitis can be associated with both the pes cavus and pes planus foot structures, orthoses

Fig. 3. Lateral flare on athletic shoe.

and footwear modifications aimed at minimizing the abnormal supination or pronation associated with these foot types may also be effective in reducing stress on the plantar fascia. Variable success has been reported using over-the-counter heel wedges, heel cups, arch supports, and full length insoles [29,30]. Custom orthoses may also incorporate a viscoelastic polymer-filled relief at the tender area of the medial calcaneal tubercle. In some cases, a SACH modification to the shoe may offer additional pressure relief (Fig. 4).

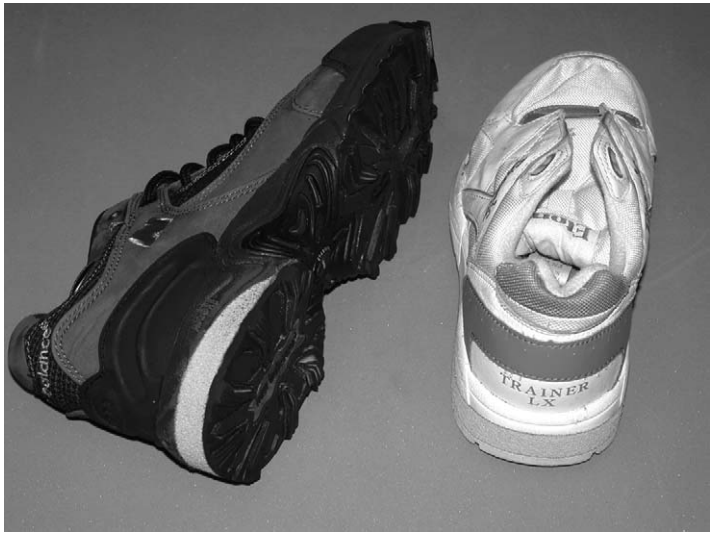

Fig. 4. An example of how an athletic shoe can be modified with a SACH heel.

Achilles tendinitis

The primary objective in treating Achilles tendinitis is to reduce tension on the Achilles tendon. This reduction can be accomplished using a firm heel cushion that actually lifts the heel. Heel elevation can also be placed in the shoe to minimize the strain on the Achilles tendon. In more chronic cases, or when the tendinitis is associated with excessive pronation or an equinus deformity, a custom orthoses with the medial posting modifications previously described for the pes planus foot, in combination with a deep heel cup or cradle, may also be helpful in reducing symptoms.

Haglund's deformity and retrocalcaneal bursitis

The goal for Haglund's deformity and retrocalcaneal bursitis is simply to relieve pressure on the resulting bony prominence or inflamed bursa. A shoe with a heavily padded heel counter that will disperse the pressures may be adequate, or it may be necessary to cut out a portion of the heel counter to provide relief for the irritated area.

Sever's disease

Sever's disease occurs in adolescents, usually as the result of running on hard surfaces or using footwear with poor shock absorption. Tenderness is experienced at the heel and with stretching of the Achilles tendon. Over-the-counter insoles with a good arch support and shock absorption is often adequate when used with footwear that provides heel control and a shock-absorbing sole.

Summary

Foot orthoses have been effective in the treatment of a variety of sport-related foot conditions. Although their use is well-established in clinical practice, many of the orthoses have not been evaluated in experimental conditions. Of the clinical studies that have examined the biomechanical changes associated with their use, many do not have predictable results. The failure of some studies to find trends for a particular variable does not preclude this variable being affected by the orthoses in an individual patient; rather, it may speak to the highly subject-specific responses with orthotic use.

It is important to recognize that foot orthoses cannot be considered independent of a rehabilitation protocol that includes stretching and strengthening-specific therapies, as well as a consideration of training surfaces and training regimes. Additionally, foot orthoses must be considered in concert with the footwear recommendation.

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