Effects of Foot Orthoses on Patients with Chronic Ankle Instability

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Chronic instability of the ankle can be the result of mechanical and functional deficits. An acute ankle sprain can cause mechanical and functional instability, which may or may not respond to standard rehabilitation programs. Chronic instability results when there is persistent joint laxity of the ankle or when one or more components of neuromuscular control of the ankle are compromised. A loss of balance or postural control seems to be the most consistent finding among athletes with chronic instability of the ankle. Recent research in patients with acute and chronic ankle instability has revealed positive effects of foot orthoses on postural control. This article reviews the current research relevant to the use of foot orthoses in patients with chronic ankle instability and clarifies the suggested benefits and the shortcomings of these investigations. (J Am Podiatr Med Assoc 97(1): 19-30, 2007)

During the past 40 years, foot orthoses have been prescribed by medical professionals to treat a variety of injuries and chronic conditions affecting the athlete.[1-5] An overall patient-satisfaction rate of 70% to 80% for these devices has been reported in the medical literature.[6-9]

Scrutiny of these reports of positive treatment effects with custom functional foot orthoses reveals numerous areas of concern. Most studies published in the medical literature relevant to foot orthotic therapy are retrospective, and few, if any, used a control group. In most of these studies, the patients received multiple treatments, thus obscuring an accurate assessment of the specific contribution of foot orthotic therapy to overall success. After reviewing more than 50 studies relevant to foot orthotic treatment in athletes and nonathletes, Landorf and Keenan[10] pointed out the need for further randomized controlled trials assessing outcomes for specific clinical conditions.

The kinetic and kinematic effects of foot orthoses on running and walking subjects has been extensively studied.[11-20] Nigg and coworkers[21] performed a critical review of the literature relevant to the effects of shoes, shoe inserts, and orthotic devices on injuries in sport. They suggest that the concept of "aligning the skeleton" by using foot orthoses has not been substantially proved while also questioning whether the modest improvements in cushioning provided by these devices can actually prevent injury. Nigg[22] proposed a new paradigm of the role of orthotic devices and footwear in altering function of the lower extremity of the athlete. This theory suggests that foot orthoses may act as a filter of impact forces on the foot, modulating muscular response and allowing the athlete to maintain a "preferred movement path."

The medical literature already contains evidence that foot orthotic devices can alter or enhance neuromuscular function in the athlete. Much of this information has surfaced from the study of athletes with either acute or chronic ankle instability. This article reviews the concept of chronic ankle instability and the role of foot orthoses in treating this condition.

Terminology

Hertel[23] proposed that the term *lateral ankle instability* should describe an ankle that has been rendered unstable by disruption of the lateral ligaments. The term is usually reserved for an acute condition. Hertel describes chronic ankle instability as a condition of repetitive bouts of lateral ankle instability resulting from numerous ankle sprains. Chronic ankle instability can result from mechanical instability, functional instability, or both.

Mechanical instability of the ankle describes a condition of laxity, usually resulting from ligamentous disruption.[24] However, other pathologies can

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also compromise the intrinsic stability of the ankle joint. Multiple sprains of the ankle can lead to synovial hypertrophy and impingement, which can also cause mechanical instability. Mechanical instability of the ankle has also been attributed to osteophytic spurring, or soft-tissue impingement, which can alter range of motion of the ankle and its neighboring joints.[23]

Functional instability of the ankle was first described by Freeman[25] as a condition in which a patient experiences recurrent sprains or a feeling of "giving way" of the ankle. Freeman attributed this condition to proprioceptive deficits. Subsequent investigation[26] has suggested that functional instability may result from deficits in a variety of mechanisms that provide neuromuscular control of the ankle.

Whether there are distinct groups of patients with either mechanical or functional instability remains a debated subject. Studies[24, 27] of large groups of athletes with a history of functional instability of the ankle showed that only half demonstrated actual mechanical instability on stress radiographs. Conversely, it has been pointed out that previous studies have not considered other causes of mechanical instability, such as restricted joint motion, synovial hypertrophy, and impingement spurs.[23] Also, there has been a suggestion that mechanical instability of the subtalar joint may lead to functional instability of the ankle.[28]

Neuromuscular Control of the Ankle

Active maintenance of stability of the ankle joint is an intricate, multisystem mechanism that is still not well understood. A comprehensive review on this subject has been presented previously.[29] The essential elements of the neuromuscular control mechanism of the ankle joint are proprioception, balance and postural control, muscle reaction time, and muscular strength. Evaluation of each mechanism will allow better understanding of the role of orthoses in enhancing functional control of the ankle.

Impaired proprioception of the ankle joint has been demonstrated in studies[30-33] of subjects who have a history of repetitive ankle sprains. These investigations measured either kinesthetic awareness (ie, the ability to detect movement) or the ability to perform ankle joint positioning tasks. Why proprioception is lost after an ankle sprain is still unclear. It is speculated that mechanoreceptors located in the capsule and ligaments of the ankle become disconnected from afferent nerve fibers after an ankle sprain.[34] However, when local anesthetic was applied to the ligaments of the ankle and knee, no significant loss of position sense occurred.[35-37] It has been speculated that other equally important sources of afferent feedback of ankle joint position are provided by the surrounding skin and tendons.[36, 38, 39] Feuerbach et al[36] emphasized the importance of cutaneous receptors around the ankle after showing that application of a semirigid ankle orthosis significantly improved ankle joint proprioception as measured by joint positioning tasks.

Loss of afferent input from ankle joint proprioceptors will lead to delayed peroneal reaction time, which could significantly impair the dynamic defense mechanism protecting from an ankle sprain.[39-41] Karlsson and Andreasson[42] found that application of tape or an external ankle brace significantly improved peroneal reaction time in subjects with lateral ankle instability. Delays in peroneal muscle reaction time are not always found in studies[43, 44] of patients with functional instability of the ankle. However, differences in the findings of these studies may be due to different methods of perturbation and measurement of muscular response.

Loss of proprioception or delayed peroneal reaction time may be the result of the peripheral nerve injury that can accompany an ankle sprain. Delayed nerve conduction velocity involving the superficial and deep peroneal nerves has been shown in patients for 4 to 8 days after inversion ankle sprains.[45] Nitz et al[46] found abnormal nerve conduction in the deep peroneal and tibial nerves in patients after grades II and III ankle sprains. It was speculated that compromised nerve function could be due to localized compartment syndrome, hematoma, or nerve traction.

Neuromuscular control of the ankle depends on adequate afferent and efferent input to the ankle musculature and on adequate strength of the muscles themselves. However, studies of strength deficits in patients with functional instability of the ankle have led to conflicting findings. Early studies[25, 47] using manual muscle testing showed weakness of ankle eversion in patients with functional ankle instability. However, studies[48-50] using newer technologies, such as isokinetic dynamometry, have shown that concentric evertor strength deficits are not found in patients with functional ankle instability.

If strength deficits are found in patients with lateral ankle instability, they are usually in concentric invertor strength.[50, 51] This insight seems to contradict the notion that the ankle evertors are the primary dynamic defense for preventing an inversion ankle sprain. In one of the few studies showing predictive factors of ankle sprains, Baumhauer et al[52] found that when ankle joint evertors showed greater concentric strength than invertors, the risk of ankle sprain increased. Compared with concentric muscle function, eccentric invertor strength deficits were found in a study of 16 subjects with chronic ankle instability by Munn and coworkers.[53] They theorized that the medial ankle invertors are called on to reduce lateral displacement of the leg over the foot in static stance. Thus lateral sway of the body over the fixed foot is actually resisted by eccentric contraction of the ankle invertors.

Balance and Postural Control

The ability to maintain the body's center of mass over the supportive foot is termed *postural control.*[24] *Balance* refers to the ability of a human to remain upright in stance.[23] Although these functions seem similar, postural control is simply one measure of balance. Yet, in terms of evaluating patients with functional instability of the ankle, postural control is most often cited in the literature as the single physiologic parameter that can help diagnose, monitor, and treat patients with this disorder.[23] Deficits in postural control seem to be the most consistent findings in patients with chronic ankle instability.[24, 54-58] Loss of postural control has also been demonstrated in patients after acute ankle sprain.[59-61] Assessment of postural control can be performed in the clinical setting by having the patient perform a modified Romberg test.[24, 25] In this test, the patient stands on one foot, with arms crossed over the chest, with both eyes closed (Fig. 1).

Stabilometry is a technique to quantify postural control using a force platform that evaluates mediolateral and anteroposterior migration of center of pressure. Magnitude and velocity of deviation of center of pressure during single-leg stance are two common parameters of stabilometry studies.[59, 60] Newer instruments have been developed to measure postural control in the clinical setting. The Chattecx Balance System (Chattecx Corp, Chattanooga, Tennessee) was used in two of the studies[62, 63] reviewed in this article. The MatScan (Tekscan Inc, Boston, Massachusetts) device has been popular for clinical assessment of postural control, but this instrument cannot provide the stabilometry measures necessary for investigative research (Fig. 2).

Figure 1. Photograph of a patient in the modified Romberg position.

Studies of balance and postural control have far-reaching implications beyond athletes with repetitive ankle sprains. Tripping or falling injuries in the geriatric population are a critical concern and have received increased attention from scientists and physicians. The mechanisms protecting people from tripping or falling have been extensively studied, and much of this research has been published in the neuroscience literature.[64-70] Impaired postural control is thought to be due to a loss of proprioception and a loss of neuromuscular control over the ankle, ie, an interruption in the afferent and efferent loop.[23] However, the specific sensory components of proprioception and their role in balance and postural control remain poorly understood.

Jerosch and Prymka[71] use the term *proprioception* to describe all sensory mechanisms used by the body to maintain joint stability. In agreement, Mergner et al[72] recognize that proprioception in humans involves a multisensory system, particularly when used for postural control. They propose that four sensory signal sources are used to maintain balance and postural control: 1) visual, 2) vestibular (otoliths and semicircular canals), 3) proprioceptive input from the ankle ligaments and surrounding muscles, and 4) somatosensory signals from the plantar surface of the foot.

Role of the Foot in Postural Control

The existence of a somatosensory system located on the plantar surface of the foot is a concept not well known among clinicians treating ankle sprains. Yet research has shown that in addition to sensory nerves there are multiple types of mechanoreceptors found on the plantar surface of the foot. These receptors provide specific types of information to the central nervous system, which subsequently leads to muscular activation for control of body posture.

Merkel cell complexes respond to pressure and are found in the epidermal layer of the plantar integument.[73] Vibration is detected in various frequencies by

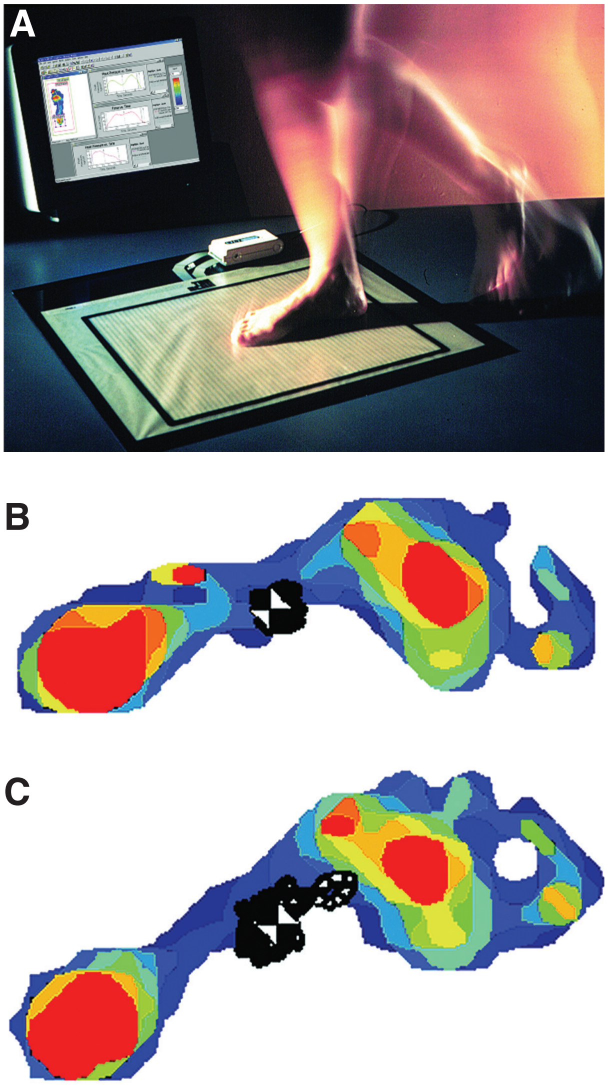

Figure 2. A, An example of a pressure mat used to track the excursion of center of pressure to measure postural sway. B, A tracing of the migration of center of pressure in a healthy subject in single-leg stance, with eyes open, for 10 sec. C, A tracing of the same subject in single-leg stance, with eyes closed, demonstrating greater migration of center of pressure. (Courtesy of Tekscan Inc, Boston, Massachusetts.)

two specific types of mechanoreceptors. Meissner corpuscles are located in the superficial layer of the plantar integument and respond to vibrations in the range of 5 to 40 Hz.[74] Pacinian corpuscles, located in the deeper subdermal layer, respond to a higher frequency of vibration, in the range of 60 to 300 Hz.[73, 75]

Application of vibration to the plantar surface of the foot can evoke a direct postural response. Kavounoudias and coworkers[76] studied the effect of vibration applied to the soles of the feet of ten healthy individuals in terms of affecting body sway during upright stance. High-frequency (100-Hz), low-amplitude mechanical vibrations were delivered to either the forefoot or the heel of the right or left foot or both while the subjects stood upright. Body sway or tilt was measured by tracking center-of-pressure migration on a force platform. In all of the subjects, whole-body tilt occurred in a direction away from the location of application of vibration on the sole of the foot. For example, when vibration was applied to the right heel, body tilt occurred in a direction that was forward and to the left. The authors concluded that vibration stimulates a pressure sensation in a specific area of the foot and activates a compensatory body sway to decrease pressure in this region.

It is still unclear whether body sway is a compensation to avoid damaging pressure to the sole of the foot or whether this localized pressure is telling the body that sway has occurred and that correction is needed. Kavounoudias et al[76] proposed that the latter mechanism is most likely because application of vibration to two areas on the plantar surface of the foot evoked a postural lean in a direction that was the vectorial sum of the responses when each area was stimulated separately. This finding suggests that the central nervous system integrates pressure information from the sole of the foot in a spatial orientation, resulting in an essential cue indicating the direction and amplitude of whole-body inclination. The authors thus describe the sole of the foot as a "dynamometric map," which can spatially code pressure information to correct body alignment and equilibrium.

The importance of the human foot as a sensory organ for whole-body balance has been reported in several studies published in the neuroscience literature. These studies[77-79] involved blocking afferent sensory input from the soles of the feet by cooling, anesthetizing, or applying an ischemic blockade. In each condition, increase in postural sway occurred with loss of sensory input from the foot.

Interventions or conditions that decrease pressure under the foot may actually compromise the somatosensory mechanism necessary for balance and postural control. Wu and Chiang[80] found that a soft foam surface decreased plantar pressure but also decreased muscular response for correction of body alignment. In contrast, Okubo and coworkers[81] found that postural control was improved when subjects stood on a platform covered with shotgun pellets, which presumably enhanced tactile and pressure sensory input.

The potential negative effect of cushioning in athletic shoes and inserts has been reported in the medical literature. Robbins and coworkers[82, 83] proposed that athletic shoes cause negative effects in athletes by decreasing mechanical stability and compromising normal muscular activation necessary for dissipation of impact forces. They further suggest that athletic footwear has the potential to decrease the position sense of the foot.[84, 85] Conversely, foot orthoses can potentially enhance postural control. A variety of studies[86-92] have been performed that shed light on the mechanism by which foot orthoses can enhance neuromuscular control over the ankle.

Foot Orthoses and Postural Control

Orteza et al[86] were the first to study the effect of foot orthoses on patients after acute ankle sprain. Fifteen healthy subjects were compared with nine subjects who had experienced an acute ankle sprain in the previous 6 weeks. The subjects were evaluated for "time out of balance" on a tilt board under three conditions: with a molded orthotic device, with a flat (unmolded orthotic) insole, and with no orthotic device. The molded orthotic device was made from ⅛-inch Aquaplast (Smith & Nephew Inc, Germantown, Wisconsin) and was direct-molded to the subject's foot, which was held in a neutral position at the subtalar joint. Forefoot posting was applied if a forefoot varus deformity was present. Injured ("ankle sprain") subjects had a significant decrease in balance control compared with noninjured subjects, and molded orthotic devices significantly improved balance scores for the injured group only. Unmolded orthotic devices did not improve balance scores for either injured or noninjured subjects. In addition, in the injured group, the molded orthotic devices significantly reduced pain while jogging compared with the flat-orthotic and no-orthotic conditions. Because noninjured subjects did not improve balance with any orthotic condition, the authors concluded that improvements seen in the injured group with the molded orthotic devices must have been due to factors other than increased structural support. These molded orthotic devices seemed to compensate for the deficit in balance created by the ankle sprain, whatever that mechanism may be. The authors speculated that maintaining the foot in a neutral position at the subtalar joint helped decrease ligamentous stress and improved function.

Guskiewicz and Perrin[62] used a more sophisticated instrumentation to measure postural sway in subjects with and without an ankle sprain. The Chattecx Balance System was used to determine the excursion of the center of gravity of the subject during single-leg stance (modified Romberg position) on a platform that was moved in the medial/lateral and inversion/eversion planes. Thirteen subjects with acute ankle sprain were compared with 12 healthy, noninjured subjects under two treatment conditions (orthoses *versus* nonorthoses) and four platform movements. The foot orthoses were fabricated from impressions taken with foam blocks, holding the foot in the subtalar neutral position. The orthoses were fabricated from positive casts that corrected according to the deformities revealed by the impression. The material composition and posting of the orthoses were not described. The subjects stood directly on the orthotic devices, which were placed directly on the forceplate, ie, no shoes were worn. The results demonstrated that injured subjects with ankle sprains showed significantly more postural sway than uninjured subjects without orthotic intervention. With orthoses, postural sway improved in the injured subjects only. The authors proposed that the foot orthoses provided increased support to the foot, which decreased excessive movement at the subtalar and talocrural joints. Furthermore, they speculated that the orthoses may have placed the ligaments about the talocrural joint in a more optimal position to allow the joint mechanoreceptors to detect abnormal motion and improve overall postural control. Finally, these authors speculated that enhanced tactile stimulation of the plantar surface of the foot was provided by the foot orthoses, which improved the somatosensory feedback necessary for balance control.

Ochsendorf et al[63] studied the effects of foot orthoses on reducing postural sway in healthy subjects who had been subjected to fatigue of their plantar flexor and dorsiflexor muscle groups. It has been shown previously that muscular fatigue in the ankle plantar flexors and dorsiflexors in healthy subjects reduces postural control as measured by sway amplitude.[87]

Eight healthy male subjects were studied before and after fatigue of these muscle groups using the Chattecx Balance System by measuring postural sway during single-leg stance. Testing was performed with and without custom foot orthoses, before and after fatiguing contractions of the ankle dorsiflexors and plantar flexors, using an isokinetic dynamometer. The custom foot orthoses were fabricated from impressions taken from foam blocks and then were balanced according to deformity revealed by the impression. The results demonstrated a significant decrease in postural sway when foot orthoses were used in the prefatigue and postfatigue conditions compared with the no-orthotic, postfatigue condition. There was a significant decline in postural stability when the ankle muscles were fatigued and when no orthoses were worn. No such decline was observed when orthoses were worn. Thus foot orthoses seemed to offset the negative effects of muscular fatigue compromising postural control in healthy subjects. The authors theorized that the foot orthoses maintained a more neutral position of the subtalar joint, which decreased demand on surrounding muscles to maintain stability. However, no measurements of improvement of rearfoot alignment with the orthoses were performed. Also, it was speculated that the "cradling effect of the orthotic device" improved tactile sensation on the bottom of the foot, thus improving afferent input for postural control.

Hertel and coworkers[88, 89] conducted two studies of various types of foot orthoses to determine their effect on postural control. In the first study, subjects with acute ankle sprains were tested for balance under six conditions: shoe only, a custom direct-molded Aquaplast foot orthosis (nonposted), a neutral prefabricated Superfeet Synergizer footbed (Superfeet Worldwide LLC, Ferndale, Washington), medially (7°) and laterally (4°) posted Superfeet Synergizer footbeds, and a Sprained Ankle Orthotic (laterally posted prefabricated heel wedge) (Cramer Corp, Gardner, Kansas). All of the orthoses were worn in shoes, and comparisons were made with the shoe-only condition. Postural sway was significantly increased for the injured side in two of the three testing sessions spread across 4 weeks. However, none of the orthoses significantly reduced postural sway in the impaired limb. The authors explained that compared with previous investigations, the results reflected the difference of custom molding of orthotic devices or the need for posting of such devices when used to treat patients with an acute ankle sprain.

Hertel and coworkers[89] performed a follow-up study of the same types of orthoses on 15 healthy subjects. Postural control was again measured under six conditions, comparing the shoe-only condition and the five orthotic devices described in the previous study. Significant differences in frontal plane sway velocity and length of center-of-pressure excursion were found between the devices. The medially posted orthosis significantly decreased frontal plane sway compared with the shoe-only condition and some of the other devices. The laterally posted Sprained Ankle Orthotic device caused the greatest frontal plane sway amplitude and velocity. No differences were found in sagittal plane sway among any of the conditions. In this study of healthy subjects, the authors point out that overall excursions of center of pressure are smaller than in injured subjects; thus the ability of an off-the-shelf or nonposted orthotic device to control sway in injured subjects may not be as effective. The authors suggested that reducing rearfoot pronation seems to be the important effect of a medially posted orthosis on balance and postural control compared with the effects of a laterally posted orthosis with poor medial arch contour.

Percy and Menz[90] studied the effects of prefabricated orthotic devices and insoles on postural stability in healthy professional soccer players. Postural sway was measured at the waist using an optical measuring device (Wilhelm Mikroelektronik GmbH, Lunen, Germany). There was no significant change in postural sway whether the subjects were barefoot, wore PPT polyurethane insoles (Langer Biomechanics Group, Deer Park, New York), or wore prefabricated polypropylene foot orthoses with 4° inverted rearfoot posts. However, there was a high degree of intersubject variability in postural sway in response to the orthoses. The authors concluded that response to orthoses may depend on foot type and that their findings may have been different if custom rather than prefabricated foot orthoses had been used.

Prefabricated foot orthoses affected mediolateral sway in a prospective randomized controlled study by Rome and Brown.[91] Fifty healthy subjects with pronated feet, as determined by means of the Foot Posture Index, were studied in bipedal stance, with postural sway measured using the Balance Performance Monitor (SMS Healthcare, Harlow, England). Prefabricated foot orthoses composed of high-density ethylene vinyl acetate (70 Shore) with a 5° rearfoot post were worn by the subjects in athletic shoes, and postural sway was compared with that of a control group (pronated feet with no orthoses) at baseline and after 4 weeks of wear. At baseline, there was no difference between groups. After 4 weeks, the orthoses group showed significantly decreased mediolateral postural sway. The authors point out that this study was unique in following the effects of the orthoses across 4 weeks of use and the selection of subjects with pronated feet, differing from other studies of healthy subjects that showed no effects of orthoses. The findings suggest that healthy subjects with pronated feet can improve postural control with medially wedged foot orthoses. The authors also point out the potential benefit of rigid material used in the test orthoses. Previous studies[84, 85] have shown that mechanoreceptors could be better stimulated by rigid materials, providing better feedback for postural control.

Another study on patients with abnormal foot structure was conducted by Cobb et al.[92] In this prospective controlled study, 12 participants with more than 7° of forefoot varus were compared with five participants with less than 7° of forefoot varus. Only the group with more than 7° of forefoot varus were treated with custom polypropylene foot orthoses manufactured from foam box impression casts. These orthoses did not have any posting applied. Compared with the control group, the treatment group with foot orthoses improved anteroposterior and mediolateral postural sway but only after 6 weeks of orthosis use. At the time of initial dispensing of the foot orthoses, postural sway was not improved. After wearing the orthoses for 6 weeks, the treatment group also demonstrated improved postural control when tested while not wearing the devices. The authors suggested that there is a period after orthotic device dispensing when improved mechanoreceptor function on the plantar surface of the foot occurs.

Foot Orthoses and Postural Control: Proposed Mechanisms

In the studies performed to date, consistently positive outcomes have been reported when foot orthoses are used to improve balance and postural control. Yet, in each of these studies, the investigators could not fully explain the mechanism by which the orthoses achieved the observed results. The ability of a foot orthosis to improve postural control in humans was attributed in the previously cited studies to any of the following mechanisms: 1) reducing range of motion of the ankle joint or subtalar joint, 2) maintaining alignment of the foot in a "neutral position" at the subtalar joint and enhancing ligament mechanoreceptor function, 3) improving tactile sensation on the plantar surface of the foot, and 4) reducing muscular strain about the ankle.

To my knowledge, no study published to date has documented the ability of a foot orthosis to reduce range of motion of the talocrural joint during static single-leg stance. In terms of the subtalar joint, changes of alignment in walking or running subjects with foot orthoses are relatively minimal according to published data.[11-16] In the studies of balance control cited earlier,[62, 63, 86] there was speculation about improvements of alignment in the talocrural and subtalar joints of subjects with foot orthoses, yet none of these investigations included any protocols to measure or verify such treatment effects.

Several studies on postural control cited earlier speculated that custom foot orthoses would align the subtalar joint of subjects in a "neutral position." Yet, for the podiatric physician, the method of orthosis casting and fabrication used in these studies would seem to be significantly different from existing practice standards in the United States. Two studies[62, 63] used foam blocks and a semiweightbearing technique to capture the shape and alignment of the foot. Three other studies[86, 88, 89] used a direct mold technique of Aquaplast to the foot of the subject, which was held in the subtalar neutral position. Both techniques lack the ability to produce an orthotic device that is shaped over a corrected model of the foot. According to currently accepted podiatric medical practice, the corrected model must be created from a negative cast of the foot when the subtalar joint is positioned in neutral, the midtarsal joint is maximally pronated, and the first ray is allowed to lie in its neutral or plantarflexed position.[93] Clearly, the techniques used in the previous studies indicate that a standard of orthotic therapy has not been accepted among the various specialties treating foot and ankle pathologies.

The potential benefit of a podiatric medical approach to impression casting, balancing of a corrected positive model, and fabrication of functional foot orthoses was demonstrated by Mundermann et al.[94] Twenty-one recreational runners were studied under three orthotic conditions: a 6° medially posted flat insole, a balanced "molded" functional orthotic device, and a balanced "molded" functional foot orthotic device with an additional 6° of medial posting. Fifteen kinematic, kinetic, and electromyographic variables were studied, and the results indicated a systematic improvement with the balanced "molded" orthotic device compared with the other devices. The authors suggested that molding of the orthotic footplate to a corrected positive cast of the patient's foot in a neutral position was more effective in improving the objective measures than the effect of posting and posting with molding.

Improvement in tactile sensation has been proposed as a mechanism of benefit in postural control when orthoses are used in patients with lateral ankle instability. However, none of the authors of the studies previously cited here offer any explanation of how the particular orthotic design used actually improved tactile sensation. In only one study[91] was the precise physical characteristic of the orthosis described in terms of material hardness. Studies[89, 94] showing the benefits of contoured devices, whether prefabricated or custom molded to the plantar surface of the foot, suggest a tactile stimulus-response benefit that is not seen with flat orthotic insoles.

What seems to be most viable, in terms of a theory of mechanism of action of foot orthoses on balance and postural control, is the effect of these devices on muscular function of the lower extremity. In upright stance, balance and postural control of the body involves four key segments: the head, the trunk, the legs, and the feet. In healthy subjects, measurements of postural control in single-leg stance reveal head, trunk, and leg function as one unit, with rotations and corrections occurring about the ankle. Mergner et al[72] describe this mechanism as an "inverted pendulum," in which the entire body rotates over the fixed foot at the ankle joint.

Healthy subjects have been described as using an "ankle strategy" to adjust the position of the leg, trunk, and head over the fixed foot.[95] When ankle joint proprioception is diminished or when neuromuscular control of the ankle is lost, the subject will be observed to use a "hip strategy" to correct body postural alignment for balance control.[96] It is speculated that an ankle strategy is more efficient than a hip strategy for maintenance of postural control during single-leg stance.[23] An ankle strategy requires finely tuned short-range corrections, whereas a hip strategy requires gross movements in a larger range of motion.

Investigators of postural control use the term *ankle strategy* to describe movements of the foot that correct whole-body sway. Whereas forward and backward body sway can result from ankle (talocrural) joint motions, mediolateral body sway corrections must result from inversion/eversion of the foot. Such movements would not be possible at the ankle joint but would occur at the subtalar joint. Because the most common ankle sprain is an inversion sprain, motion at the subtalar joint should be carefully considered as a significant part of the pathomechanics of this injury.

Foot orthoses are thought to exert their primary influence on the subtalar joint.[1, 4, 11, 13] Despite this accepted mechanism of action, studies of effects of foot orthoses on rearfoot alignment have shown improvements in the range of only a few degrees.[11-16] However, these findings may be significant considering that proprioception appears diminished when a joint is moved toward end range of motion.[31] Foot orthoses, by limiting rearfoot movements by only a few degrees, may keep proprioceptive mechanisms functioning at optimal capacity.

Almost all of the studies of changes in rearfoot alignment using foot orthoses published in the literature have noted that these devices reduce pronation rather than supination of the rearfoot.[10-21] Studies of walking subjects measuring changes in migration of center of pressure have shown results similar to those of single-leg stance studies. McPoil et al[97] found that foot orthotic devices limited pronation and migration of center of pressure in subjects with forefoot varus deformities. In one of the previous studies cited, Hertel et al[89] concluded that reduction of pronation was the primary mechanism by which foot orthotic devices could improve postural control, yet no explanation of this cause-effect relationship was given. Although several studies have shown no benefit of foot orthoses in improving postural control in healthy subjects, one study demonstrated benefit in healthy subjects with excessively pronated feet.[91]

Theories of Lateral Sway and Ankle Sprains

Munn and coworkers[53] showed that eccentric strength deficits are found in the medial ankle muscles of patients with ankle instability. They propose a mechanism of instability in single-leg stance where lateral body sway causes a closed-chain eversion of the subtalar joint, which is resisted by the medial ankle invertors. Weakness of the ankle invertors could, thus, be less effective in resisting lateral body sway. When lateral body sway continues beyond the range of subtalar joint eversion, Munn et al propose that the body will then carry the foot into sudden inversion, with subsequent inversion moment delivered to the talocrural joint. Thus it has been proposed that eversion of the subtalar joint to end range of motion on a fixed foot may occur before the lateral fall of the body forces the foot and ankle into sudden inversion (Fig. 3).

Several investigators cited in this review proposed that foot orthoses improve postural control by reducing pronation of the subtalar joint. According to the theory of Munn et al,[53] reduction of foot pronation would decrease lateral body sway and decrease load on the medial ankle musculature.

Foot orthotic devices have been demonstrated to reduce inversion moment to the rearfoot.[98, 99] These studies were conducted on running subjects and suggested that in certain situations, foot orthoses could reduce strain on the medial ankle ligaments and tendons. However, it has yet to be proved whether foot orthotic devices can affect ankle joint moments during mediolateral sway of the body over a fixed foot. Also, the notion that foot orthoses can reduce pronation of the foot during lateral body sway has yet to be validated in any published kinematic study, to my knowledge. Thus the concept that foot orthoses reduce pronation moment and thus lateral body sway remains speculative.

This proposed mechanism of lateral body sway, followed by foot eversion to end range of motion, followed by sudden foot inversion, is only one possible mechanism of a lateral ankle sprain. It is recognized that medial body sway on a fixed foot will cause an inversion motion of the subtalar joint, which could also lead to subluxation and sprain of the lateral ankle ligaments. In this situation, the peroneal musculature would play a primary role in correcting medial whole-body sway. However, studies have shown that significant peroneal muscular weakness is not a consistent finding in subjects with chronic ankle instability.[48-50]

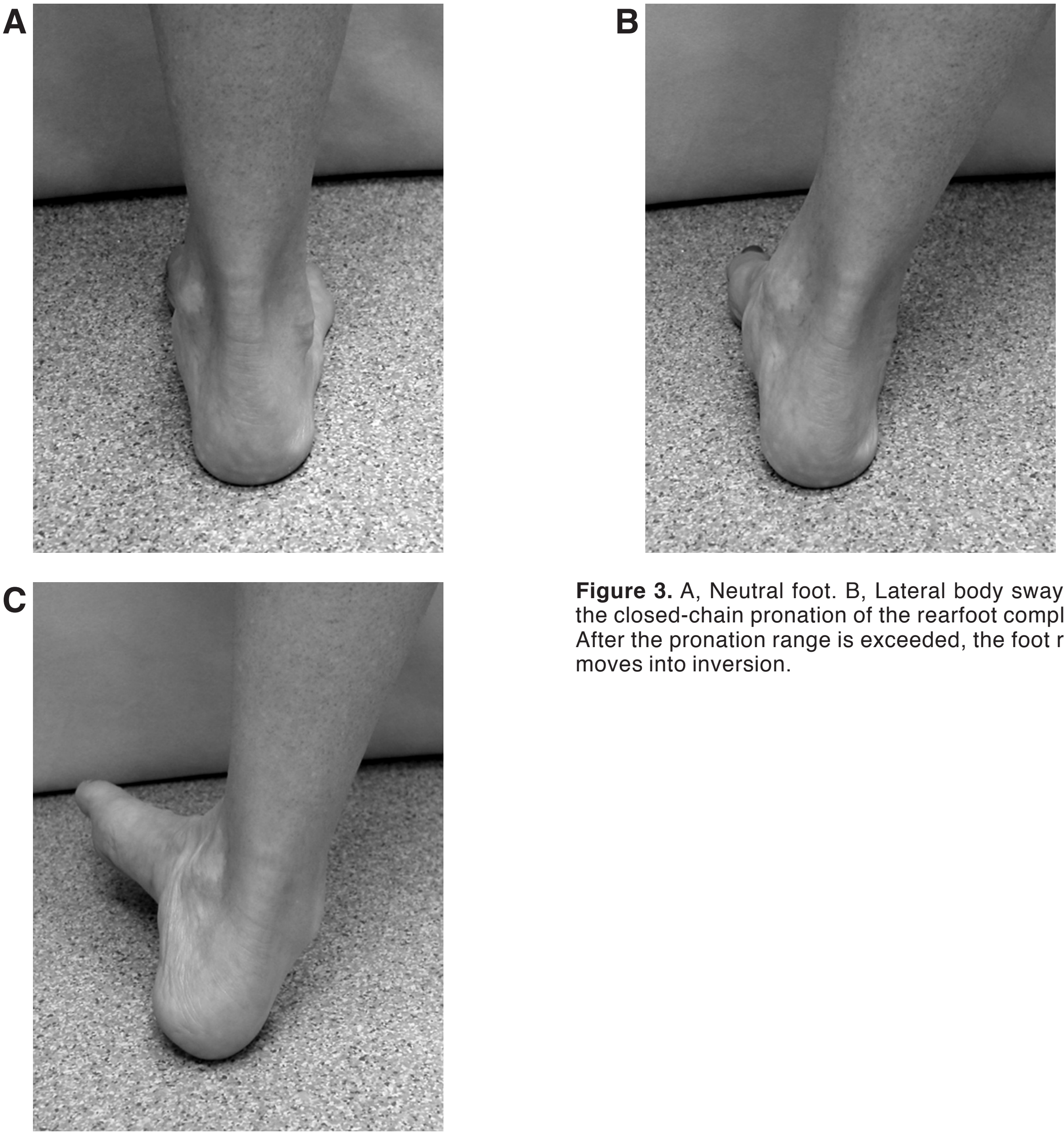

Figure 3. A, Neutral foot. B, Lateral body sway. Note the closed-chain pronation of the rearfoot complex. C, After the pronation range is exceeded, the foot rapidly moves into inversion.

Sway or actual falling of the body on a fixed foot, simulated in these studies, may not be the mechanism of a true ankle sprain in sport. Authorities agree that most ankle sprains occur when there is contact of the athlete with another player or when the foot lands on an unstable surface. In most instances, the ankle is in a plantarflexed position.[23]

The studies cited in this review evaluated postural sway in static stance, with the foot flat on the ground. Ankle sprains in sport activity probably do not occur in this position. Loss of balance during midstance of walking gait may occur more often in the elderly population. Evaluation of the mechanics of joint motion and muscular response with the foot flat may have more relevance to this population than the running or jumping athlete.

Conclusion

Foot orthoses have been shown to have a positive influence on subjects who have recently experienced an ankle sprain and on subjects with chronic ankle instability. The mechanism by which these devices improve function in patients with these impairments remains somewhat obscure. There is evidence that foot orthoses can influence multiple levels of neuromuscular control of the ankle. Improvements in somatosensory feedback and reduced muscular load seem to be the most viable mechanisms by which foot orthoses may positively affect patients with chronic ankle instability.

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References

1. Blake RL, Denton JA: Functional foot orthoses for athletic injuries: a retrospective study. JAPMA **75:** 359, 1985.
2. Ferguson H, Raskowsky M, Blake RL, et al: TL-61 *versus* Rohadur orthoses in heel spur syndrome. JAPMA **81:** 439, 1991.
3. Richie DH, Olson WR: Orthoses for athletic overuse injuries: comparison of two component materials. JAPMA **83:** 492, 1993.
4. Bates BT, Osternig LR, Mason B, et al: Foot orthotic devices to modify lower extremity biomechanics. Am J Sports Med **7:** 338, 1979.
5. Saxena A, Haddad J: The effect of foot orthoses on patellofemoral pain syndrome. Lower Extremity **5:** 9, 1998.
6. James SL, Bates BT, Osternig LR: Injuries to runners. Am J Sports Med **6:** 40, 1978.
7. Donatelli R, Hurlbert C, Conaway D, et al: Biomechanical foot orthotics: a retrospective study. J Orthop Sports Phys Ther **10:** 205, 1998.
8. Gross ML, Davlin LB, Evanski PM: Effectiveness of orthotic shoe inserts in the long-distance runner. Am J Sports Med **19:** 409, 1991.
9. Moraros J, Hodge W: Orthotic survey: preliminary results. JAPMA **83:** 139, 1993.
10. Landorf KB, Keenan AM: Efficacy of foot orthoses: what does the literature tell us? JAPMA **90:** 149, 2000.
11. Cavanagh PR, Clarke TE, Williams K, et al: An evaluation of the effect of orthotics on force distribution and rearfoot movement during running. Paper presented at the American Orthopaedic Society for Sports Medicine Meeting, June 1978, Lake Placid, NY.
12. Clarke TE, Frederick EC, Hlavac HF: Effects of a soft orthotic device on rearfoot movement in running. Podiatr Sports Med **1:** 20, 1983.
13. Smith LS, Clarke TE, Hamill CL, et al: The effects of soft and semi-rigid orthoses upon rearfoot movement in running. JAPMA **76:** 227, 1986.
14. Eng J, Pierrynowski MR: The effect of soft foot orthotics on three-dimensional lower-limb kinematics during walking and running. Phys Ther **74:** 836, 1994.
15. Nawoczenski DA, Cook TM, Saltzman CL: The effect of foot orthotics on three-dimensional kinematics of the leg and rearfoot during running. J Orthop Sports Phys Ther **21:** 317, 1995.
16. Stacoff A, Reinschmidt C, Nigg BM, et al: Effects of foot orthoses on skeletal motion during running. Clin Biomech **15:** 54, 2000.
17. Clarke TE, Frederick EC, Cooper LB: Effects of shoe cushioning upon ground reaction forces in running. Int J Sports Med **4:** 247, 1983.
18. Nigg BM, Luethis SM, Denoth J, et al: “Methodological Aspects of Sport Shoe and Sport Surface Analysis,” in *Biomechanics VIII-B*, ed by H Matsui, K Kobayashi, p 1041, Human Kinetics, Champaign, IL, 1983.
19. Williams DS, McClay Davis I, Baitch SP: Effect of inverted orthoses on lower extremity mechanics in runners. Med Sci Sports Exerc **35:** 2060, 2003.
20. Nigg BM, Stergiou P, Cole G, et al: Effect of shoe inserts on kinematics, center of pressure, and leg joint moments during running. Med Sci Sports Exerc **35:** 314, 2003.
21. Nigg BM, Nurse MA, Stefanyshyn DJ: Shoe inserts and orthotics for sport and physical activities. Med Sci Sports Exerc **31** (suppl)**:** S421, 1999.
22. Nigg BM: The role of impact forces and foot pronation: a new paradigm. Clin J Sports Med **11:** 2, 2001.
23. Hertel J: Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athl Train **37:** 364, 2002.
24. Tropp H, Odenick P, Gillquist J: Stabilometry recordings in functional and mechanical instability of the ankle joint. Int J Sports Med **6:** 180, 1985.
25. Freeman MA: Instabilities of the foot after lateral ligament injuries of the ankle. J Bone Joint Surg Br **47:** 669, 1965.
26. Hertel J: Functional instability following lateral ankle sprain. Sports Med **29:** 361, 2000.
27. Vaes PH, Duquet W, Piere-Powel C, et al: Static and dynamic roentgenographic analysis of stability in braced and non-braced stable and functionally unstable ankles. Am J Sports Med **26:** 692, 1998.
28. Hertel J, Denegar CR, Monroe MM, et al: Talocrural and subtalar joint instability after lateral ankle sprain. Med Sci Sports Exerc **31:** 1501, 1999.
29. Richie DH: Functional instability of the ankle and role of neuromuscular control: a comprehensive review. J Foot Ankle Surg **5:** 79, 2003.
30. Garn SN, Newton RA: Kinesthetic awareness in subjects with multiple ankle sprains. Phys Ther **68:** 1667, 1988.
31. Glencross D, Thornton E: Position sense following joint injury. J Sports Med Phys Fitness **21:** 23, 1981.
32. Lentell G, Baas B, Lopez D, et al: The contributions of proprioceptive deficits, muscle function, and anatomic laxity to functional instability of the ankle. J Orthop Sports Phys Ther **21:** 206, 1995.
33. Konradsen L, Magnusson P: Increased inversion angle replication error in functional ankle instability. Knee Surg Sports Traumatol Arthrosc **8:** 246, 2000.
34. Freeman MR, Dean ME, Hanham IF: The etiology and prevention of functional instability of the foot. J Bone Joint Surg Br **47:** 678, 1965.
35. DeCarlo MS, Talbot RW: Evaluation of ankle joint proprioception following injection of the anterior talofibular ligament. J Orthop Sports Phys Ther **8:** 70, 1986.
36. Feuerbach MA, Brabiner MO, Koh TJ, et al: Effect of an ankle orthosis and ankle ligament anesthesia on ankle joint proprioception. Am J Sports Med **20:** 223, 1994.
37. Barract RL, Skinner HB, Brunet ME: Functional performance of the knee after intraarticular anesthesia. Am J Sports Med **11:** 258, 1983.
38. McCluster GM, Blackburn TA, Lewis T: Prevention of ankle sprains. Am J Sports Med **4:** 151, 1976.

39. Skinner HB, Wyatt MP, Hodgdon DW, et al: Effect of fatigue on joint position sense of the knee. J Orthop Res **4:** 112, 1986.
40. Konradsen L, Voight M, Hojsgaard C: Ankle inversion injuries: the role of the dynamic defense mechanism. Am J Sports Med **25:** 54, 1997.
41. Lofvengerg R, Karrholm J, Sudelin G, et al: Prolonged reaction time in patients with chronic lateral instability of the ankle. Am J Sports Med **23:** 414, 1995.
42. Karlsson J, Andreasson GO: The effect of external ankle support in chronic lateral ankle joint instability: an electromyographic study. Am J Sports Med **20:** 257, 1992.
43. Isakov E, Mizrahi J, Solzi P, et al: Response of the peroneal muscles to sudden inversion of the ankle during standing. Int J Sport Biomech **2:** 200, 1986.
44. Nawoczenski DA, Owen MG, Ecker ML, et al: Objective evaluation of peroneal response to sudden inversion stress. J Orthop Sports Phys Ther **7:** 107, 1985.
45. Kleinrensink GJ, Stoeckart R, Meulstee J, et al: Lowered motor conduction velocity of the peroneal nerve after inversion trauma. Med Sci Sports Exerc **26:** 877, 1994.
46. Nitz AJ, Dobner JJ, Kersey D: Nerve injury and grades II and III ankle sprains. Am J Sports Med **13:** 177, 1985.
47. Bosien W, Staples O, Russell S: Residual disability following acute ankle sprains. J Bone Joint Surg Am **37:** 1237, 1955.
48. Lentell GL, Katzman LL, Walters MR: The relationship between muscle function and ankle stability. J Orthop Sports Phys Ther **11:** 605, 1990.
49. McKnight C, Armstrong C: The role of ankle strength in functional ankle instability. J Sport Rehabil **6:** 21, 1997.
50. Ryan L: Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. Aust J Physiother **40:** 41, 1994.
51. Wilkerson G, Pinerola J, Caturano R: Invertor *versus* evertor peak torque and power deficiencies associated with lateral ankle ligament injury. J Orthop Sports Phys Ther **26:** 79, 1997.
52. Baumhauer JF, Alosa DM, Renström FH, et al: A prospective study of ankle injury risk factors. Am J Sports Med **223:** 564, 1995.
53. Munn J, Beard D, Refshauge K, et al: Eccentric muscle strength in functional ankle instability. Med Sci Sports Exerc **35:** 245, 2003.
54. Garn SN, Newton RA: Kinesthetic awareness in subjects with multiple ankle sprains. Phys Ther **68:** 1667, 1988.
55. Tropp H, Odenrick P: Postural control in single-limb stance. J Orthop Res **6:** 833, 1988.
56. Gauffin H, Tropp H, Odenrick P: Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. Int J Sports Med **9:** 141, 1988.
57. Forkin DM, Koczur C, Battle R, et al: Evaluation of kinesthetic deficits indicative of balance control in gymnasts with unilateral chronic ankle sprains. J Orthop Sports Phys Ther **23:** 245, 1996.
58. Perrin PP, Bene MC, Perrin CA, et al: Ankle trauma significantly impairs postural control: a study in basketball players and controls. Int J Sports Med **18:** 387, 1997.
59. Cornwall MW, Murrell P: Postural sway following inversion sprain of the ankle. JAPMA **81:** 243, 1991.
60. Friden T, Zatterstrom R, Lindstrand A, et al: A stabilometric technique for evaluation of lower limb instabilities. Am J Sports Med **17:** 118, 1989.
61. Hertel J, Buckley WE, Denegar CR: Serial testing of postural control after acute lateral ankle sprain. J Athl Train **35:** 363, 2001.
62. Guskiewicz KM, Perrin DH: Effect of orthotics on postural sway following inversion ankle sprain. J Orthop Sports Phys Ther **23:** 326, 1996.
63. Ochsendorf DT, Mattacola CG, Arnold BL: Effect of orthotics on postural sway after fatigue of the plantar flexors and dorsiflexors. J Athl Train **35:** 26, 2000.
64. Dietz V, Berger W: Spinal coordination of bilateral muscle activity during balancing. Exp Brain Res **47:** 172, 1982.
65. Nashner LM: Balance adjustments of humans perturbed while walking. J Neurophysiol **44:** 650, 1980.
66. Nashner LM, Black FO, Wall C: Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. J Neurosci **2:** 536, 1982.
67. Dietz V: Human neuronal control of automatic functional movements: interaction between central programs and afferent input. Physiol Rev **72:** 33, 1992.
68. Dietz V, Quintern J, Sillem M: Stumbling reactions in man: significance of proprioceptive and pre-programmed mechanisms. J Physiol **386:** 149, 1987.
69. Nashner LM: Adapting reflexes controlling the human posture. Exp Brain Res **26:** 59, 1976.
70. Berger WG, Dietz V, Quintern J: Corrective reactions to stumbling reactions in man: neuronal coordination of bilateral leg muscle activity during gait. J Physiol Lond **357:** 109, 1984.
71. Jerosch J, Prymka M: Proprioception and joint stability. Knee Surg Sports Traumatol Arthrosc **4:** 171, 1996.
72. Mergner T, Maurer C, Peterka RJ: A multisensory posture control model of human upright stance. Prog Brain Res **142:** 189, 2003.
73. Rothwell J: *Control of Human Voluntary Movement*, 2nd Ed, p 86, Chapman & Hall, New York, 1994.
74. Martin JH, Jessel TM: "Modality Coding in the Somatic Sensory System," in *Principles of Neural Science*, 3rd Ed, ed by ER Kandel, JH Schwartz, TM Jessell, p 341, Appleton & Lange, Norwalk, CT, 1994.
75. Lynn B: "Cutaneous Sensation," in *Physiology, Biochemistry and Molecular Biology of the Skin*, 2nd Ed, ed by L Goldsmith, p 779, Oxford University Press, New York, 1991.
76. Kavounoudias A, Roll R, Roll JP: The plantar sole is a "dynamometric map" for human balance control. Neuroreport **9:** 3247, 1998.
77. Magnusson M, Embon H, Johansson R, et al: Significance of pressor input from the human feet in anterior-posterior postural control. Acta Otol **110:** 182, 1990.
78. Thoumie P, Do MC: Changes in motor activity and biomechanics during balance recovery following cutaneous and muscular deafferentation. Exp Brain Res **110:** 289, 1996.
79. Mauritz KH, Dietz V: Characteristics of postural instability induced by ischemic blocking of leg afferents. Exp Brain Res **38:** 117, 1980.
80. Wu G, Chiang JH: The significance of somatosensory stimulations to the human foot in the control of postural reflexes. Exp Brain Res **114:** 163, 1997.
81. Okubo J, Watanabe I, Baron JB: Study on influences of

the plantar mechanoreceptor on body sways. Agressologie **21:** 61, 1980.

82. Robbins SE, Gouw GJ: Athletic footwear: unsafe due to perceptual illusions. Med Sci Sports Exerc **23:** 217, 1991.
83. Robbins S, Waked E: Balance and vertical impact in sports: role of shoe sole materials. Arch Phys Med Rehabil **78:** 463, 1997.
84. Robbins S, Waked E, Gouw GJ, et al: Athletic footwear affects balance in men. Br J Sports Med **28:** 117, 1994.
85. Robbins S, Waked E, Allard P, et al: Foot position awareness in younger and older men: the influence of footwear sole properties. J Am Geriatr Soc **45:** 61, 1997.
86. Orteza LC, Vogelbach WD, Denegar CR: The effect of molded and unmolded orthotics on balance and pain while jogging following inversion ankle sprain. J Athl Train **27:** 80, 1992.
87. Lundin TM, Feurbach JW, Grabiner MD: Effect of plantar flexor and dorsiflexor fatigue on unilateral postural control. J Appl Biomech **9:** 191, 1993.
88. Hertel J, Denegar CR, Buckley WE, et al: Effect of rearfoot orthotics on postural sway after lateral ankle sprain. Arch Phys Med Rehabil **82:** 1000, 2001.
89. Hertel J, Denegar CR, Buckley WE, et al: Effect of rearfoot orthotics on postural control in healthy subjects. J Sport Rehabil **10:** 36, 2001.
90. Percy ML, Menz HB: Effects of prefabricated foot orthoses and soft insoles on postural stability in professional soccer players. JAPMA **91:** 194, 2001.
91. Rome K, Brown CL: Randomized clinical trial into the impact of rigid foot orthoses on balance parameters in excessively pronated feet. Clin Rehabil **18:** 624, 2004.
92. Cobb SC, Tis LL, Johnson JT: The effect of 6 weeks of custom-molded foot orthosis intervention on postural stability in participants with greater than 7 degrees of forefoot varus. Clin J Sports Med **16:** 316, 2006.
93. Losito JM: “Impression Casting Techniques,” in *Clinical Biomechanics of the Lower Extremities*, ed by RL Valmassy, p 279, CV Mosby, St Louis, 1996.
94. Mundermann A, Nigg BM, Humble RN, et al: Orthotic comfort is related to kinematics, kinetics and EMG in recreational runners. Med Sci Sports Exerc **35:** 1710, 2003.
95. Rietdyk A, Patla A, Winter M, et al: Balance recovery from medio-lateral perturbations of the upper body during standing. J Biomech **32:** 1149, 1999.
96. Pintsaar A, Brynhildsen J, Tropp H: Postural corrections after standardized perturbations of single leg stance: effect of training and orthotic devices in patients with ankle instability. Br J Sports Med **30:** 151, 1996.
97. McPoil TG, Adrian M, Pidcoe P: Effects of foot orthoses on center-of-pressure patterns in women. Phys Ther **69:** 149, 1989.
98. Mundermann A, Nigg BM, Humble RN, et al: Foot orthotics affect lower extremity kinematics and kinetics during running. Clin Biomech **18:** 254, 2003.
99. Williams DS, Davis IM, Baitch SP: Effect of inverted orthoses on lower-extremity mechanics in runners. Med Sci Sports Exerc **35:** 2060, 2003.