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Foot and Ankle

Biomechanical basis of foot orthotic prescription

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Foot orthoses are prescribed to improve posture in the foot and ankle. The decade of the 1980s witnessed the widespread use of foot orthoses in an attempt to produce relief of a variety of symptoms in the foot and leg and pathologies due to hindfoot and/or forefoot malalignments. While it is documented that many overuse injuries of the lower limb can be relieved with the use of foot orthoses, it remains unclear how an orthosis can produce this effect. The following review examines the use of foot orthoses in various foot pathologies and their relationship to the biomechanics of the foot. © 2000 Harcourt Publishers Ltd

INTRODUCTION

Whitman (1889) is thought to be the father of modern functional foot orthoses.[1] He used a metal sheet brace to treat pes plano-vagus. Whitman's intention was to motivate the patient to keep the foot in its neutral position. He believed when wearing the device, pressure at the talar head would cause the patient to pull away from the brace; thus the foot posture would be overcorrected by voluntary muscle activity and eventually the plate could be discarded.

Roberts (1915) developed Whitman's device and increased the depth of the medial flange in an attempt to supinate the hind-foot using a varus wedge.[2] The Whitman–Roberts orthosis, using the deep inverted heel cup with the medial-lateral flanges, maintains the heel in a vertical position and stimulates supination.[3] Both investigators attributed the aetiology of the overpronated foot to muscular weakness. This theory was based on the false belief that muscles were the prime supporters of the arch on weight bearing, and that in pronation of the foot they were weak.

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The 1950s heralded a greater understanding of lower extremity biomechanics and increased interest in foot orthoses. Several authors reported the association between subtalar motion and tibial rotation[4–6] including Rose (1962) who, having applied the basic principles of biomechanics as suggested by the previous authors, constructed a model of the foot incorporating the axes of the ankle, subtalar joint, first and fifth rays.[7] This model is very important as hind-foot control can be obtained not only by using a hind-foot post, but with a combined forefoot post which encases the hind-foot and mid-foot together.

In 1966, Root used the principles of Rose to develop the concept of functional foot orthoses which are still firmly established as the standard for foot orthoses used today.[8] The basic principle is to maintain the subtalar joint (STJ) as close to its neutral position as possible during the mid-stance phase of gait by use of intrinsically (inside the orthosis) or extrinsically (outside the orthosis) placed wedges or posts.

However, in situations where large deformities or excessive subtalar pronation existed the Root functional orthosis failed to achieve a full control. Thus numerous researchers and orthotic laboratories have tried to accommodate the problem of large deformities using the improved method of positive cast correction. The most important design was introduced by Blake (1986) and his device is referred to in the literature as the 'inverted functional orthosis'.[9] The 'inverted functional orthosis' design aims to control excessive subtalar pronation. Other designs developed include 'the polysectional triaxial posting' method (positive cast is separated in three areas the hind-foot, mid-foot and forefoot and separate posts are placed in each area) that allows more complete accommodation of foot deformities,[10] the functional foot orthosis described by Dannanberg[11] for hallux rigidus deformity, the so called Kinetic Wedge Insole (an insole with a first ray cut out which allows plantarflexion of the first ray), and finally the Kirby method (the medial heel skive technique)[12] that allows foot orthosis modification enhancing the posture of the excessively pronated foot.

In general terms today the construction of functional foot orthosis is based on the Root, the inverted functional orthosis and Kinetic Wedge Insole principles (Fig. 1). These innovations have proved useful in the construction of a functional foot orthosis but there is a controversy about the optimal material and fabrication technique from which functional foot orthosis should be made. Overall the success of a functional orthotic device depends on clinical examination of the foot pathology, the biomechanical examination, the fabrication technique, the casting technique, and the education of the patient.

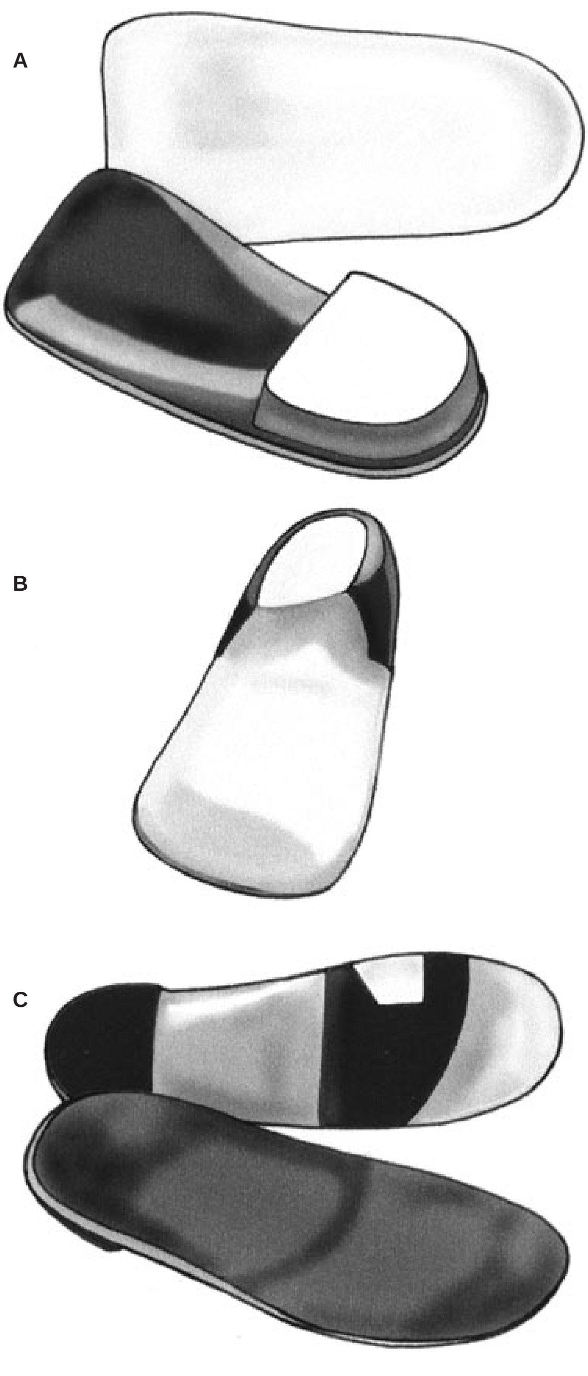

Fig. 1 (A) The Root orthosis. (B) The inverted functional orthosis. (C) The Kinetic Wedge Insole.

BIOMECHANICS

Pronation and supination are important in determining whether the foot will behave as a flexible or rigid structure during the gait cycle (Fig. 2). When the foot meets the ground, pronation is produced by simultaneously everting the calcaneus then adducting and plantarflexing the talus while supination occurs through the opposite movement of calcaneal inversion.[13–16]

If inversion contracture of the forefoot upon the rear-foot occurs at the midtarsal joint, this is called forefoot supinatus. This contracture is often mistaken for an inverted forefoot. If the STJ has developed in such a way and the rear-foot is in an everted or inverted position when the foot is neutral this is referred to as an everted or inverted rear-foot respectively (Fig. 3). Excessive and prolonged pronation or supination causes abnormal delay in external/internal rotation resulting in various symptoms in the lower leg. Therefore, a less efficient and a less powerful gait is one consequence of these biomechanical deformities, which can produce overuse syndromes.[17,18]

For gait abnormalities generated in the foot or in the leg itself compensation has to take place. Compensation in these circumstances is a change of structure, position or function of one part of the body in any attempt to adjust to a deviation of structure, position or function of another part. Normal compensation is that motion of the foot (within the limits of the range of motion of the joints) that adjusts to any irregularities of the supporting surface or to deviations in the position of any part of the trunk or lower extremity. Abnormal compensation is that motion in which the foot moves to adjust for abnormal structure or function of the trunk or lower extremity. Structural or positional abnormalities create a recurrent or persistent demand for compensation that may result in pathology.[19] From a practical viewpoint, when structural deformities exist in the foot, normal and abnormal compensation is accomplished by STJ and midtarsal joint (MTJ) motion. STJ compensation provides the motion needed to minimize the disruption of human locomotion created by the foot deformities.

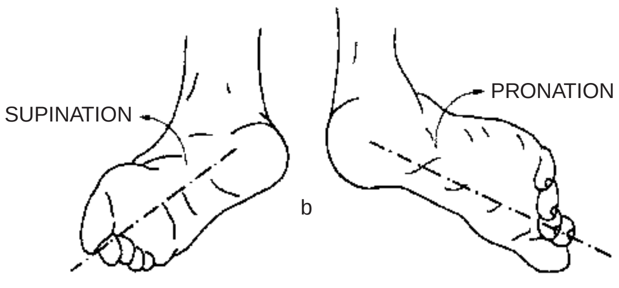

Fig. 2 Supination—pronation movements permitted by the subtalar and talocalcaneonavicular joints. In supination the sole of the foot moves in a medial direction; in pronation the sole of the foot moves in a lateral direction.

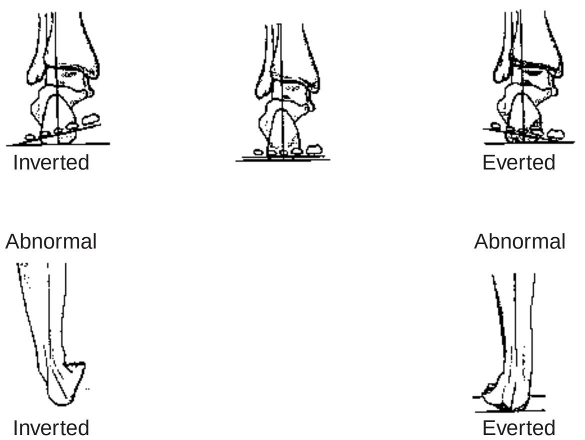

Fig. 3 In the normal foot the horizontal plane of the forefoot is perpendicular to the heel with the subtalar joint in the neutral position. In inversion there is a combination of supination and forefoot adduction. In eversion there is a combination of pronation and forefoot abduction.

It is generally accepted that foot orthoses most affect the stance phase of the gait cycle, comprizing 60% of the total gait cycle, and functional foot orthoses are used to correct or compensate for biomechanical abnormality at points throughout this weight-bearing chain. Thus, to be able to assess exactly what position is required for foot casting and orthotic prescription, the interrelationship between the foot and the ground and between the foot and its proximal segments is essential. For this to be gained requires a through measurement of the foot and leg statically and dynamically.

LOWER LEG PROBLEMS AND FOOT ORTHOSES

The authors do not intend to describe every possible treatment in detail to the reader as there are many textbooks that fully describe therapeutic techniques to which the reader can be directed. This article reviews the orthotic treatment available for conservative management of common foot disorders: flat feet, neuromuscular disorders, metatarsalgia and various forms of foot tendonitis such as plantar fasciitis, Achilles, tibialis posterior or tibialis anterior and peroneal tendonitis.

Flatfoot

The arch of the foot can be made to disappear in two ways: the whole structure can simply collapse in a sagittal plane (type 1), or the foot can rotate so that the arch seems to disappear (hyperpronated foot or flexible flatfoot) (type 2). The type 1 is relatively uncommon and gives no symptoms other than anxiety to those relatives who notice that the foot is flat. Arch supports are of no benefit.

The hyperpronated foot is another matter altogether. The main cause is generalized joint hypermobility with tightness of various posterior leg muscle groups such as the gastrosoleus complex. At preschool age treatment consists of application of an ankle foot orthosis or a functional foot orthosis. In older children application of a functional orthosis is indicated in order to maintain the foot in the neutral position while growth takes place. If it remains untreated, the hyperpronated foot may become fixed. The use of orthotic treatment in children under 6 years of age is a controversial issue. The work of Elfman[20] in the early part of the 20th century has led to the view that an orthosis can prevent normal valgus rotation of the talar head and neck, creating an inverted forefoot. McPoil et al disputed the connection between talar neck rotation and inverted forefoot[21] and Penneau et al seriously questioned the value of the longitudinal arch orthosis.[22]

It must be emphasized however that functional foot orthoses have never been claimed to improve the arch. Personal experience shows that functional foot orthoses based on the inverted technique are of great value in the treatment of hyperpronated feet when treatment is started at 16 months of age and before 2.5 years old. The success rate becomes very low when therapy starts above the age of 4 years. Ironically, the orthopaedic literature often supports leaving hyperpronated feet untreated until the age of four. Some hyperpronated feet resolve spontaneously with growth by the age of 10. This is not universal and not all hyperpronated feet correct in this way. Another important parameter that is often overlooked is that most doctors suggest barefoot walking for the treatment of hyperpronated feet. Personal experience suggests the opposite but more research is needed for this to be proved scientifically.

Neuromuscular disorders

For the purpose of this article, we classify neurological disorders according to the level of pathology in the neuromuscular axis and start by considering the myopathies. This includes proximal myopathies (muscular dystrophy), distal myopathies (infant/late onset and distal muscular dystrophy) and alcoholic myopathies. Myopathy also refers to any disease affecting muscle, especially weakness of the proximal muscles, which changes the gait style by alterations in hip and lateral trunk movements. Usually, orthotic treatment is based on ankle foot orthoses rather than functional foot orthoses. Personal experience suggests that in the early stages of myopathy, even in Duchenne patients, excellent control can be achieved by means of functional foot orthoses.

Plantar fasciitis

In this condition, there is pain beneath the anterior part of the calcaneus due to overstress of the plantar fascia.[23] Symptoms may or may not be associated with a radiologically demonstrable calcaneal spur. Irritation of the plantar fascia, principally involving the medial slip, is commonly demonstrated in patients with fore-foot abduction (pes planus) or inherent tightness of the fascia (pes cavus). Morning heel pain is one of the common symptoms. Plantar fasciitis is associated with a partially uncompensated inverted rear-foot or forefoot, compensated inverted rear-foot or forefoot, flexible or rigid everted forefoot and rear-foot equinus, which increases forefoot loading, which in turn increases loading on the plantar fascia, particularly in pes valgus. Treatment of this condition involves oral medication, injection, foot orthotics, physical therapy, cryotherapy, ultrasound and laser therapy.[24–26] Orthotic treatment is based on the control of rotational movements of the forefoot using soft functional foot orthoses or taping rather than controlling the tension of the plantar fascia.[27] Accommodative foot orthoses may be considered for relief of the tender areas and increasing the weight bearing by increasing the contact area.

Metatarsalgia

This inflammatory reaction generally affects the plantar aspect of the foot, especially the second and third metatarsal joints. Plantar pain at the level of the specific joints involved, with erythema and oedema, may be noted. As symptoms are exacerbated by weight bearing and activity, with pain being present primarily in the early propulsive gait, accommodative or functional foot orthoses are prescribed when the cause of this pathology is due to a fixed or flexible foot function. In the case of Morton's metatarsalgia or Morton's neuroma there is an affection of a digital nerve, characterized typically by metatarsal pain combined with a radiating pain (burning paraesthesia-numbness) in the third and fourth toes.[28] Less commonly this can occur between the second-third and fourth-fifth metatarsals. Pain in the forefoot during standing or walking is a typical symptom. Relief of pain can be achieved by taking the shoe off, then squeezing and massaging the forefoot. These symptoms suggest a mechanical problem of the foot due to rotational movements of the forefoot. Excessive rotational and transverse movements between the two rays contribute to formation of a fibrous thickening to the nerve distal to the edge of the intermetatarsal ligament. Interdigital neuritis is associated with forefoot inversion or eversion, a hypermobile first ray, partially compensated rear-foot inversion and equinus deformity. Orthotic treatment is based on the control of rotational movements of the forefoot using functional foot orthoses. Transverse movements are very difficult to control by means of functional foot orthoses. A metatarsal pad is another option and can also help by causing increased dorsiflexion of the metatarsals and therefore proximal phalanx plantarflexion, which decreases the angulation of the digital nerves as they course underneath the distal edge of the intermetatarsal ligament. In a report by Mann and Reynolds,[29] 50% of patients studied found their neuroma symptoms were relieved by an orthotic insole. Only 20% of the remainder required surgery. Gaynor et al[30] suggested that orthotic therapy is very successful when an underlying biomechanical anomaly is the cause of this pathology. The authors suggests that treatment by means of a functional foot orthosis is very successful in the early stages of the pathology, otherwise more than a month of treatment may be needed in chronic cases to alleviate the symptoms and even then the treatment is not always successful.

Tendonitis

This is an inflammation of a tendon, which may be caused by overuse or compensation. In most cases tendonitis is strongly related to abnormal function of the lower extremity.

Achilles tendonitis is a painful inflammatory reaction with or without swelling around the Achilles tendon.[31,32] Inflammation of this area may be caused by a congenitally tight or functionally contracted gastrocnemius-soleus complex. As this tendon does not have a true synovial sheath but is surrounded by a paratenon, an acute case of Achilles tendonitis involves the paratenon rather than the tendon itself. In more chronic cases of this condition, microtears of the tendon occur and scar tissue forms in the body of the tendon. This condition may be associated with a totally or partially compensated inverted forefoot, flexible everted forefoot and congenital gastrocnemius equinus. Functional foot orthoses dramatically improve function and reduce symptoms as in this tendonitis the gastro-soleus complex tends to contract over a longer period of time in attempting to reduce abnormal pronation. In chronic Achilles tendonitis, maintaining the heel in a vertical position will reduce symptoms but a stretching and physiotherapy programme is also necessary.

Tibialis anterior tendonitis is characterized by pain in the anterior aspect of the ankle.[15] It is associated with compensation for overpronation as the tibialis anterior is one of the major invertors of the foot. This condition may also occur as an attempt is made to supinate the foot to offload the medial plantar part of the foot such as forefoot supinatus, totally or par tially compensated inverted forefoot, flexible everted forefoot and compensated gastrocnemius equinus. Functional foot orthoses are always capable of reducing progression of symptoms.

In peroneal tendonitis pain is present at the tip of the lateral malleolus due to a valgus hind-foot, the tendons being pinched between the lateral wall of the calcaneus and the tip of the fibula. Lateral compartment syndrome refers to symptoms more proximally in the calf. This condition typically occurs in persons with a hyperpronated foot, lateral peroneal nerve dysfunction in an unbalanced peroneus longus-tibialis posterior pulley system, an inverted rear-foot, flexible ankles, uncompensated inverted rear-foot or forefoot and flexible or rigid everted forefoot. Orthoses are usually very successful and by putting the heel in the vertical position this increases the overall stability of the foot.

Tibialis posterior tendonitis is characterized by pain posterior and inferior to the medial malleolus or at the insertion of the navicular, which usually is associated with an enlarged navicular tuberosity. This condition is generally found in persons with hyperpronated feet. As the foot pronates more than normal, the tibialis posterior tendon pulls harder at its insertion at the navicular to supinate the foot during the gait cycle as it is the major invertor of the foot. Lowering of the medial arch, forefoot abduction and excessive calcaneal eversion are the basic signs of this condition. Other deformities associated with this condition are totally or partially compensated inverted forefoot, flexible everted forefoot and compensated gastrocnemius equinus. Orthotic management of the tendonitis caused by the abnormal function of the foot where the muscles must work harder and longer attempts to reduce the abnormal movements of the foot due to excessive subtalar or midtarsal pronation. Thus functional foot orthoses in combination with high top boots or even an ankle foot orthosis could be used to reduce frontal plane motion of the rear-foot and forefoot. It should be mentioned that in uncompensated inverted deformity or marked sagittal plane congenital anomaly cases, orthoses do not control symptoms and surgical intervention is recommended.

We believe that all the pathological conditions presented in this paper are related to abnormal function of the foot which is a mechanical problem. All are capable of being treated effectively using mechanical treatment via a functional or an accommodative foot orthosis. In cases where the pathological conditions do not respond to the use of foot orthosis, surgical intervention may be necessary. Finally, postoperative use of foot orthoses should be considered to avoid recurrence of the pathology or restore the normal function of the foot.

CONCLUSION

The use of functional foot orthoses has been remarkably successful in the treatment of a range of lower limb pathologies.[33,34] Relief from pain and the ability to return to previous levels of activity are the major criteria for determining success with orthotic therapy. Also of note, in a review of the literature, is the near absence of reports regarding complications resulting from the use of functional foot orthoses.[35,36] This may be because patients simply remove an uncomfortable orthosis before any injury occurs. It is also possible that some patients are not wearing foot orthoses as long as required because instant success is not achieved. Footwear is another important consideration for failure of foot orthoses. Generally, it is thought that shoes with different designs and material properties act like an orthosis because they prevent hyperpronation. Lack of education of the patient also seems to be one of the factors causing failure. Thus, it is very difficult to draw conclusions about an incorrect design for a specific foot pathology.

Although the use of orthoses is well established within the clinical practice of the orthopaedic surgeons, podiatrists and physiotherapists, most of the orthotic treatment plans have had no scientific testing to evaluate their performance. While some designs are successful in treating certain foot disorders, many orthoses do not have predictable results. It is therefore obvious that a good understanding of the amount of control obtained through orthotic treatment should be available in order to make medical decisions more reliable. Since 30% of the current £38 million budget for orthoses in NHS is spent on foot orthoses further research is necessary to reduce unit cost and justify the use of these devices.[37] Future studies using a more advanced three dimensional kinematic analysis system, synchronized with an appropriate kinetic and EMG system, may be useful in resolving questions and controversy in the subject.

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