The Evolution of Foot Orthoses in Sports—Part 3

American Academy of Podiatric Sports Medicine

Here's a review of the history and research on these devices.

BY KEVIN A. KIRBY, DPM

This is a continuation of a series of sports medicine articles, which were written by members, fellows, board members, and past-presidents of the American Academy of Podiatric Sports Medicine (AAPSM). Excerpts are credited from the evidence-based textbook Athletic Footwear and Orthoses in Sports Medicine, Springer, NY, written by Matthew B. Werd, DPM that includes more than 30 AAPSM chapter-contributing authors. This is the third in a three-part series.

The AAPSM serves to advance the understanding, prevention and management of lower extremity sports and fitness injuries. The Academy believes that providing such knowledge to the profession and the public will optimize enjoyment and safe participation in sports and fitness activities. The Academy accomplishes this mission through professional education, scientific research, public awareness and membership support. For additional information on becoming a member of the AAPSM please visit www.aapsm.org.

Over the last few decades there has been a surge in the quality and number of foot orthosis biomechanics research studies on both athletes and non-athletes.

Editor's Note: *In parts 1 and 2 of this article Dr Kirby presented the historical evolution of foot orthoses, a basic overview of research and theory on orthosis function, and a look at research on therapeutic effectiveness. In this part he discusses research that has been done on the biomechanical effects of foot orthoses.*

Research on the Biomechanical Effects of Foot Orthoses

As mentioned previously in this article, over the last few decades there has been a surge in the quality and number of foot orthosis biomechanics research studies on both athletes and non-athletes. Much of the improvement in the quality of research studies on foot orthoses is likely due to many new technological advances that are now avail-

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able within the modern lower extremity biomechanics laboratory. These facilities are able to perform advanced biomechanical analyses in a relatively short period of time on subjects using accelerometers, force plates, pressure mats, pressure insoles, strain gauges and computerized three-dimensional motion analysis. In addition, advanced computer modelling techniques, such as inverse dynamics analysis and finite element analysis, have allowed researchers to better understand the kinetics of gait and investigate the changes in internal loading forces that occur in feet with different orthosis designs. All of these technological advances have allowed researchers to provide very meaningful insights into how foot orthoses biomechanically produce their significant positive therapeutic effects in the treatment of foot and lower extremity injuries.[21] Since early research on the effects of foot orthoses on running biomechanics showed that there was little to no change in the kinematics of gait function with foot orthoses, many doubted whether foot orthoses had any significant biomechanical effect on the foot and lower extremity of the individual.[65,66,67,68] However, as the sophistication of biomechanics research has progressed over the past few decades, important new research has now demonstrated how foot orthoses may change the mechanical function of the foot and lower extremities and help heal injuries in athletes and non-athletes.[69,70,71,72,73] With the newer, more sophisticated research, the multiple alterations that occur in the internal forces and internal moments (i.e., kinetics) of the lower extremities with foot orthoses can now be determined, which has produced considerable research evidence regarding how foot orthotics may produce their biomechanical effects.

Foot Orthoses Alter Foot and Lower Extremity Kinematics and Kinetics

Foot orthoses have now been conclusively shown to alter the motion patterns (i.e., kinematics) of the foot and lower extremities in numerous scientific research studies. Research has now shown a decrease in maximum rearfoot eversion angle,[65,66,73,74] a decrease in maximum rearfoot eversion velocity,[66,73] a decrease in maximum ankle dorsiflexion angle,[73] a decrease in maximum internal tibial rotation,[72,74,75,76] and a decrease in knee adduction.[72,74,76]

Foot orthotics have also been shown to conclusively alter the internal forces and internal moments (i.e., kinetics) acting on the seg-

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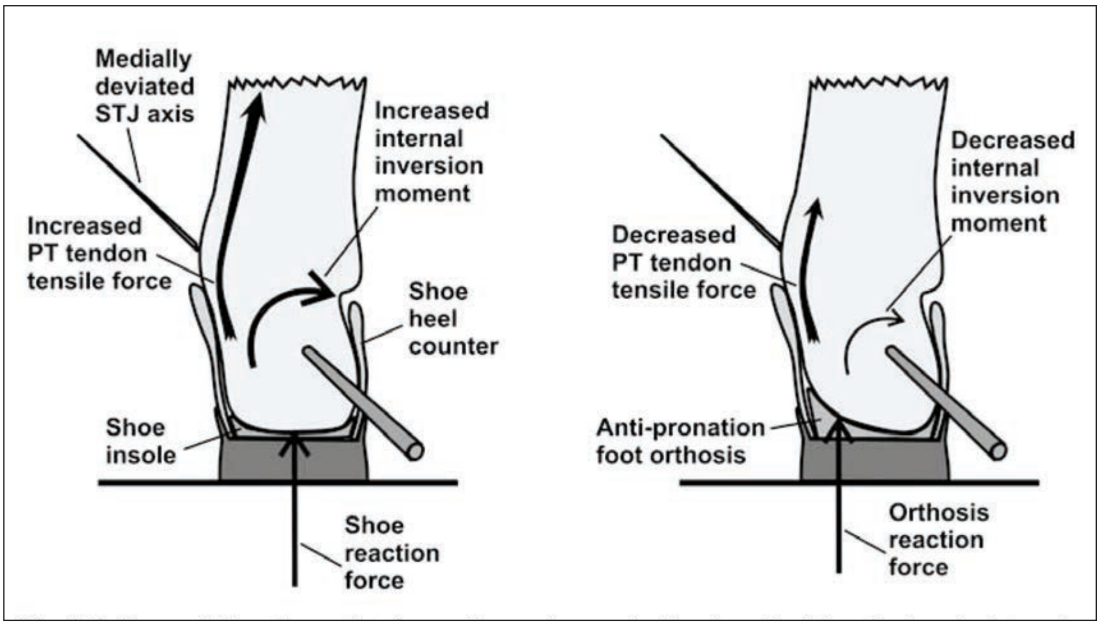

Figure 1: Research has shown that foot orthoses change the kinetics of gait by altering the internal forces acting on the segments of the foot and lower extremity. In the model illustrated above of the posterior aspect of a right foot with a medially deviated STJ axis, when the posterior tibial muscle contracts with increased force to cause increased tensile force on its tendon, an increased internal inversion moment will be measured (left). However, when an anti-pronation custom foot orthosis is designed for the foot to shift the orthosis reaction force more medial on the plantar heel and longitudinal arch, the resultant increase in external STJ supination moment from the orthosis (see Figure 4) will cause a decrease in posterior tibial muscle contractile force and a decrease in tendon tensile force which will also result in a decrease in measured internal inversion moment (right). It is by this proposed mechanism that foot orthoses may relieve symptoms and heal injuries in the athlete and non-athlete but, in doing so, may also cause little change in measured foot and lower extremity gait kinematics.

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ments of the foot and lower extremity during running. Recent research has shown a decrease in maximum internal ankle inversion moment,[71,72,73] (Figure 1) changes in maximum knee external rotation moment[71] and changes in knee abduction moment[72] during running with foot orthoses. In addition, a decrease in impact peak and maximum vertical loading rate was seen in runners treated with foot orthoses.[71]

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In addition to the more prevalent research on the biomechanical effects of foot orthoses on running, recent studies have now shown that these devices significantly affect the biomechanics of walking. Decreased rearfoot pronation and decreased rearfoot pronation velocity with varus-wedged orthoses and increased rearfoot pronation with valgus-wedged orthoses were shown in subjects that walked on both varus-wedged and valgus-wedged foot orthoses.[77,78] In addition, patients with RA that wore foot orthoses for 12 months showed significant reductions in rearfoot eversion and internal tibial rotation.[79] These studies conclusively demonstrate that foot orthoses are able to alter both the motion patterns and internal forces and moments acting within the foot and lower extremity during both running and walking activities. The more recent research on the kinetics and kinematics of foot orthosis function also support the theories mentioned earlier that proposed that foot orthoses work largely by altering the internal forces within the foot and lower extremity by changing the moments acting across the joints of the human locomotor apparatus.[3,18,47,51,54,55,56,59,60,61]

Foot Orthoses Alter Contractile Activity of Lower Extremity Muscles

Research has also shown that foot orthoses significantly affect the contractile activity of muscles during running and other activities. Foot orthotics were found to alter the EMG activity of the biceps femoris and anterior tibial muscles during running[80] and to significantly change the EMG activity of the anterior tibial muscle during walking.[81] Recent research has shown that changes in foot orthosis design may cause significant changes in EMG activity in many of the muscles of the lower extremity during running.[82] A correlation between perceived foot comfort with different types of foot orthoses and the EMG activity of the lower extremity muscles has also been demonstrated.[83]

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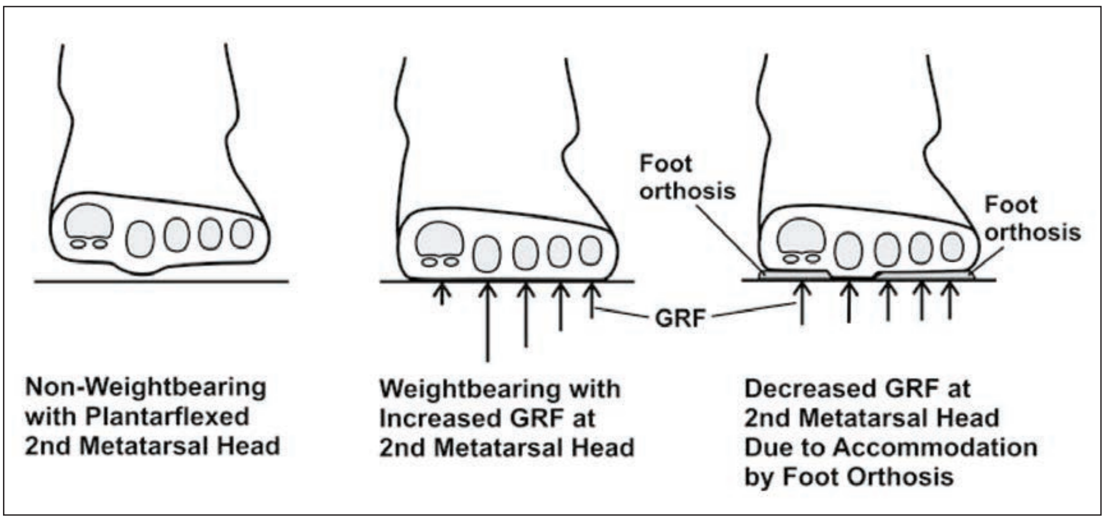

Figure 2: Research has shown that foot orthoses may be designed to reduce the plantar pressures and forces acting on the foot. In the model above, a frontal plane cross-section of the metatarsal heads in a foot with a plantarflexed second metatarsal is illustrated. When the forefoot is close to contacting with the ground, but still is non-weightbearing, the plantarflexion deformity of the 2nd metatarsal is obvious (left). However, once the forefoot becomes weightbearing, the increase in ground reaction force (GRF) that occurs at each of the metatarsal heads will be particularly increased at the 2nd metatarsal head (middle) which may cause injuries to the osseous and/or soft tissue structures of the 2nd metatarsal or 2nd metatarsophalangeal joint. To treat the increased compression forces and stresses at the 2nd metatarsal head, a foot orthosis may be designed to increase the GRF plantar to the 1st, 3rd, 4th and 5th metatarsal heads and decrease the GRF plantar to the 2nd metatarsal head (right). This redistribution of GRF on the plantar foot, away from high pressure areas toward lower pressure areas, is the most likely mechanism behind the ability of foot orthoses to reduce pathologic pressures away from specific areas of the plantar foot.

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Foot Orthoses Improve Postural Stability

There is experimental evidence that foot orthoses can also improve the postural stability of individuals. Postural sway was reduced when subjects wearing foot orthotics were subjected to inversion/eversion and medial/lateral platform movements, which indicated that undesirable motion at the foot and ankle may have been restricted and/or the ability of joint mechanoreceptors to detect motion perturbations may have been enhanced by orthoses.[84] Subjects balancing on one foot were likewise shown to have significant decreases in frontal plane CoP length and velocity with medially posted orthoses—which possibly indicated that foot orthoses enhanced their postural control abilities.[85] In another study involving subjects with excessively pronated feet, foot orthoses produced reductions in medial-lateral sway during bipedal standing, indicating improved balance.[86]

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Foot Orthoses Reduce Plantar Forces and Pressures

Research on the ability of foot orthoses to reduce the forces and pressures on injured or painful areas of the plantar foot provides yet another therapeutic mechanical action of foot orthoses (Figure 2). In a prospective study of 151 subjects with cavus foot deformity, those subjects wearing custom foot orthoses after 3 months showed significant decreases in foot pain, increases in quality of life and showed three times the forefoot plantar pressure reduction when compared to sham insoles.[87] In 42 subjects with metatarsalgia, foot orthoses were found to not only decrease the metatarsal head pain but also significantly decrease the force impulse and peak pressure at the metatarsal heads. Significant reductions in plantar pressures and loading forces were shown in another study that measured the ef-

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fects of foot orthoses on both normal and RA subjects.[89] In 81 patients with Type II diabetes, maximum peak plantar pressures were reduced by 30% with foot orthoses[90] and in 34 adolescent Type I diabetic patients both peak pressure and pressure-time integral was reduced while wearing foot orthotics.[91] In a study of eight patients with plantar neuropathic ulcerations that had become healed with custom foot orthoses, it was found that their custom foot orthoses significantly reduced peak vertical pressure, reduced the pressure/time integral and increased the total contact surface area versus the no-insole condition.[92] In another study using computer-simulated three-dimensional finite element analysis of a foot exposed to different orthosis constructions, orthosis shape was found to be more important in reducing peak plantar pressures than was orthosis stiffness.[93]

Conclusion

Foot orthoses have been used for well over a century by clinicians as a means to reduce pain, improve gait mechanics and heal injury to the foot, lower extremity and lower back. There is considerable research evidence that supports the therapeutic efficacy and significant mechanical effects of foot orthoses on standing, walking and running activities. Theoretical explanations as to how foot orthoses actually produce their therapeutic and mechanical effects have been previously proposed and are being continually refined as exciting new research evidence is brought to light and discussed in academic forums. There is great promise for increased understanding and further development of foot orthoses as a valuable therapeutic tool in the treatment of mechanically-based musculoskeletal injuries for the athletic and non-athletic population of today and for future generations. **PM**

Editor's Note: *The following list of references is for all three parts of Dr. Kirby's article. Part 1 appeared in September 2014; part 2 appeared in February 2015.*

Significant reductions in plantar pressures and loading forces were shown in another study that measured the effects of foot orthoses on both normal and RA subjects.

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