The Evolution of Foot Orthoses in Sports—Part 2

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

BY KEVIN A. KIRBY, DPM

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

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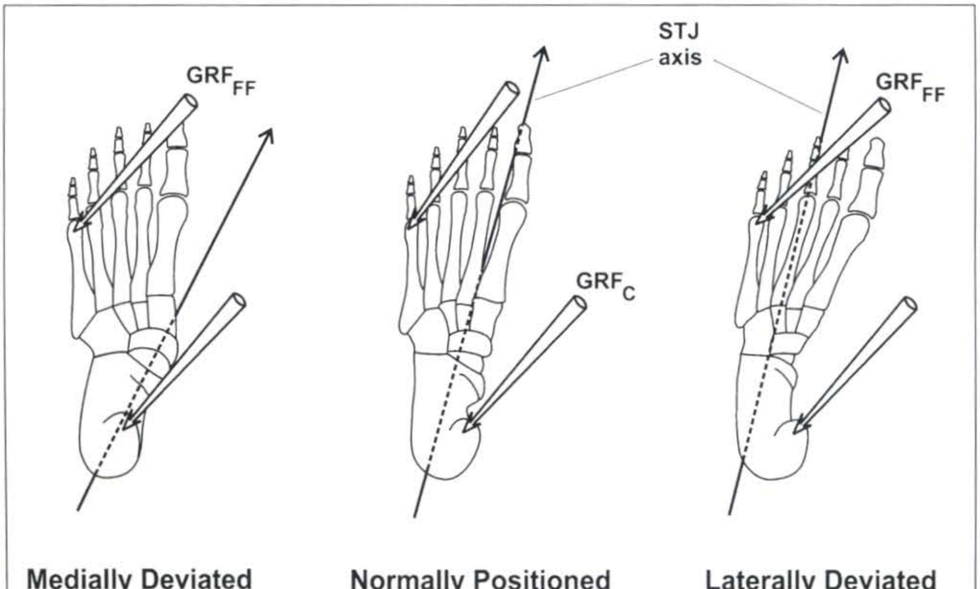

Figure 1: In a foot with a normally positioned subtalar joint (STJ) axis (center), the ground reaction force plantar to the calcaneus (GRF$_C$), will cause a STJ supination moment since it acts medial to the STJ axis. Ground reaction force acting plantar to the 5th metatarsal head (GRF$_{FF}$) will cause a STJ pronation moment since it acts lateral to the STJ axis. In a foot with a medially deviated STJ axis (left), since the plantar calcaneus now has a decreased STJ supination moment arm when compared to normal, GRF$_C$ will cause a decreased magnitude of STJ supination moment. Since the 5th metatarsal head has an increased STJ pronation moment arm, GRF$_{FF}$ will cause an increased magnitude of STJ pronation moment when compared to normal. However, in a foot with a laterally deviated STJ axis (right), since the plantar calcaneus now has an increased STJ supination moment arm, GRF$_C$will cause an increased magnitude of STJ supination moment and since the 5th metatarsal head has a decreased STJ pronation moment arm, GRF$_{FF}$ will cause a decreased magnitude of STJ pronation moment when compared to normal. Therefore, the net result of the mechanical actions of ground reaction force on a foot with a medial deviated STJ axis is to cause increased magnitude of STJ pronation moment and the net mechanical result of a laterally deviated STJ axis is to cause increased magnitude of STJ supination moment. (Reprinted with permission from Kirby KA: Subtalar joint axis location and rotational equilibrium theory of foot function. *JAPMA*, 91:465-488, 2001.)

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***Editor's Note:** In part 1 of this article Dr Kirby presented the historical evolution of foot orthoses, a basic overview of research and theory on orthosis function, and a look at research on therapeutic effectiveness. In part 2 he more deeply discusses theories on orthotic function.*

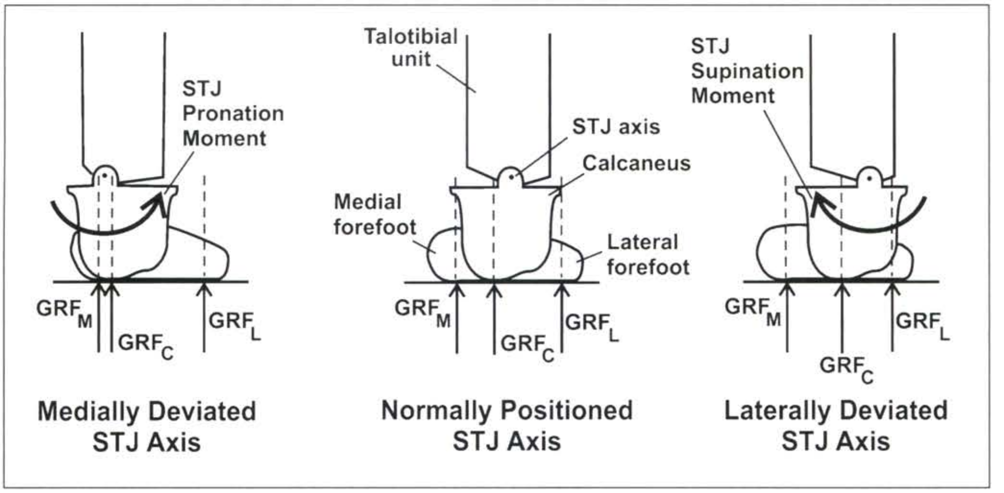

Figure 2: In the model above, a posterior view of the right foot and ankle are modeled as consisting of the talus and tibia combined together to form the talotibial unit which articulates with the foot at the subtalar joint (STJ) axis. The external forces acting on the foot include ground reaction force (GRF) plantar to the calcaneus (GRF$_C$), GRF plantar to the medial forefoot (GRF$_M$), and GRF plantar to the lateral forefoot (GRF$_L$). In a foot with a normal STJ axis location (center), the more central location of the STJ axis relative to the structures of plantar foot allows GRF$_C$, GRF$_M$, and GRF$_L$ to cause a balancing of STJ supination and STJ pronation moments so that more normal foot function occurs. In a foot with a medially deviated STJ axis (left), the more medial location of the STJ axis relative to the plantar structures of the foot will cause a relative lateral shift in GRF$_C$, GRF$_M$, and GRF$_L$, increasing the magnitude of STJ pronation moment and causing more pronation-related symptoms during weightbearing activities. In a foot with a laterally deviated STJ axis (right), the more lateral location of the STJ axis relative to the plantar structures of the foot will cause a relative medial shift in GRF$_C$, GRF$_M$, and GRF$_L$, increasing the magnitude of STJ supination moment and causing more supination-related symptoms.

Theories of Foot Orthosis Function

Even though the therapeutic efficacy of foot orthoses has been well documented within the medical literature for the past quarter century, the biomechanical explanation for the impressive therapeutic effects of foot orthoses has been a matter of speculation for well over a century. In 1888, Whitman made a metal foot brace that worked on the theory that the foot could be pushed into proper position either by force, or by pain, by the use of medial and lateral flanges that would rock into inversion once the patient had stepped on it.[5] Morton, in 1935, believed that a "hypermobile first metatarsal segment" was the cause of many foot maladies and that his "compensating insole" with an extension plantar to the first metatarsophalangeal joint would relieve "concentration of stresses on the second metatarsal segment".[8] Even though early authors claimed excellent clinical results with foot orthoses,[1,2,9] none offered coherent mechanical theories that described how foot orthoses might accomplish their impressive therapeutic results.

In the late 1950's and early 1960's, Root and his co-workers from the California College of Podiatric Medicine developed a classification system based on an ideal or "normal" structure of the foot and lower extremity that used Root's original concept of the subtalar joint (STJ) neutral position as a reference position of the foot.

In the late 1950's and early 1960's, Root and his co-workers from the California College of Podiatric Medicine developed a classification system based on an ideal or "normal" structure of the foot and lower extremity that used Root's original concept of the subtalar joint (STJ) neutral position as a reference position of the foot.[2,5,6,7] Root and co-workers also integrated their ideas of "normal" structure into an orthosis prescription protocol that had the following goals: 1) to cause the subtalar joint to function in the neutral position, 2) to prevent compensation, or abnormal motions, for foot and lower extremity deformities, and 3) to "lock the midtarsal joint."[1]

New ideas on foot function came in 1987 when Kirby first proposed that abnormal STJ rotational forces (i.e., moments) were responsible for many mechanically-based pathologies in the foot and lower extremity and that abnormal STJ axis spatial location was the primary cause of these pathological STJ moments.[2] A foot with a medially deviated STJ axis was suggested to be more likely to suffer from pronation-related symptoms since ground reaction force (GRF) would cause increased magnitudes of external STJ pronation moments (Figures 1 and 2). A

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foot with a laterally deviated STJ axis would tend to suffer from supination-related symptoms since GRF would cause increased magnitudes of external STJ supination moments.[49]

Medial and lateral deviation of the STJ axis were also proposed to cause changes in the magnitudes and directions of STJ moments that are produced by contractile activity of the extrinsic muscles of the foot (Figure 3).[49,51] When STJ axis spatial location was combined with the mechanical concept of rotational equilibrium, a new theory of foot function, the "Subtalar Joint Axis Location and Rotational Equilibrium (SALRE) Theory of Foot Function", emerged to offer a coherent explanation for the biomechanical cause of many mechanically-based pathologies of the foot and lower extremity.[3,4,49]

In 1992, Kirby and Green first proposed that foot orthoses functioned by altering the STJ moments

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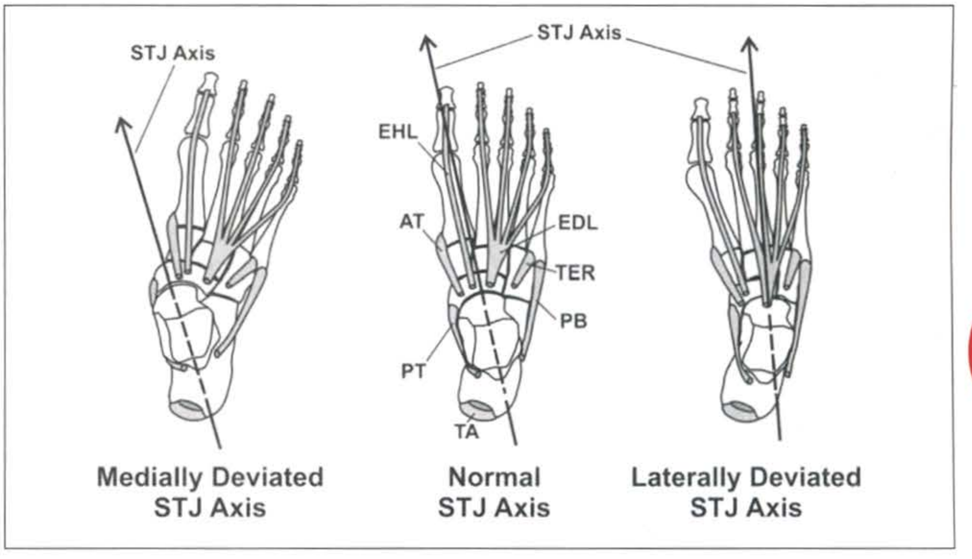

Figure 3: In a foot with a normal STJ axis location (center), the posterior tibial (PT), anterior tibial (AT), extensor hallucis longus (EHL) and Achilles tendons (TA) will all cause a STJ supination moment when they exert tensile force on their osseous insertion points since they all insert medial to the STJ axis. However, the extensor digitorum longus (EDL), peroneus tertius (TER), peroneus brevis (PB) tendons will all cause a STJ pronation moment when they exert tensile force on their insertion points since they all insert lateral to the STJ axis. However, in a foot with a medially deviated STJ axis (left), since the muscle tendons located medial to the STJ axis have a reduced STJ supination moment arm, their contractile activity will cause a decreased magnitude of STJ supination moment when compared to normal. In addition, since the muscle tendons lateral to the STJ axis have an increased STJ pronation moment arm, their contractile activity will cause an increased magnitude of STJ pronation moment. In addition, in a foot with a laterally deviated STJ axis (right), since the muscle tendons medial to the STJ axis have an increased STJ supination moment arm, their contractile activity will cause an increased magnitude of STJ supination moment when compared to normal. Since the muscle tendons lateral to the STJ axis have a decreased STJ pronation moment arm, their contractile activity will cause a decreased magnitude of STJ pronation moment. Therefore, the net mechanical effect of medial deviation of the STJ axis on the actions of the extrinsic muscles of the foot is to cause increased magnitudes of STJ pronation moment and the net mechanical effect of lateral deviation of the STJ axis on the actions of the extrinsic muscles of the foot is to cause increased magnitudes of STJ supination moment.

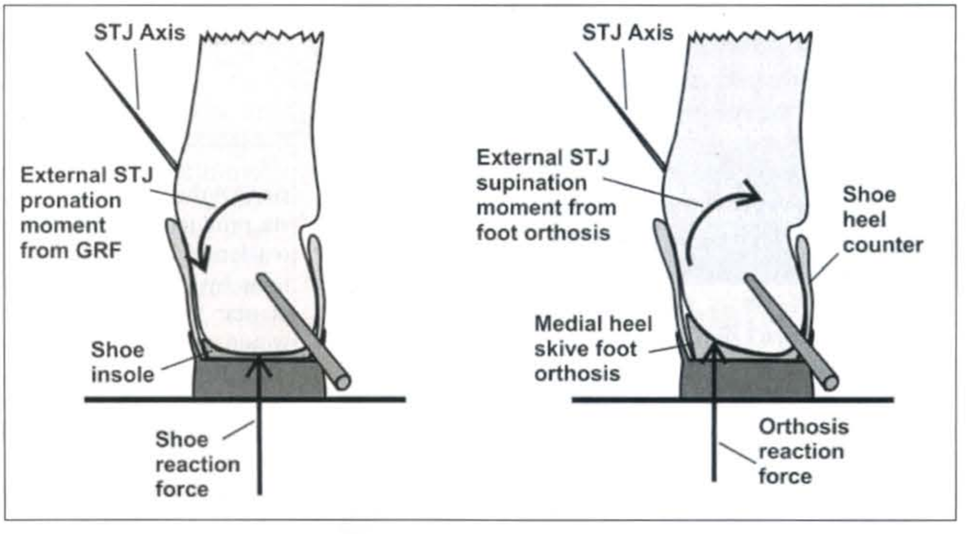

Figure 4: In the illustrations above, the posterior aspect of the right foot with a medially deviated subtalar joint (STJ) axis is shown in a shoe without an orthosis (left) and also is shown in a shoe with a medial heel skive foot orthosis (right). In the shoe with only the insole under the foot (left), the medially deviated STJ axis will cause increased STJ pronation moment since the shoe reaction force is more centrally located at the plantar heel. However, when the varus heel cup of a medial heel skive foot orthosis is added to the shoe (right), the resultant medial shift in orthosis reaction force will cause a decrease in STJ pronation moment and an increase in STJ supination moment. Therefore, foot orthoses with varus heel cup modifications, such as the medial heel skive, are more effective at treating symptoms caused by excessive foot pronation due to their ability to shift reaction forces more medially on the plantar foot and, thereby, greatly increase the STJ supination moment acting on the foot.

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that were created by the mechanical actions of ground reaction force (GRF) acting on the plantar foot during weight-bearing activities. They hypothesized that foot orthoses were able to exert their ability to "control pronation" by converting GRF acting lateral to the STJ axis into a more medially located orthosis reaction force (ORF) that would be able to generate increased STJ supination moments during weight-bearing activities. Using the example of a foot orthosis with a deep inverted heel cup, known as the Blake Inverted Orthosis,[3,14-16] they proposed that the inverted heel cup orthosis produced its impressive clinical results in reducing rearfoot pronation and relieving pronation-related symptoms by increasing the ORF on the medial aspect of the plantar heel so that increased STJ supination moments would result.[47]

Kirby later introduced a foot orthosis modification called the medial heel skive technique (Figure 4) that also produced an inverted heel cup in the orthosis to increase STJ supination moment and more effectively treat difficult pathologies such as pediatric flatfoot deformity, posterior tibial dysfunction and sinus tarsi syndrome.[17]

Foot and lower extremity pathologies caused by

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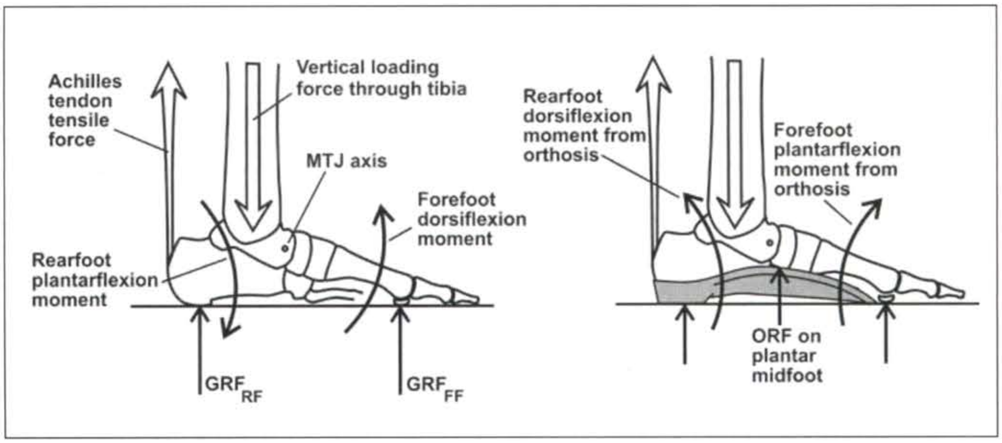

Figure 5: During standing without a foot orthosis (left), ground reaction force acting plantar to the rearfoot (GRF_{RF}), Achilles tendon tensile force acting on the posterior rearfoot and vertical loading force from the tibia acting onto the superior talus work together to mechanically cause a rearfoot plantarflexion moment which tends to cause the rearfoot to plantarflex at the ankle. In addition, ground reaction force acting plantar to the forefoot (GRF_{FF}) causes a forefoot dorsiflexion moment which tends to cause the forefoot to dorsiflex at the midtarsal joint (MTJ). Both the resultant rearfoot plantarflexion moment and forefoot dorsiflexion moment tend to cause the longitudinal arch of the foot to flatten. However, when a custom foot orthosis is constructed for the foot that applies a significant orthosis reaction force (ORF) to the plantar aspect of the longitudinal arch (right), the resultant increase in ORF at the plantar midfoot combined with the resultant decrease in GRF_{RF} and GRF_{FF} will cause an increase in rearfoot dorsiflexion moment and an increase in forefoot plantarflexion moment. By this mechanical method, foot orthoses help resist longitudinal arch flattening to produce one of the strongest biomechanical and therapeutic effects of orthoses on the foot and lower extremity.

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excessive magnitudes of external STJ supination moment, such as chronic peroneal tendinopathy and chronic inversion ankle sprains, were also proposed by Kirby to be caused by the interaction of GRF acting on the foot with an abnormally laterally deviated STJ axis.[3,18,50,51]

It was suggested that the abnormal STJ supination moments would be best treated with an increased valgus construction within the foot orthosis, including a lateral heel skive technique[3] within the heel cup of the orthosis. In this fashion, the orthosis would mechanically increase the magnitude of external STJ pronation moments by shifting ORF more laterally on the plantar foot to more effectively treat supination-related symptoms.

In the late 1980's and 1990's, a number of other authors also started focusing on the idea that orthosis treatment should not be determined by the results of measuring "deformities" of the foot and lower extremity, as proposed by Root and co-workers, but rather should be determined by the location and nature of the internal loading forces acting on injured structures of the patient.

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reliable estimates of these forces could instead be made with more effective models of the foot and lower extremity.[4-6]

However, it was not until 1995, when McPoil and Hunt first coined the term "Tissue Stress Model", that one of the most recent foot orthosis treatment models was given a proper name. McPoil and Hunt suggested that foot orthosis therapy should be directed toward reducing abnormal levels of tissue stress in order to more effectively design mechanical treatment aimed at healing musculoskeletal injuries caused by pathological tissue stress.

Fuller described how the location of the center of pressure on the plantar foot, relative to the spatial location of the STJ axis may help direct orthosis therapy for foot pathologies resulting from abnormal STJ moments.

They felt that by focusing the clinician's attention on the abnormal stresses causing the injury, rather than on measuring "deformities" of the lower extremity, that optimal mechanical foot therapy could be better achieved.[7]

Following up on the ideas embodied within the Tissue Stress Model, Fuller described, in 1996, how computerized gait evaluation and modelling techniques could be effectively used to guide foot orthosis treatment by aiding in the prediction of abnormal stresses within the foot and lower extremity.[8] Three years later, Fuller described how the location of the center of pressure on the plantar foot, relative to the spatial location of the STJ axis, may help direct orthosis therapy for foot pathologies resulting from abnormal STJ moments.[9] In later published works, Fuller and Kirby further explored the idea of reducing pathological tissue stress with orthoses and how this could be integrated with the SALRE Theory of Foot Function and an analysis of midtarsal joint kinetics (Figure 5) to guide the clinician toward a better understanding of foot

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orthosis function and toward more effective foot orthosis treatments for their patients with mechanically-based foot and lower extremity injuries.[3,10,11]

Another new theory of foot orthosis function, the "Preferred Movement Pathway Model", was proposed by Nigg and co-workers and was claimed to be a "new paradigm for movement control." Basing their new theory on previous scientific research, Nigg and co-workers proposed that foot orthoses do not function by realigning the skeleton but rather function by producing a change in the "muscle tuning" of the lower extremity via their alteration of the input signals into the plantar foot during athletic activities. It was suggested that if the preferred movement path is counteracted by the orthosis/shoe combination, then muscle activity would be increased, but conversely, if the preferred movement path is allowed by the orthosis/shoe combination, then lower extremity muscle activity would be reduced.[10,11]

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Even though their theory has received considerable attention within the international biomechanics community, their theory, and all the other above-mentioned theories, will require much further research to either support or reject their validity. These and other theories of foot function have been described in much greater detail in the excellent review articles by Paynex and Lee.[11] **PM**

References

[1] Schuster RO: A history of orthopedics in podiatry. J Am Pod Assoc, 64:332, 1974.

[2] Dorland's Illustrated Medical Dictionary, 25th ed., W.B. Saunders, Philadelphia, 1974.

[3] Kirby KA: Foot and Lower Extremity Biomechanics II: Precision Intricast Newsletters, 1997-2002. Precision Intricast, Inc., Payson, AZ, 2002.

[4] Dagnall, JC: History of foot supports. British J Chiropody, 32 (1):5-7, 1967.

[5] Whitman, Royal: Observations of forty-five cases of flat-foot with particular reference to etiology and treatment. Boston Med. Surg. J. 118:598,1888.

[6] Whitman, R: The importance of positive support in the curative treatment of weak feet and a comparison of the means employed to assure it. Am. J. Orth. Surg. 11:215-230, 1913.

[7] Roberts, PW: The initial strain in weak foot, its mechanics, and a new method of treatment. New York Medical Journal, 102(9):441-442, 1915.

[8] Morton DJ: The Human Foot: Its Evolution, Physiology and Functional Disorders. Columbia University Press, New York, 1935.

[9] Helfet AJ: A new way of treating flat feet in children. Lancet, 1:262-267, 1956.

[10] Root ML: How was the Root functional orthotic developed? Podiatry Arts Lab Newsletter, 1981.

[11] Lee WE: Podiatric biomechanics: an historical appraisal and discussion of the Root model as a clinical system of approach in the present context of theoretical uncertainty. Clin Pod Med Surg, 18:555-684, 2001.

[12] Root ML, Orien WP, Weed JH, RJ Hughes: Biomechanical Examination of the Foot, Volume 1. Clinical Biomechanics Corporation, Los Angeles, 1971.

[13] Henderson WH, Campbell JW: U.C.B.L. shoe insert casting and fabrication. Technical Report 53. Biomechanics Laboratory, University of California at San Francisco and Berkeley, 1967.

[14] Blake RL, Denton JA: Functional foot orthoses for athletic injuries: A retrospective study. JAPMA, 75:359-362, 1985.

[15] Blake RL: Inverted functional orthoses. JAPMA, 76:275-276, 1986.

[16] Blake RL, Ferguson H: Foot orthoses for the severe flatfoot in sports. JAPMA, 81:549, 1991.

[17] Kirby KA: The medial heel skive technique: improving pronation control in foot orthoses. JAPMA, 82: 177-188, 1992.

[18] Kirby KA: Foot and Lower Extremity Biomechanics: A Ten Year Collection of Precision Intricast Newsletters. Precision Intricast, Inc., Payson, Arizona, 1997.

[19] Valmassy, R.L.(ed): Clinical Biomechanics of the Lower Extremities. Mosby, St. Louis, 1996.

[20] Sackett DL, Rosenberg WMC, Gray JAM et al: Evidence based medicine: what it is and what it isn't. British Medical Journal, 312:71-72., 1996.

[21] Kirby KA: Emerging concepts in podiatric biomechanics. Podiatry Today. 19:(12)36-48, 2006.

[22] Eggold JF: Orthotics in the prevention of runner's overuse injuries. Phys. Sports Med., 9:181-185, 1981.

[23] D'Ambrosia RD: Orthotic devices in running injuries. Clin. Sports Med., 4:611-618, 1985.

24 Dugan RC, D'Ambrosia RD: The effect of orthotics on the treatment of selected running injuries. Foot Ankle, 6:313, 1986.

[25] Kilmartin TE, Wallace WA: The scientific basis for the use of biomechanical foot orthoses in the treatment of lower limb sports injuries-a review of the literature. Br. J. Sports Med., 28:180-184, 1994.

[26] Gross ML, Davlin LB, Evanski PM: Effectiveness of orthotic shoe inserts in the long distance runner. Am. J. Sports Med., 19:409-412, 1991.

[27] Blake RL, Denton JA: Functional foot orthoses for athletic injuries: A retrospective study. JAPMA, 75:359-362, 1985.

[28] Saxena A, Haddad J: The effect of foot orthoses on patellofemoral pain syndrome. 93:264-271, 2003.

[29] Donatelli R, Hurlbert C, Conaway D, St. Pierre R: Biomechanical foot orthotics: A retrospective study. J Ortho Sp Phys Ther, 10:205-212, 1988.

[30] Moraros J, Hodge W: Orthotic survey: Preliminary results. JAPMA, 83:139-148, 1993.

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[31] Walter JH, Ng G, Stoitz JJ: A patient satisfaction survey on prescription custom-molded foot orthoses. JAPMA, 94:363-367, 2004

[32] Kusomoto A, Suzuki T, Yoshida H, Kwon J: Intervention study to improve quality of life and health problems of community-living elderly women in Japan by shoe fitting and custom-made insoles. Gerontology, 22:110-118, 2007.

[33] Finestone A, Giladi M, Elad H, et al.: Prevention of stress fractures using custom biomechanical shoe orthoses. Clin Orth Rel Research, 360:182-190, 1999.

[34] Simkin A, Leichter I, Giladi M, et al.: Combined effect of foot arch structure and an orthotic device on stress fractures. Foot Ankle, 10:25-29, 1989.

[35] Eng JJ, Pierrynowski MR: Evaluation of soft foot orthotics in the treatment of patellofemoral pain syndrome. Phys Therapy, 73:62-70, 1993.

[36] Thompson JA, Jennings MB, Hodge W: Orthotic therapy in the management of osteoarthritis. JAPMA, 82:136-139, 1992.

[37] Marks R, Penton L. Are foot orthotics efficacious for treating painful medial compartment knee osteoarthritis? A review of the literature. Int J Clin Practice, 58:49-57, 2004.

[38] 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 Ortho Sp Phys Ther, 32:149-157, 2002.

[39] Slattery M, Tinley P: The efficacy of functional foot orthoses in the control of pain and ankle joint disintegration in hemophilia. JAPMA, 91:240-244, 2001.

[40] Chalmers AC, Busby C, Goyert J, et al.: Metatarsalgia and rheumatoid arthritis-a randomized, single blind, sequential trial comparing two types of foot orthoses and supportive shoes. J Rheum, 27:1643-1647, 2000.

[41] Woodburn J, Barker S, Helliwell PS: A randomized controlled trial of foot orthoses in rheumatoid arthritis. J Rheum, 29:1377-1383, 2002.

[42] Mejjad O, Vittecoq O, Pouplin S, et al.: Foot orthotics decrease pain but do not improve gait in rheumatoid arthritis patients. Joint Bone Spine, 71:542-545, 2004.

[43] Powell M, Seid M, Szer IA: Efficacy of custom foot orthotics in improving pain and functional status in children with juvenile idiopathic arthritis: A randomized trial. J Rheum, 32:943-950, 2005.

[44] Rose GK: Correction of the pronated foot. JBJS, 40B:674-683, 1958.

[45] Rose GK: Correction of the pronated foot. JBJS, 44B:642-647, 1962.

[46] Sgarlato TE (ed): A Compendium of Podiatric Biomechanics. California College of Podiatric Medicine, San Francisco, 1971.

[47] Kirby KA, Green DR: Evaluation and Nonoperative Management of Pes Valgus, pp. 295-327, in DeValentine, S.(ed), Foot and Ankle Disorders in Children. Churchill-Livingstone, New York, 1992.

[48] Root ML, Weed JH: Personal communication. 1984.

[49] Kirby KA: Methods for determination of positional variations in the subtalar joint axis. JAPMA, 77: 228-234, 1987.

[50] Kirby KA: Rotational equilibrium across the subtalar joint axis. JAPMA, 79: 1-14, 1989.

[51] Kirby KA: Subtalar joint axis location and rotational equilibrium theory of foot function. JAPMA, 91:465-488, 2001.

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