

An Overview of Footwear and Orthotics

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Abstract

Understanding how shoe wear and orthotics affect the biomechanics of the lower extremity is paramount in the treatment of foot and ankle pathology. The technology and products used in footwear and orthotic design continue to evolve. This review covers shoe wear and orthotic design and provides fundamental treatment principles for numerous foot and ankle conditions.

1.1. Footwear

According to a Transparency Market Research published report, the global footwear market was valued over 190 billion U.S. dollars in 2014, and is expected to top 220 billion by 2020. This enormous market has recently seen remarkable changes in shoe design and technology for reasons from fashion to function. Technological advances have allowed for increased customization and specialization of athletic shoes in particular. However, there may still be limitations in patients' abilities to navigate through the seemingly innumerable options to select the option that suits them. For example, a previous survey of cross country runners reported only 57% knew their arch type and only 36% knew their shoe mileage at replacement.¹ Understanding one's arch type and shoe mileage should both be considered when buying a pair of athletic shoes.

1.2. Minimalist Footwear

Epperly and Fields, have previously stated that 31% of running injuries are related to the foot and ankle.² Through a systematic review of the literature, Lopes

was able to determine three of the most common injuries related to running were achilles tendinopathy, plantar fasciopathy, and ankle sprains.³ In hopes of decreasing these large number of running related injuries, a number of design changes have been implemented in athletic shoes. A couple of relatively recent developments include "trail" running shoes and "minimalist style" running shoes. The minimalist style shoes and their possible sequelae have garnered significant attention from the orthopaedic community. A review by Roth, Neumann, and Tao, on "barefoot and minimalist running" presents recent literature on traditional shod running versus the minimalist style as well as a discussion on injury prevention and treatment.⁴ The minimalist style shoe encourages a forefoot strike (FFS) pattern as opposed to the rearfoot strike (RFS) pattern typically employed by distance runners. This is displayed in a study comparing biomechanics in adolescent runners with large heel trainers, track flats, and barefoot. Not surprisingly, the runners landed on their heels nearly 70% of the time while wearing trainers, but around only 30% of the time while wearing the

flats or barefoot. This is evidence that footwear directly influences biomechanics.⁵

FFS pattern can also increase cadence and reduce loading. In a FFS pattern, impact force equals 58% body weight, while the impact force equals 189% body weight in a RFS pattern.⁶ Squadrone and Gallozi, compared barefoot, minimalist, and cushion shod running. They found runners were better able to estimate direction and amplitude of the support slope while wearing a minimalist style shoe.⁷ Minimalist style shoes and the typical FFS pattern they induce have been associated with complications. Salzler et al. presented a retrospective series of injuries in minimalist runners. That series included 10 patients, and 8/10 patient injuries were metatarsal stress fractures.⁸ The popularity of minimalist style running will likely continue to increase as it has been billed as “the natural way to run”, continued investigation of its risks and benefits are warranted.

1.3. Footwear and Sport

Jain et al. looked at injuries sustained and time lost by members of a

European Premier League football team over a four-year period and found foot and ankle injuries accounted for 20% of all injuries sustained. The most common foot and ankle injuries encountered over this time period were injuries to the anterior talofibular ligament (ATFL), 5th metatarsal, and syndesmosis. They plan to continue with this research to develop prevention strategies.⁹ Organizations such as the National Football League have funded research evaluating playing surfaces and shoe wear, in hopes of improving performance and protection for athletes.^{10,11} Ramanathan et al. reported that thicker soles result in a more powerful eversion response from the peroneal muscles to oppose the increasing lever arm at the ankle and subtalar joint complex following sudden foot inversion. They go on to suggest that thicker soles place the lateral ankle ligaments at increased risk for injury if the protective response of the peroneal tendons is overwhelmed.¹²

1.4. Footwear and Fashion

The possibility of footwear playing a role in injury or altered gait biomechanics is not unique to athletic

endeavors. High fashion footwear and its' possible negative affect on foot and ankle kinematics has been previously discussed. Kim et al. found decreased ankle dorsiflexion and eversion in subjects who consistently wore high-heeled shoes compared to those who wore flat shoes. They went on to recommend a stretching program to improve ankle motion for habitual high-heeled shoe wearers.¹³ Powers et al evaluated the ankle kinematics and EMG activity of participants wearing both high heel and low heel shoes. They found significantly greater peak inversion angles and significantly increased peroneus longus activity in the high heeled condition.¹⁴ Hong et al. showed via EMG results that consistent high-heeled shoewear negatively affects muscle control in the quadriceps and paraspinal musculature.¹⁵

Many of the modifications to modern foot wear continue to be driven by customer demand with little to no proven safety or benefit. As the shoe wear industry continues to grow this trend is likely to continue. Further research related to biomechanical and clinical effects of these advancements is warranted.

2.1. Shoe Components

Though technology and material continues to improve, the basic components of the modern shoe have remained fairly consistent. The upper is the top portion of the shoe above the insole that encloses the foot and includes the toe box, quarter, and vamp. The toe box is the most distal portion of the upper that houses the toes. The quarter is the most posterior portion of the upper that covers the hindfoot. The vamp is the mid-portion of the upper that covers the dorsal midfoot. The lower is the bottom portion of the shoe plantar to the foot and includes the insole, midsole, and outsole. The insole is the portion of the lower that makes direct contact with the plantar foot. The outsole is in contact with the ground. The midsole is the area between the insole and outsole.

In the past, shoes were designed primarily with a protective function in mind. More recently, shoes have undergone customization to improve function in specific environments. Research and development driven mostly by market demand has led to an increasing number of shoe options. The available

options cover recreation, vocation, to therapeutic. Now patients with mild foot pathology may be able to obtain pain relief by increased access to off-the-shelf accommodative or corrective shoe wear. Patients with forefoot malalignment have an enormous selection of wide toe-box athletic shoes to choose from which may alleviate pressure and subsequently pain caused by their forefoot deformities. Numerous running shoe manufacturers produce shoe styles with varying degrees of arch support to accommodate athletes with pes planus or pes cavus. These shoes can improve comfort, particularly in active patients with mild planus or cavus. Diabetic patients also have access to therapeutic shoes designed with a soft upper and a cushioned insole to reduce pressure.

2.2. Shoe Modifications

Despite the increased availability of off-the-shelf footwear choices, the orthopaedist still encounters numerous patients who would benefit from further customization of their shoes. Footwear modifications are necessary for a multitude of reasons: increasing stability, increasing ambulatory efficiency, off-

loading areas of high pressure, or compensating for decreased motion. These modifications can involve a single portion of the shoe, such as a flare or shank. A flare is outrigger of sorts to provide extra width to the outsole of the heel for increased stability. The flare can even be offset laterally to help reduce ankle sprains in those with chronic lateral ankle ligament instability. A shank, typically constructed of steel or carbon fiber, is added to the sole to increase stiffness and decrease bending. Rocker soles have extra material added to the midsole of the shoe to create a rocker so the foot can roll from heel strike to toe off. Various types of rockers are available: mild rocker, heel to toe, toe only, and double rocker. The rocker portion typically acts to unload pressure distal to the apex, and must be positioned appropriately so its desired function is realized. The rocker bottom modification can be useful in a number of different situations. A previous study showed the addition of a rocker bottom in those who have previously undergone ankle arthrodesis or use a solid ankle-foot-orthosis could be beneficial.¹⁶ Another recent study evaluated the rocker bottom sole effect on foot kinematics, and

reported a reduced ‘windlass effect’ during rocker bottom use. These findings suggest the rocker bottom sole may be useful in treating plantar fasciitis.¹⁷ In-depth shoes are designed with an extra 0.25 to 0.375-inch depth and readily exchangeable insoles for deformity accommodation. The term “relasting” refers to customizing a standard shoe while maintaining its normal appearance to the casual observer. Custom shoes as the name suggests are customized specifically to the patient by using a mold or CT scan.

While young, active patients may be unaccepting of shoe wear modifications, some alterations may delay surgery in sedentary patients or obviate the need for in high-risk surgical patients. The upper portion of a shoe can be stretched to accommodate a deformity. A “shoe maker’s wand” can be used on the shoe to contour the upper and provide more space for a bony prominence such as a hammertoe or a bunion. The factory insole can be supplemented or replaced. Exchange of a thin standard factory insole with a thick gel, foam, or air-cushioned insole may provide pain relief for a number of conditions. In contrast, other

conditions such as hallux rigidus or midfoot arthritis can be successfully treated with the addition of a carbon fiber plate placed beneath the insole. The increased rigidity provides pain relief by decreasing bending forces and motion at these painful joints. Modifications to offload bony prominences may also be made to the insole of the shoe. A metatarsal bar pad can be positioned to offload the metatarsal heads in cases of metatarsalgia. Insoles can also be modified to correct hindfoot and/or forefoot deformities. Patients with hindfoot valgus may benefit from a medial heel wedge and the varus moment it provides. A previous report showed significantly decreased foot and knee pain in runners with pes planus after the addition of a medial heel wedge.¹⁸ In contrast, patients with hindfoot varus may benefit from the valgus moment a lateral heel wedge provides. This lateral heel wedge can act to reduce stress on the peroneal tendons and provide some protection against lateral instability.¹⁹ Forefoot posting can also affect hindfoot positioning (Figure 1). For example, medial forefoot posting in the patient with pes planus and associated forefoot varus

can decrease the valgus force on the hindfoot while a lateral forefoot post in a patient with pes cavus and plantar flexed

first ray decreases the varus force on the hindfoot.

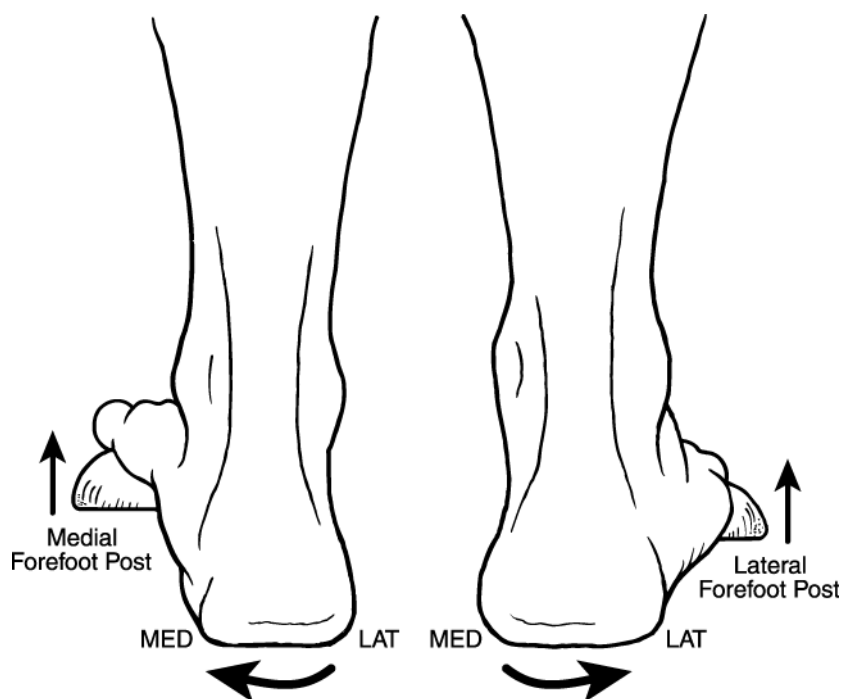


Figure 1: Medial or lateral forefoot posting accommodates a forefoot deformity. This accommodation can decrease the force transferred to the hindfoot.

3.1. Orthotic Basics

An orthosis is used to support, align, or prevent deformities and to improve gait kinematics. Numerous types are available for use at the discretion of the treating physician. An understanding of orthosis terminology and applications allows the orthopaedist to effectively communicate with the patient and orthotist. This communication is paramount to proper fabrication and treatment. Commonly, the

experienced orthotist brings his or her own treatment methods to the process. The first step in orthosis fabrication is a determination of the desired function. An orthosis is typically prescribed to alter the kinematics of the foot and ankle or to provide pain relief through pressure redistribution. The clinician should designate the function of the orthosis as accommodative, supportive, or corrective. An accommodative orthosis is typically

fabricated with cushioned material and contoured to intimately mimic the patient's anatomy to redistribute pressure along the plantar aspect of the foot. A supportive orthosis is constructed to stabilize a flexible deformity. An example would be an arch support used for the treatment of a flexible flatfoot. A corrective orthosis is manufactured to alter the alignment and biomechanics of the foot and ankle. Numerous materials are at the orthotist's disposal during orthosis fabrication. These materials can vary tremendously in their physical properties. Orthotists will commonly use molded thermoplastic to provide the overall shape of the orthosis and incorporate softer materials to provide cushioning. The orthotist can also alter the orthosis length at the request of the physician as well. A full length orthosis extends to the tip of the toes, a sulcus length orthosis extends to the base of the toes, and a $\frac{3}{4}$ length orthosis ends proximal to the metatarsal heads. The location of the pathology often

dictates orthosis length. Ankle and hindfoot pathology typically be treated with a $\frac{3}{4}$ length orthosis, but when forefoot posting is desired, a full length or sulcus length orthosis may be required.

A foot orthosis (FO) extends from the heel to the forefoot area while an ankle-foot orthosis (AFO) extends above the ankle joint. However, not all pathology located in the midfoot or hindfoot can be adequately treated with a foot orthosis. Some midfoot and hindfoot pathologies, such as midfoot or subtalar arthritis, requires an AFO to fully control the pathology. In these instances, an articulating AFO can be utilized to preserve ankle plantarflexion and dorsiflexion while simultaneously limiting hindfoot inversion and eversion. The use of an articulating AFO (Figure 2a and 2b) to control varus and valgus stress across the ankle and subtalar joint can be considered when treating posterior tibial or peroneal tendon injury.²⁰





Figure 2a & 2b: An articulating AFO controls coronal plane motion of the ankle and subtalar joints while allowing sagittal plane ankle motion.

A solid AFO (Figure 3) restricts ankle motion in the sagittal plane as well, and can be used to treat ankle arthritis. A

wrap across the dorsum of the midfoot can be incorporated onto the foot plate of an AFO to add more rotational control.



Figure 3: A solid AFO restricts ankle motion in the sagittal plane.

3.2. Orthotic Efficacy

A great deal of research has been performed on AFO use in stroke patients. A recent meta-analysis on the effect of AFOs on gait biomechanics in stroke survivors included twenty studies and found AFOs improved ankle kinematics and lowered energy cost.²¹ Another

systematic review of AFO use in stroke patients suggests AFOs generally result in improved gait velocity.²² An interesting trial by Zissimopoulos et al compared balance confidence in poststroke hemiplegics with and without an AFO. They found balance confidence was significantly higher with AFO use. This is important because balance confidence is

likely related to patient participation and activity level.²³

Numerous studies designed to evaluate orthosis efficacy have been published. One review of eleven randomized controlled trials found custom orthoses may produce clinically significant improvements in select patients. They found custom foot orthoses provided some benefit in juvenile idiopathic arthritis (JIA), rheumatoid arthritis, hallux valgus, and pes cavus deformities. They also found surgical intervention was superior to orthoses for treatment of hallux valgus deformities. The review also found outcomes in treatment of JIA with prefabricated or custom orthoses were equivocal.²⁴

An abundance of literature is available on the use of orthoses in treatment of plantar fasciitis. Two recent publications comparing the use of custom versus prefabricated orthoses in the treatment of plantar fasciitis showed both were just as effective at providing pain relief.^{25,26} In another study, the authors found the addition of a rocker sole to a foot orthoses was even more effective in relieving pain.²⁷ A recent study has also

looked at the use of an anterior or posterior nighttime AFO in the treatment of plantar fasciitis. In this study, patients reported that both decreased morning pain and stiffness, but the anterior orthosis was more tolerable at night and provided more significant pain in the morning.²⁸

Though not as prevalent as plantar fasciitis, ankle ligament instability is a common and debilitating malady. A comprehensive literature review on the use of foot orthoses in the treatment of lateral ankle instability suggests improved neuromuscular control and somatosensory feedback are results of orthosis use.²⁹ Another study looking at lateral ankle instability in cavovarus feet found an orthosis with a lateral forefoot ramp and a recess for the first metatarsal head diminished ankle instability. This orthosis functioned to decrease the typical forefoot driven hindfoot varus moment.¹⁹

Not all pathology has been shown to respond to orthosis use. One study looked at hallux valgus deformity progression in female patients randomized to an orthosis group or non orthosis group. They found no significant difference in hallux valgus and intermetatarsal angles at final follow-

up.³⁰ In a biomechanical study, Doty et al. found the use of a full length or sulcus length orthosis in patients with a hallux valgus deformity may actually increase medial pressure, and subsequently could worsen pain.³¹

Conclusions

Footwear and orthotics continue to evolve as technology improves. The

practicing orthopaedist should understand the biomechanics of varying orthotics to effectively treat diverse patient populations. This understanding of biomechanics can be coupled with knowledge of current literature to provide patients with optimal care.

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