

Update in pedorthics and orthotics designs, advance in materials

Raymond Fritz and Ann C. Anderson

Purpose of review

To review the literature findings from the past 5 years regarding materials and methods for foot orthotic fabrication.

Recent findings

Minimal advances have been obtained within the past 5 years regarding orthotic materials and design techniques. Many studies are unclear as to the benefit of orthotic therapy for pathology of the foot and ankle.

Summary

The continuing controversy surrounding orthotic efficacy must be addressed with additional research to advance orthotic designs and gain scientific evidence to support the benefit of foot orthotic therapy.

Keywords

foot orthotics, orthotic materials, orthotics

Curr Opin Orthop 18:145–152. © 2007 Lippincott Williams & Wilkins.

Allentown Family Foot Care, P.C., Allentown, Pennsylvania, USA

Correspondence to Raymond Fritz, Allentown Family Foot Care, P.C., 1633 North 26th Street, Allentown, PA 18104, USA
Tel: +1 610 434 7000; e-mail: rfritz@affc.com

Current Opinion in Orthopaedics 2007, 18:145–152

© 2007 Lippincott Williams & Wilkins
1041-9918

Introduction

Foot orthotic devices have been around for centuries. Hippocrates wrote about technical devices for foot ailments in 400 BC [1]. The interest in shoe devices, arch supports and foot orthoses has increased over the last century. This multimillion dollar industry continues to grow and expand worldwide at a rapid pace [2].

With the growing popularity of foot orthoses comes increased interest in providing these services. The podiatric community was the premier advocate for the functional orthotic based on the Root theory [3]. With the heightened interest in treatment of foot and ankle pathology by other specialties, orthotics are now commonly prescribed by podiatric physicians, orthopedic surgeons, pedorthists, physical therapists, chiropractors, orthotists and other sports clinicians. Each specialty incorporates its own theory into orthotic design, which is evident from the multitude of practitioners performing research on orthotic materials and design [4].

In spite of the many technological advances in computer-aided casting techniques and orthotic fabrication techniques, there have been few advances in the materials used for orthotic fabrication. Even with advances in methodology, the materials used for orthotic fabrication have remained unchanged over the last 5 years. It is evident that over the past 100 years the old leather and cork composite orthotics have been replaced by newer, heat-moldable materials. The following discussion will review the more commonly used materials and recommendations for orthotic devices to address specific foot and ankle pathology.

Types (uses) of orthotics

Orthotic efficacy and theory are questioned by studies that arrive at inconsistent conclusions [5,6]. Many studies conclude that kinematic skeletal changes caused by foot orthotics are 'small, and may not be sufficient to account for the outcomes achieved with foot orthoses' [6,7]. Even in the face of conflict, the literature does support the fact that foot orthotics do reduce pain and provide clinical benefits [4,8–10].

When considering orthotic devices to address patient pathology, it is important to fully evaluate the patient, including pathology, shoe gear, compliance, and so on before fabricating an orthotic device. The subjective response to orthotics is highly variable and individualized. Since orthotics are used to address a wide range of

clinical pathologies, it is important to recognize that communication between patients, clinicians and technicians is important in orthotic device fabrication and effectiveness [11].

Orthotic devices can be used to accommodate foot deformities or modify the function of the foot and lower limb [10]. Accommodative foot orthotics aim to provide cushioning and padding as well as shock absorption during gait, whereas functional orthotics aim to achieve weight-bearing realignment of the foot and lower limb, prevent abnormal motion, redistribute load and provide shock absorption.

Functional orthotics are fabricated from various types of firm, moldable materials to control excessive motion of the foot throughout gait. (Figs 1 and 2). Polymers such as polypropylene, carbon fiber graphite and acrylics are used for functional orthotic fabrication. Specific products such as TL-2100, TL-Blue, carboplast as well as polypropylene are manufactured in varying thicknesses to produce a semi-flexible to rigid device. Many practitioners recommend these materials to treat conditions such as flexible flatfoot, tibialis posterior tendon dysfunction, tendonitis and plantar fasciitis [11].

Accommodative orthotics are fabricated with softer materials of various densities (Fig. 3). The goal of accommodative devices is to direct pressure away from problem areas by redistributing weight over a greater surface area. An accommodative device is most often recommended for patients with diabetes with insensate feet and patients with severe osseous deformities that need reduction of pressure over bony prominences.

Figure 1 Functional orthotic



TL-2100 semi-rigid orthotic with full-length extension. Courtesy of Jeff Fry Creative Orthotics Laboratories.

Figure 2 Functional orthotic

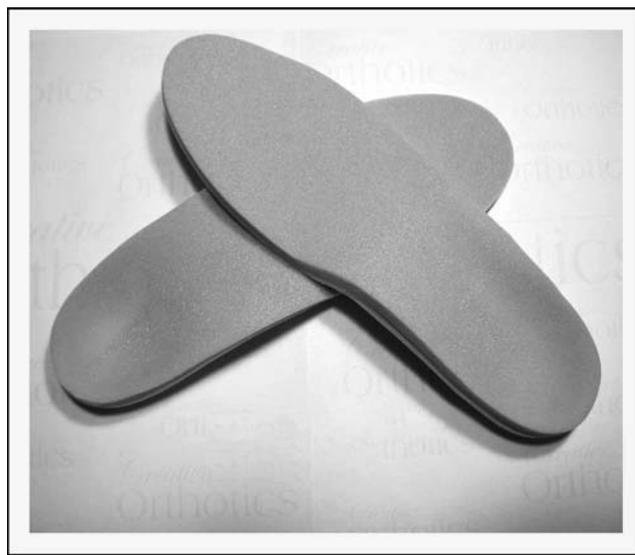


Carboplast II with naugahyde top cover and leather bottom cover.

Shoe selection

Orthotic success is also dependent on shoe recommendation, selection and willingness of the patient to change shoe style. The pedorthic community has stressed the importance of prescribing orthotics and footwear together and, therefore, shoe style must be considered prior to orthotic fabrication. It is important to realize that orthotics do not function independently of footwear and shoe modifications when needed [5]. Patients may impose resistance to change in shoe style and thereby

Figure 3 Accommodative plastizote composite orthotic with porozote top cover



This orthotic is typically used with in-depth shoes for the Medicare Diabetic Shoe bill. Photo courtesy of Dr Raymond Fritz Jr.

influence orthotic design. Ultimately the success and the clinical outcome will depend on the patients and their willingness to accept changes.

Orthotic casting techniques

Patient compliance and outcomes are directly affected by orthotic comfort, fit and functionality. Often, orthotic fabrication labs are blamed when patients cannot tolerate their devices; more likely this is due to provider variability including casting techniques, material selection and patient request. Orthotic return rates to any given lab may vary significantly, which indicates the lack of consistency between providers (Jeff Fry Creative Orthotics Labs, personal communication). It has been shown that the training and experience of the professional obtaining the negative cast improves reliability and consistency of capturing structural relationships in the foot [12]. This reinforces the fact that the casting method is just as important as the orthotic device itself in capturing the intricacies of foot pathology and producing an orthotic device that patients will tolerate.

A custom molded prescription orthotic is a final result of a series of steps whereby materials are pressed and molded on a positive replicated model of a patient's foot (Figs 4 and 5). Traditionally, this positive model was the end result of a negative cast of the patient's feet. Negative casting techniques include nonweight-bearing and partial weight-bearing impressions. There are many materials used to capture a negative cast of the foot, including the traditional plaster, fiberglass stockings and foam. Structural relationships, including arch height, forefoot to rearfoot relationships and foot widths vary with different casting techniques [13]. The different

Figure 4 Positive orthotic mold with forefoot platform, arch and lateral expansion



Photo courtesy of Jeff Fry Creative Orthotics Laboratories.

Figure 5 Vacuum press to heat mold plate material over positive mold



Photo courtesy of Jeff Fry Creative Orthotics Laboratories.

negative impression techniques will influence the final orthotic device.

Based upon the type of orthotic device, that is accommodative versus functional, different casting methods are recommended. It is recommended that functional orthotics be casted using a nonweight-bearing technique, while accommodative devices are casted using a weight-bearing technique [13]. McPoil and Hunt [14] noted that there is a consistent forefoot to rearfoot alignment that is reproducible with nonweight-bearing casting methods which is important for a functional orthotic device. Based upon the research, it is recommended to use a plaster nonweight-bearing casting method as the most reliable and valid method for functional orthotics [13]. The same researchers advocate a partial weight-bearing laser scan method to reliably capture all measurements and produce reproducible rearfoot and forefoot widths for accommodative orthotics.

With the new age of digital technology upon us it is imperative that new studies examine the reliability and accuracy of computerized casting techniques in capturing foot pathology and producing orthotic devices that patients will tolerate.

Materials

There are many factors affecting material selection for orthotic devices, including foot structure, pathology, flexibility, shoe gear, patient activity and provider philosophy. Ultimately patient and provider preference will influence the fabrication of a device that is comfortable, relieves patient symptoms, addresses pathology and encourages patient compliance [10].

Figure 6 Example of functional orthotic made of Polydur amber and fluorescent green acrylic material for rigid control in pediatric cases



Photo courtesy of Jeff Fry Creative Orthotics Laboratories.

Functional orthotic materials such as polypropylene and carbon graphite are recommended for the treatment and control of hyperpronation in the feet due to their semi-rigid and rigid nature. These materials have strength to withstand weight-bearing stress and are able to control foot motion.

Polydur (Fig. 6) is a rigid material that is used successfully for the control of hyperpronation in the pediatric population. Rigid materials have the advantages that they require much less space in shoes with maximal effect. Thin graphite devices are great choices for today's shoe styles when functional control is the primary goal – that is, hyperpronation conditions.

Accommodative materials include EVA, plastizote and PPT and poron. These materials are measured in durometers with the higher number reflecting an increase in the firmness. Accommodative materials are used to reduce pressure under bony deformities and to provide cushioning to rigid foot deformities. Plastizote materials are widely used for the Medicare diabetic shoe program orthotics and inserts in the United States as they are great materials for accommodating bony prominences and reducing high-pressure areas prone to skin breakdown.

Top layer materials can be just as important as the orthotic shell to accommodate and cushion foot pathology and deformity. Top cover choices include naugahyde, natural leather, plastizote and Spenco. These materials

Figure 7 Combination orthotic incorporating functional and accommodative materials



Note the accommodating area in the rigid polypropylene shell for a rigid, bony prominence.

help to cushion bony deformities, reduce shear pressure on the insensate foot and allow for the incorporation of pressure reduction offloading padding into the orthotic device.

There are many ways that materials can be combined to affect foot function and accommodate pathologic deformity (Fig. 7). No one orthotic design will serve every patient's needs, therefore it is unfair to completely categorize orthotics as either functional or accommodative when many orthotics are a combination of materials individualized to patient needs. Combining more rigid and softer materials is important to address multiple, complicated foot deformities that need both structural support and cushioning. Severe pronatory forces must be addressed with a firmer material or shell component that can be combined with a softer, more accommodative top cover to address areas of skin irritation or painful plantar bony prominences (Figs 8 and 9).

Orthotic selection based on foot type

Patients can be classified into three basic foot types, including pes planus, pes cavus and a neutral foot. These foot types are separated by arch height. These general foot type categories are addressed with different types of orthotic devices. It is important to remember that most patients have a combination of rigid and flexible foot pathologies which require a combination of hard and soft materials to address individual pathologies.

Many clinicians choose a functional orthotic for flexible foot deformities with excessive subtalar joint pronation as

Figure 8 Composite orthotic with polypropylene shell and soft materials incorporated above and below the shell

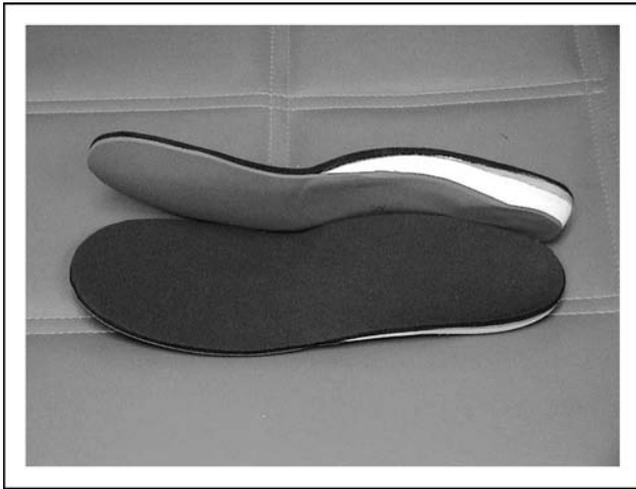


Photo courtesy of Jeff Fry Creative Orthotics Laboratories.

in a flexible, pes planus foot. Rigid materials such as polypropylene and carbon graphite in functional Root orthotic designs have been shown to delay forefoot loading during gait which is effective in controlling excessive pronation [15]. Incorporation of medial arch, medial heel and medial forefoot posting in conjunction with straight-last/motion control footwear with medial midsole reinforcement is recommended for a flexible pes planus type foot [5]. The rigid materials serve to control the excessive motion in the foot throughout gait. Research shows that the use of orthotics in shoes compared with barefoot selectively recruits the tibialis posterior tendon

Figure 9 Orthotic with thin polypropylene shell with layers of surrounding composite material

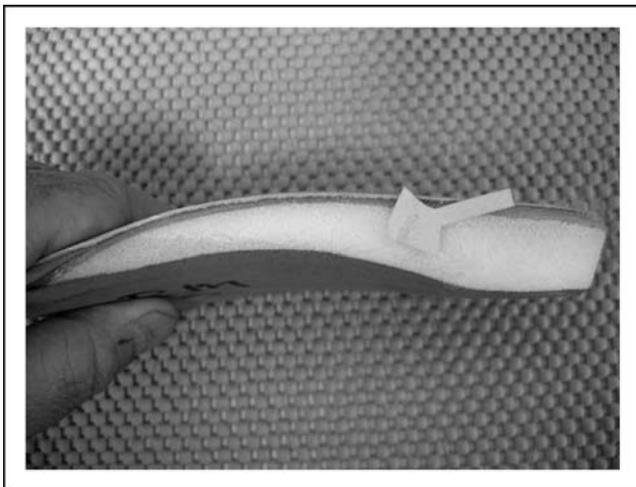


Photo courtesy of Jeff Fry Creative Orthotics Laboratories.

during rehabilitation for strengthening and treatment of tibialis posterior tendon dysfunction [16]. One study [17] suggests that it is not the shell or the posting directed at the subtalar control, but rather the filler under the medial column that may have more influence on controlling pronation [17]. Any medial posting technique is beneficial in controlling hyperpronation [17].

Softer materials are recommended for a high arch, cavus foot type or with rigid foot deformities. Softer materials such as EVA, poron and plastizote have shock-absorbing qualities that can help reduce stress, reduce plantar pressures and provide relief for plantar foot structures [5,18]. Mechanically, the cavus foot with supinatory forces tends to compress a softer orthotic design along the lateral border and eventually, as memory recedes, the foot tends to roll out even more [5].

A total contact orthosis with metatarsal head relief under the first and fifth metatarsal heads with a valgus post is recommended to relieve excess ankle and rear foot supination [5]. A lateral flare can also be added to footwear to reduce subtalar joint inversion and relieve lateral ankle stress [5].

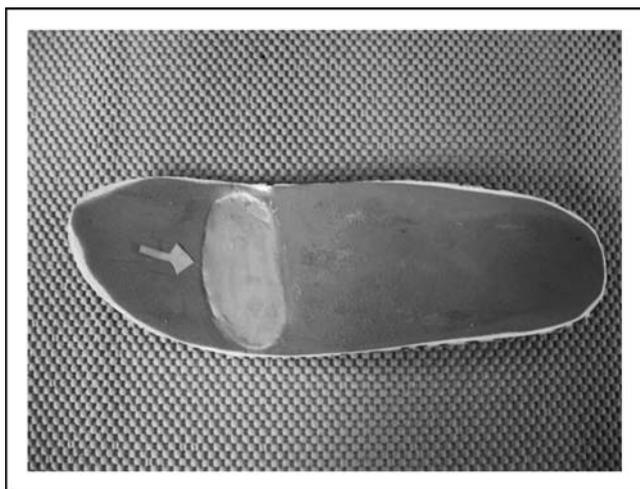
Rigid foot deformity is also best addressed with an accommodative orthotic to cushion and alleviate specific areas of pressure, for example rigid pes planus. Accommodative materials such as plastizote or silicone provide pressure relief when incorporated over a prominent navicular tuberosity [5].

Orthotic selection based on symptom complex and pathology

The patient's symptom complex and specific pathology influence material selection. Various pads and material adaptations are now being incorporated into orthotic devices to address specific symptoms. There are the classic metatarsal pads, heel pads and heel cutouts. Other innovations include silicone-type polymers impregnated into an orthotic to address high-pressure areas. The silicone incorporation or 'sweet spot' is applied directly under a bony prominence or a problem metatarsal head to disperse pressure and provide additional padding (Fig. 10).

Forefoot padding including use of silicone gels, poron, and plastizote materials are recommended for treatment of morton's neuroma, metatarsalgia, metatarsal stress fractures and sesamoiditis. These conditions respond well to increased forefoot cushioning, which provides improved shock absorption and limits excessive pressure on the forefoot [5,19]. Viscoelastic polymers can be incorporated into the orthotic at high-pressure areas to reduce symptomatology. Orthotic devices have been shown to reduce the incidence of stress fractures [19].

Figure 10 Orthotic with silicone polymer used under the metatarsal heads for cushioning



Note that the top cover has been removed. Photo courtesy of Dr Raymond Fritz Jr.

Rigid materials such as polypropylene reinforced with viscoelastic polymers, silicone and polyurethane along the medial column are recommended to control hyperpronation [5]. These materials are recommended for the treatment of hyperpronation conditions such as tibialis posterior tendon dysfunction, pediatric pes planus and plantar fasciitis. Polypropylene orthotic shells are effective in controlling excessive pronation and reducing pain associated with hyperpronation syndromes [20,21]. To address specific pathology, the orthotic shell can be modified. For plantar fasciitis, a cutout over plantar medical calcaneal tubercle filled with a soft material can be incorporated into the orthotic design to reduce direct pressure over the symptomatic area in a functional orthotic [5] (Fig. 11). Much research based on plantar fasciitis has found that mechanical control with both custom and over-the-counter orthotics is effective in reducing pain from plantar fasciitis [21,22].

Orthotic selection based upon sporting activity

Many sports participants report increased injury associated with hyperpronation, increased tibial torsion, increased vertical ground reactive forces, increased ankle inversion moment, increased knee abduction, and increased knee external rotation [5]. These abnormal movements contribute to multiple acute and overuse injuries throughout the athletic community. The goals of orthotic use in the athletic community are to alter the abnormal lower extremity mechanics and patterns of movement [5].

Many sporting activities require specific shoe gear. Biking, skiing and skating often present practitioners

Figure 11 Orthotic with polypropylene shell with a drilled cutout and silicone added to cushion heel

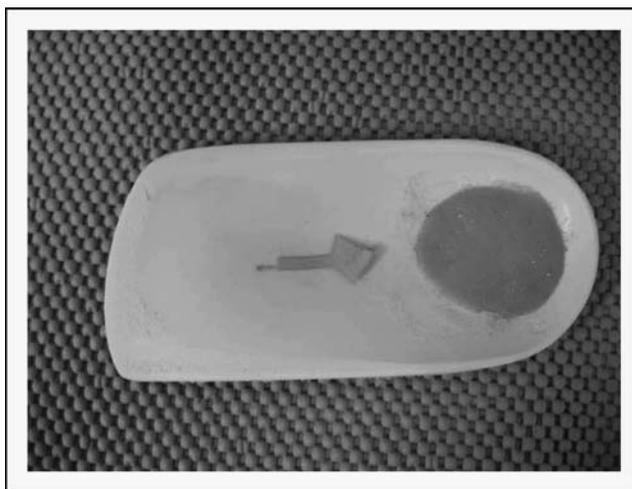


Photo courtesy of Dr Raymond Fritz Jr.

and athletes with space limitations within the shoe. Rigid orthotic devices are favored by athletes and physicians alike because they are effective, can enhance performance and require little volume in the shoe. Ballistic sports with side-to-side as well as jumping movements will benefit from a thin semi-flexible polypropylene or carbon graphite shell [5]. A composite orthotic is recommended for high-impact sporting activities that require shock absorption.

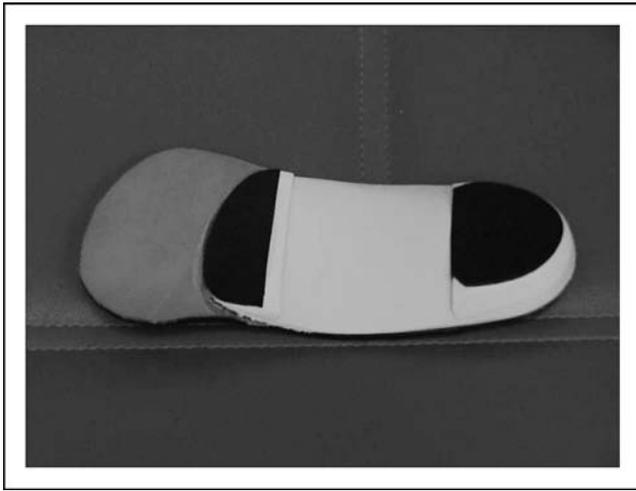
Orthotic posting

Posting the orthotic is a technique used to control the motion of the subtalar joint. The posting helps to control the pronation or supination of the foot. Posting can be incorporated into the orthotic or can be added to the outside shell to obtain the correct foot support to allow joint control.

In principle, rear foot varus posting is thought to further supinate the subtalar joint, lock the midtarsal joint complex and plantarflex the first metatarsal via the peroneal tendon mechanism. There are conflicting reports on the effect of posting on the plantar flexion of the first ray and the motion at the first metatarsophalangeal joint [10,17]. Varus posting has been shown to be statistically more beneficial for the reduction of medial column foot pressures when compared with valgus foot posting [10]. Other studies suggest that posting has less influence on foot mechanics and that the positive effect is due to the addition of material at any point under the medial column [17].

Van Gheluwe and Dananberg [23] studied the effects of in-shoe forefoot and rear foot wedging on pressure. They

Figure 12 Polypropylene orthotic with both rear foot and forefoot post



concluded that inverting the rear foot did not necessarily reinforce first ray stability, but additional factors including the orthotic shell have an effect on first ray stability and subtalar joint control. This reinforces the point that selection of orthotic materials is important to obtain the best functional result and clinical outcome. Mundermann *et al.* [24] found that the effects of molding can be increased by combining it with posting. Their 2006 study [25^{••}] showed that structural components of foot orthoses affect lower extremity muscle activity.

Using an intrinsic posting technique to balance the forefoot to the rear foot eliminates the need for additional material and bulk in the shoe. The orthotic posting is added intrinsically by modifying the positive mold rather than secondarily incorporating it into the moldable shell.

External or 'extrinsic' posting is accomplished by adding various posting materials, including corex, cork, high-density EVA, acrylics and other materials to the outer shell of the formed orthotic device. These firm posting materials are thought to add additional control and further limit pathologic forces (Fig. 12).

Conclusion

The discussion encompasses a review of foot orthotic materials, orthotic casting techniques and orthotic selections to address select foot pathology. A true custom prescription is a personalized work of art that is individualized for each patient. There are many variables which affect orthotic design and material selection. Ultimately, an orthotic is successful if it fits in the patient's shoe gear and if the patient is compliant with the device.

Much of the evidence for orthotic therapy is contradictory, with both positive and negative study outcomes. It is evident that much of the discrepancy stems from the difference in orthotic fabrication methods, materials, variations in footwear and testing conditions, lack of study design and statistical power. We agree with the many authors that the continuing controversy surrounding orthotic efficacy must be addressed with additional research to gain scientific evidence to support the benefit of foot orthotic therapy [4,6,7].

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 189).

- 1 Ivanic G. Orthotics and insoles for the forefoot: the European way. *Foot Ankle Clin N Am* 2003; 8:671–682.
- 2 Rome K, Gray J, Stewart F, Hannant S, *et al.* Evaluating the clinical effectiveness and cost-effectiveness of foot orthoses in the treatment of plantar heel pain. *J Am Podiatr Med Assoc* 2004; 94:229–238.
- 3 Skliar JD. Critique of podiatric biomechanics by William Eric Lee. *DPM Clin Podiatr Med Surg* 2001; 18:685–690.
- 4 Ball K, Afheldt M. Evolution of foot orthotics. Part 1: Coherent theory or coherent practice? *J Manipulative Physiol Ther* 2002; 25:116–124.
- 5 Nawoczenski D, Janisse D. Foot orthoses in rehabilitation: what's new. *Clin Sports Med* 2004; 23:157–167.
- 6 Payne C, Pod D, Chutter V. The clash between theory and science on the kinematic effectiveness of foot orthoses. *Clin Podiatr Med Surg* 2001; 18:705–713.
- 7 Ball K, Afheldt M. Evolution of foot orthotics. Part 2: Research reshapes long-standing theory. *J Manipulative Physiol Ther* 2002; 25:125–134.
- 8 Mejjad O, Vittecoq O, Pouplin S, Grassin-Delyle L, *et al.* Foot orthotics decrease pain but do not improve gait in rheumatoid arthritis patients. *Joint Bone Spine* 2004; 71:542–545.
- 9 Esterman A, Pilotto L. Foot shape and its effect on functioning in Royal Australian Air Force recruits. Part 2: Pilot, randomized, controlled trial of orthotics in recruits with flat feet. *Military Med* 2005; 170:629–633.
- 10 Smith C, Spooner S, Fletton J. The effect of 5-degree valgus and varus rear foot wedging on peak hallux dorsiflexion during gait. *J Am Podiatr Med Assoc* 2004; 94:558–564.
- 11 Whitney K. Foot deformities, biomechanical and pathomechanical changes associated with aging including orthotic considerations, part II. *Clin Podiatr Med Surg* 2003; 20:511–526.
- 12 Leung AK, Cheng JC. Orthotic design and foot impression procedures to control foot alignment. *Prosthet Orthot Int* 2004; 28:254–262.
- 13 Laughton C, Davis I, Williams D. A comparison of four methods of obtaining a negative impression of the foot. *J Am Podiatr Med Assoc* 2002; 92:261–268.
- 14 McPoil T, Hunt G. Evaluation and management of foot and ankle disorders: present problems and future directions. *J Orthop Sports Phys Ther* 1995; 21:381–388.
- 15 Reed L, Bennett P. Changes in foot function with the use of Root and Blake orthoses. *J Am Podiatr Med Assoc* 2001; 91:184–193.
- 16 Kulig K, Burnfield J, Reischel S, *et al.* Effect of foot orthoses on tibialis posterior activation in persons with pes planus. *Med Sci Sports Exerc* 2005; 24–29.
- 17 Nawoczenski D, Ludewig P. The effect of forefoot and arch posting orthotic designs on first metatarsophalangeal joint kinematics during gait. *J Orthoped Sports Phys Ther* 2004; 43:317–327.
- 18 Jackson L, Binning J, Potter J. Plantar pressures in rheumatoid arthritis using prefabricated metatarsal padding. *J Am Podiatr Med Assoc* 2004; 94:239–245.
- 19 Finestone A, Giladi M, Elaad A, *et al.* Prevention of stress fractures using custom biomechanical shoe orthosis. *Clin Orthop* 1999; 360:182–190.

- 20** Gross MT, Byers JM, Krafft JL, *et al.* The impact of custom semirigid foot orthotics on pain and disability for individuals with plantar fasciitis. *J Orthoped Sports Phys Ther* 2002; 32:149–156.
- 21** Martin JE, Hosch JC, Goforth WP, *et al.* Mechanical treatment of plantar fasciitis: a prospective study. *J Am Podiatr Med Assoc* 2001; 91:55–62.
- 22** Seligman DA, Dawson DR. Customized heel pads and soft orthotics to treat heel pain and plantar fasciitis. *Arch Phys Med Rehabil* 2003; 84:1564–1566.
- 23** Van Gheluwe B, Dananberg H. Changes in plantar foot pressure with in-shoe varus or valgus wedging. *J Am Podiatr Med Assoc* 2004; 94:1–11.
- 24** Mundermann A, Nigg BM, Humble RN, *et al.* Foot orthotics affect lower extremity kinematics and kinetics during running. *J Clin Biomech* 2003; 18:254–262.
- 25** Mundermann A, Nigg BM, Humble RN, *et al.* Foot orthoses affect frequency components of muscle activity in the lower extremity. *Gait Posture* 2006; 23:295–302.

Most recent review of orthotic materials.