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TECHNIQUE

Midfoot Arthritis: Nonoperative Options and Decision Making for Fusion

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ABSTRACT

Arthritis of the midtarsal and tarsometatarsal joints (midfoot) has emerged as a challenging problem because of its high potential for chronic foot pain and functional disability. Although the incidence of patients presenting with midfoot arthritis is increasing at an alarming rate, guidelines for clinical decision making are lacking in the literature. The primary aim of treatment is to afford pain relief by enhancing midfoot stability and modifying loads sustained at the inflamed joints. These treatment goals are attempted initially through conservative management such as orthoses followed by surgery. This manuscript discusses strategies for conservative management and details the operative techniques for tarsometatarsal fusion. In addition, outcomes after intervention are presented.
Keywords: midfoot, Lisfranc, arthrodesis, fusion

HISTORICAL PERSPECTIVE

Incidence

Arthritis of the midtarsal and tarsometatarsal joints (midfoot) has emerged as a challenging problem because of its high potential for chronic foot pain and functional disability. As one of the leading causes of disability in the United States, arthritis, not only has a profound negative impact on quality of life but also augurs substantial economic burden for patients and their care providers. Although the incidence of patients presenting with midfoot arthritis is increasing at an alarming rate, guidelines for clinical decision making are lacking in the literature.

The etiology of midfoot arthritis includes primary (idiopathic), inflammatory, and posttraumatic causes; posttraumatic arthritis being the most common. Posttraumatic arthritis is seen most frequently after midfoot injuries, which affect approximately 55,000 people per year.[1] Midfoot injuries are commonly associated with direct and indirect trauma sustained secondary to falls, twisting, and/or crush injuries. Fractures and dislocations of the midfoot (Lisfranc fractures) are especially common in the athletic population.[2–4] Despite their seemingly low incidence, Lisfranc injuries are particularly concerning because as many as 20% are missed or misdiagnosed.[5,6] Additionally, in recent years, these injuries have increased both, in frequency and severity, secondary to motor vehicle trauma.[7–11] With the use of seat belts and air bags, significant improvements in driver and passenger safety have been noted. However, increasing numbers of front-seat occupants present with midfoot injuries due to plantar impact forces sustained with the foot in a plantar flexed position.[12] Irrespective of the mechanism of trauma, midfoot arthritis (Fig. 1) has been reported to be the inevitable sequela of significant tarsometatarsal joint injuries.[13–15]

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PATHOMECHANICS ASSOCIATED WITH MIDFOOT DISORDERS

Normal foot function during gait requires the foot to transition from a flexible structure that dissipates impact as it contacts the ground to a rigid structure that allows for efficient propulsion during push-off.[16] Midfoot stability during the midstance phase of gait is critical because it facilitates forward progression of body weight on a stable foot.[17] Loss of midfoot stability during midstance may lead to a failure to position the foot effectively for push-off. These impairments in midfoot stability not only are reflected in symptoms during level walking but also manifest as difficulty with stair ascent and descent as well as in any activities that require heel raise.

Loss of midfoot stability may manifest as abnormal foot posture,[18–22] often characterized by an increased arch angle and negative talar–first metatarsal angle. These changes correspond to lowering of the arch and

FIGURE 1. Weight-bearing, lateral, oblique, and anteroposterior radiographs of the foot in a patient with midfoot arthritis demonstrating joint space narrowing; osteophyte formation; and sclerosis of the first, second, and third tarsometatarsal joints.

may lead to increased tensile stresses on the supporting plantar ligaments as the foot is loaded, thus contributing to the development of foot pain.[23] Failure to restore the arch may compromise the ability of the foot to function effectively as a rigid lever. Arch lowering during the push-off phase of gait may also lead to greater demands on muscular and ligamentous supports, further contributing to tissue stress and ensuing pain.

In addition to abnormal foot postures and/or associated movement patterns, recent evidence supports the key relationship between plantar loading and the development of foot pain. Higher plantar loads are associated with higher pain scores.[24,25] Additionally, the location of pressures has been associated with presentation of pain in patients with midfoot arthritis.[26]

Degenerative disorders of the foot, such as arthritis, may render the foot more susceptible to foot pain due to mechanical overloading of foot regions that are not usually loaded.[27] In addition to their direct effects on tissue stress and ensuing foot pain, changes in foot posture and regional plantar loading may also have indirect consequences on the reaction forces and moments. Individually or combined, foot posture, motion, and plantar loading may be linked to abnormal articular loads and subsequent damage at the tarsometatarsal joints.

Lack of midfoot stability and/or increased loading has been postulated to exacerbate pain in patients with midfoot arthritis. The primary aim of treatment is to afford pain relief by enhancing midfoot stability and modifying loads sustained at the inflamed joints. These treatment goals are attempted initially through conservative management such as orthoses followed by surgery, if needed.

■ CONSERVATIVE MANAGEMENT

Midfoot injuries and consequent arthritis present a particularly challenging clinical problem because of the high rate of delayed morbidity.[8] Patients with midfoot arthritis present with persistent midfoot complaints including severe restriction in the ability to walk and to perform activities of daily living. Seventy-eight percent reported problems with foot posture. Patients who present with foot deformity also have problems with wearing shoes.[28] Clinically, patients with degenerative arthritis and patients with posttraumatic arthritis present with similar symptoms: pain and progressive deformity.[28]

Nonsteroidal anti-inflammatory drugs (NSAIDs) have long been considered the first line of treatment in the management of midfoot arthritis. However, the adverse effects of nonselective NSAIDs,[29] the prohibitive cost, and the concerns related to cardiovascular safety of selective NSAIDs[30] make extended NSAID use undesirable. Although cortisone and hyaluronic acid injections have had extensive study in the knee, there have been no published studies on the effectiveness of these agents in the midfoot.[31]

In the absence of treatments that prevent or cure the underlying disease process in arthritis, the onus of management shifts to conservative therapy. Orthotic intervention is attractive because of minimal adverse effects accompanying treatment.[29,30] Consequently, intervention strategies in the form of shoe modifications and foot orthoses continue to serve as the mainstay of treatment in patients with midfoot arthritis. The primary aim of treatment is to provide pain relief by modifying load to the tarsometatarsal joints.

Shoe modifications such as stiff soles or rocker-bottom soles have been used in an attempt to facilitate weight transfer during gait while modulating loads to the tarsometatarsal joints. More aggressive forms of bracing include polypropylene ankle foot orthoses. These devices allow greater restriction of foot and ankle range of motion. In addition, patellar-tendon bearing or clamshell-type orthoses enable off-loading of the foot by up to 30%.[32]

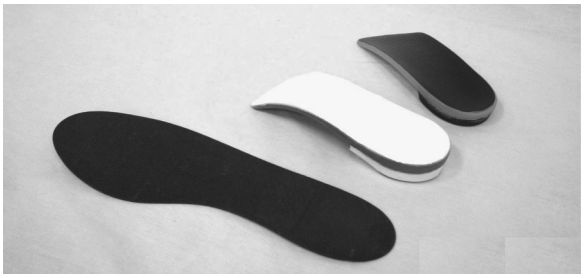

FIGURE 2. Custom molder 3Q shoe insert (2 on left) and the CFP shoe insert (1 on right).

However, these orthoses often require rocker-bottom shoes to facilitate smooth transitions during gait. These modifications are often perceived to be cumbersome and cosmetically unacceptable, thereby negatively affecting patient compliance. Shoe modifications are also less convenient for patients who use multiple pairs of footwear, some of which may not lend themselves to the required modifications. For these reasons, shoe inserts, which may be used interchangeably in different pairs of shoes, provide a reasonable alternative.

The majority of data examining orthotic effectiveness has been directed to the athletic and orthopedic population and, more recently, to patients with rheumatoid arthritis. Limited objective data exist to assist clinical decision making regarding orthotic intervention in patients with midfoot arthritis. The custom-molded three-quarter length rigid shoe insert (3Q) is often recommended in this clinical population with midfoot problems.[33] Although the 3Q may be effective in some patients, recent clinical experience has shown that patients may continue to report foot pain during walking, suggesting that this orthosis does not provide adequate control of midfoot stability. In addition, the 3Q may load the foot in regions that do not tolerate loading.

An alternative to the custom molded, 3Q is the full-length carbon foot plate (CFP; Fig. 2). A recent retrospective review[34] and preliminary studies involving patients with midfoot arthritis from our clinic[26] indicate that foot pain and dysfunction in this population may be amenable to a simple and cost-effective treatment in the form of an over-the-counter CFP shoe insert. Recent findings have shown that symptomatic improvement associated with the use of the CFP are accompanied by a 35% reduction in average pressure and a 21% reduction in contact time at the medial midfoot, compared with the 3Q condition. These results provide objective data regarding the mechanisms underlying effectiveness of shoe inserts in patients with midfoot arthritis. These positive outcomes support the use of the full-length CFP as a viable alternative in the conservative management of patients with midfoot arthritis.

Because of the differences in design features such as length and contour, shoe inserts may differ in the mechanism by which they affect foot function and loading during walking. Consequently, different shoe inserts have variable efficacy, and some may fail to offer satisfactory pain relief. In light of recent evidence that supports the use of a full-length CFP, practitioners need to carefully consider the recommendation of custom versus over-the-counter orthoses in the successful management of patients with midfoot arthritis.

INDICATIONS/CONTRAINDICATIONS FOR OPERATIVE MANAGEMENT

Similar to guidelines used in the treatment of posttraumatic midfoot arthritis,[35] in a report of patients with atraumatic midfoot arthritis, operative intervention was offered to patients who continued to report severe pain, not responding to 6 months of aggressive nonoperative treatments.[36] Mann et al[28] used the following guidelines as indication for surgery: severe loss of function due to pain, with or without deformity that had failed to respond to nonoperative treatment. *Severe loss of function* was defined as the inability to return to his/her usual occupation or to perform activities of daily living.

Average age of patients with degenerative arthritis at surgery has been reported at 60 (range, 27–84 years); average mass, 78.8 kg (range, 52.7–121.5 kg); and average height, 1.68 m (range, 1.4–2.0 m).[28,36] Patients with posttraumatic arthritis who undergo surgery tended to be younger (average age, 40 years; range, 23–67 years).

Weight-bearing radiographs of patients undergoing surgery show strong evidence of arthritic changes and the presence of foot deformity. Although the extent of arthritic changes varied, arthritic changes have been noted at the midtarsal and tarsometatarsal joints.[28] Patients also demonstrated a more pronated foot posture on weight-bearing radiographs, which was more conspicuous in degenerative arthritis than in posttraumatic arthritis.[28] Pronated foot posture manifests as negative talar–first metatarsal angle and lower medial cuneiform height.[28,35,36] Preoperative lateral talar–first metatarsal angle ranged between −5 and 24 degrees (lateral talar–first metatarsal angle in asymptomatic feet, 0 degree)[28,36] Preoperative medial cuneiform height ranged from 15 to 22 mm (medial cuneiform height in asymptomatic feet, 39 mm). Preoperative radiographs of patients with midfoot arthritis showed that, of all the joints of the medial column of the foot, tarsometatarsal joint dorsal angulation or "sagging" is most common and occurred in 33 (65%) of 51 patients who underwent fusion. In order of incidence, the authors reported sagging of the naviculocuneiform joint (7 [14%] of 51 patients), talonavicular (4 [8%] of 51 patients), or no joint (8 [16%] of 51 patients). These findings underscore the extent of foot deformity in patients with midfoot arthritis and highlight

FIGURE 3. Weight-bearing, lateral, oblique, and anteroposterior radiographs of the foot in a patient with midfoot arthritis demonstrating plate stabilization technique for midfoot fusion and compression staple.

the importance of medial tarsometatarsal integrity.[36] In addition, concomitant deformity is common in patients with midfoot arthritis (hallux valgus [11/51], rocker-bottom [5/51], pes planovalgus [27/51]—most common). After midfoot fusion, the rocker-bottom group showed relatively large sagittal plane correction of deformity, whereas patients with pes cavus deformity showed larger improvements in the transverse plane.[36] Forefoot abduction and dorsiflexion may be more severe in primary degenerative arthritis.[28]

■ PREOPERATIVE PLANNING

Weight-bearing radiographs of the foot and ankle are obtained to assess the tarsometatarsal and cuneiform-navicular joints for arthritic changes (joint space narrowing, osteophyte formation, sclerosis, and cyst formation) and alignment of the foot and ankle in the frontal and sagittal planes. The painful arthritic joints are identified and planned for operative arthrodesis. The decision making for which joints to include can be difficult, and selective lidocaine blocks of the tarsometatarsal and tarsal-tarsal joints have been suggested in the past. A recent study examining injections of the tarsometatarsal joints found that there can be leakage of the anesthetic from the second tarsometatarsal joint laterally in more than 20% of the cases. This raises the questions of the diagnostic value of these lidocaine injections. It is rare that the second tarsometatarsal joint would be an isolated arthrodesis, and therefore, recommendations for the stability of the medial column would suggest that the first, second, and potentially third tarsometatarsal joint and, if symptomatic, the corresponding cuneiform-navicular articulations be included in the arthrodesis. The surgeon will need to clinically examine these joints and discuss this with the patient and use the radiographic criteria to decide on which joints to be arthrodesed.

■ TECHNIQUE FOR MIDFOOT FUSION

A gentle "C-shaped" longitudinal incision with apex of the "C" centered over the second tarsometatarsal joint facilitates exposure to the first and second tarsometatarsal joints in the corresponding cuneiform-navicular joints. If the third tarsometatarsal joint and its corresponding calcaneonavicular joint require an arthrodesis, a supplemental straight longitudinal incision over the lateral aspect of the third metatarsal would allow for this exposure. The interval between the extensor hallucis longus and extensor hallucis brevis is exploited to the bone. Subperiosteal dissection of the joints of interest is completed with full-thickness flaps. The articular cartilage to the joints is removed using a sharp gouge and curette. Multiple K wire perforations of the remaining subchondral bone are performed. Temporary K wire stabilization of the joints for anatomical arthrodesis position is performed. The first ray is plantar flexed. This can be accomplished by hyperextending the first metatarsophalangeal joint during the temporary stabilization. A common error is to allow this first ray to become more dorsiflexed or horizontal, and this will lead to transfer metatarsalgia of the lesser toes. The second and third tarsometatarsal joints also require temporary stabilization of the K wire fixation. Care is taken to obtain a tight apposition of the second metatarsal base with the medial cuneiform as well as the first metatarsal base to reestablish Lisfranc joint alignment. Permanent compressive "lag screw" fixation of the first tarsometatarsal, medial cuneiform–second tarsometatarsal, and second tarsometatarsal–middle cuneiform and third tarsometatarsal are necessary to arthrodese these joints. Extension to the naviculocuneiform joints with lag screw fixation

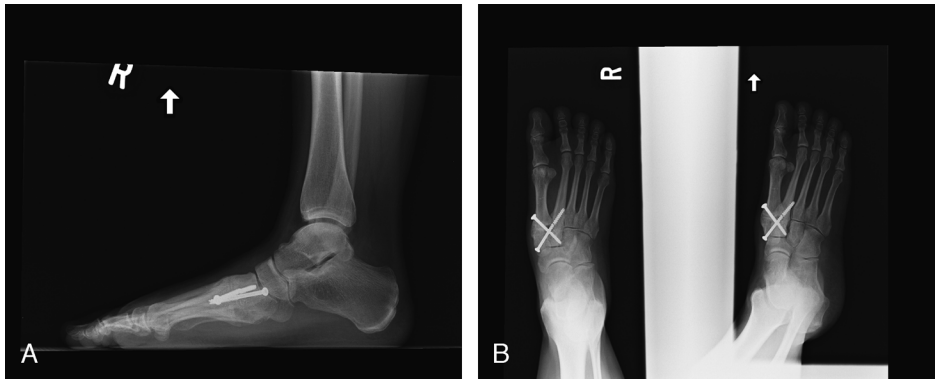

FIGURE 4. Weight-bearing, lateral, oblique, and anteroposterior radiographs of the foot in a patient with arthodesis of the first and second tarsometatarsal joint with screw fixation and subsequent complication of screw breakage.

can also be performed if painful arthritis is diagnosed within these joints. The type of screws used can include partially threaded cancellous screws or recently, variable pitched fully threaded cannulated screws. Cannulated screws provide ease of positioning with an initial K wire placement and also provide rigid fixation. Variable compression fully threaded screws may be indicated due to their higher fatigue resistance to fracture. Alternative options include a compressive plating fixation (Fig. 3). After stabilization with a screw or plate systems, the wounds are irrigated and closed with a 3.0 monocryl (absorbable) sutures with a 1-layer closure. A posterior splint is applied.

■ ADDITIONAL CONSIDERATIONS IN SURGICAL MANAGEMENT

Autologous and allograft bone supplementation for midfoot fusions have had minimal study.[37] There are no published studies examining the effectiveness of biological agents such as bone morphogenic proteins in the midfoot. Interposition arthroplasty with tendon anchoring for the fourth and fifth tarsometatarsal joints has been found to decrease pain and improve function in a small case series.[38] An alternative option, using spherical ceramic implants into the fourth and fifth tarsometatarsal joints, was also shown by the same group to decrease pain and improve function in another small group of patients.[39] To date, there have been no prospective or retrospective studies comparing these options in the midfoot.

■ POSTOPERATIVE MANAGEMENT

At one week the splint and dressing is changed and the wounds are visualized. The patient is placed in a non—weight-bearing cast for an additional 5 weeks (6 weeks total) then changed to a walking cast for 6 more weeks (12 weeks total immobilization). Radiographs are taken at the 1-, 6-, and 12-week timeframes to inspect for bone bridging indicative of fusion.

■ COMPLICATIONS

Complications after midfoot arthrodesis have been classified into the following categories[37,40]:

1. wound healing;
2. infectious, 3%[35];
3. peripheral nerves, 9%[35] and neuroma formation in 7%[28];
4. nonunions—nonunion secondary to midfoot arthrodesis occurs in 3% to 7% of patients.[28,35,37] Elderly patients are at increased risk of nonunion;
5. implant complications (Fig. 4), 6 (9%) of 65 had pain from screw irritation.[36] Plates may provide superior biomechanical strength compared with screw fixation[41–43];
6. long-term complications, 3 (4.5%) of 65 developed secondary arthritis in adjacent joints[36]; and
7. rare complications include asymptomatic nonunion, wound slough, superficial infection, and reflex sympathetic dystrophy.[35]

Although foot rigidity occurring subsequent to arthrodesis is well tolerated by patients,[28] 7% (3/41) developed stress fractures due to abnormal loading of the metatarsal heads. Metatarsalgia has been reported in 6% (2/31).[35] Twenty-six (38.8%) of 65 feet were reported to have one or more of the following painful conditions including sesamoid pain under the first metatarsal, lateral foot pain (5 [7.5%] of 67), and neuralgia of the sural nerve.[36]

■ RESULTS AND OUTCOMES AFTER OPERATIVE MANAGEMENT

Standardized validated outcome instruments are extremely valuable to systematically evaluate the effectiveness

of surgical intervention. Improvements in self-reported functional outcomes are important because reduced physical function is a strong predictor of restrictions in daily activity, future disability, and loss of independence.[44] Pain scales, generic quality of life instruments, and foot-specific scales have been used to evaluate outcomes after intervention in patients with midfoot arthritis. Limited evidence exists regarding outcomes after conservative intervention. One recent report found a 22% improvement in Foot Function Index–Revised total score after 4 weeks of intervention with the CFP shoe insert. The improvement in Foot Function Index–Revised total score was driven largely by decreases in pain (29%) and activity limitation (26%).[26] Effective early intervention may play an important role in influencing modifiable mechanical risk factors and prevent progression of symptoms. In addition, shoe inserts may be used in the postoperative rehabilitation protocol to enhance functional outcomes.

In terms of self-reported outcomes after surgery, patients with atraumatic midfoot arthritis treated operatively demonstrated SF-36 postoperative scores (44.4) that were comparable to arthritis group of US population (43.2) but continued to stay lower than US general age-matched population (45.9). American Orthopaedic Foot and Ankle Society scores showed significant improvement in pain (reduction by 60.5%), gait abnormality (59.7%), and alignment (47.1%).[35,36,45] Similarly, Foot Function Index scores showed significant improvement in pain, disability, and activity limitation subscales.[36]

Anatomical reduction has been identified as the most important predictor of good outcome.[45–47] Overall, 38 (93%) of 41 patients reported satisfactory results.[28] Sangeorzan et al[47] reported good-to-excellent results in 69% (11/16) of patients with fractures or fracture dislocations of the Lisfranc joint who had failed initial treatment and were salvaged by arthrodesis. Myerson et al[46] reported that whereas 49% achieved an excellent or good result at 4.2 years of follow-up, 51% reported fair or poor results. Although surgical intervention is accompanied by decreased pain, improvements in function may be modest.[14,15,40,45,48,49] Previous reports have concluded that age[28] and mechanism of injury[35] factors are not significant predictors of outcomes after arthrodesis.

On radiographic assessment, patients may show under-correction of deformity, evidenced as lateral talar-metatarsal angle that ranged from −1 to 10 degrees (lateral talar–first metatarsal angle in asymptomatic feet, 0 degree).[28,36] At 40.6 months (range, 12–94 months), 19 (29.2%) of 65 feet had residual low arch, and 14 (21.5%) of 65 feet had heel valgus.[36] The pronation-abduction stress test was positive for nonunion in 4 (6.25%) of 65 feet.[36] Residual strength deficit in the form of reduced posterior tibial muscle strength was noted in 21 (32.3%) of 65. Thirty-five (53.8%) of 65 graded as normal in the double-heel rise test; 29 (44.6%) of 65 graded as normal in the single-heel raise test.

SUMMARY

Arthritis of the midtarsal and tarsometatarsal joints (midfoot) has emerged as a challenging problem because of its high potential for chronic foot pain and functional disability. Although the incidence of patients presenting with midfoot arthritis is increasing at an alarming rate, guidelines for clinical decision making are lacking in the literature. The primary aim of treatment is to afford pain relief by enhancing midfoot stability and modifying loads sustained at the inflamed joints. These treatment goals are attempted initially through conservative management such as orthoses followed by surgery. Recent evidence supports the use of a full-length CFP in the conservative management of patients with midfoot arthritis. Practitioners need to carefully consider the recommendation of custom versus over-the-counter orthoses in the successful management of patients with midfoot arthritis. Arthrodesis of the arthritic joints is accompanied by decreased pain and improved function.

REFERENCES

1. Hardcastle PH, Reschauer R, Kutscha-Lissberg E, et al. Injuries to the tarsometatarsal joint. Incidence, classification and treatment. *J Bone Joint Surg Br*. 1982;64:349–356.
2. Curtis MJ, Myerson M, Szura B. Tarsometatarsal joint injuries in the athlete. *Am J Sports Med*. 1993;21:497–502.
3. Mantas JP, Burks RT. Lisfranc injuries in the athlete. *Clin Sports Med*. 1994;13:719–730.
4. Meyer SA, Callaghan JJ, Albright JP, et al. Midfoot sprains in collegiate football players. *Am J Sports Med*. 1994;22:392–401.
5. Goossens M, De Stoop N. Lisfranc's fracture-dislocations: etiology, radiology, and results of treatment. A review of 20 cases. *Clin Orthop Relat Res*. June 1983;176:154–162.
6. Englanoff G, Anglin D, Hutson HR. Lisfranc fracture-dislocation: a frequently missed diagnosis in the emergency department. *Ann Emerg Med*. 1995;26:229–233.
7. Manoli, A 2nd, Prasad P, Levine RS. Foot and ankle severity scale (FASS). *Foot Ankle Int*. 1997;18:598–602.
8. Richter M, Thermann H, Wippermann B, et al. Foot fractures in restrained front seat car occupants: a long-term study over twenty-three years. *J Orthop Trauma*. 2001;15:287–293.
9. Parenteau CS, Viano DC, Lovsund P, et al. Foot-ankle injuries: influence of crash location, seating position and age. *Accid Anal Prev*. 1996;28:607–617.

10. Wilson, LS Jr, Mizel MS, Michelson JD. Foot and ankle injuries in motor vehicle accidents. *Foot Ankle Int*. 2001;22:649–652.

11. Smith BR, Begeman PC, Leland R, et al. A mechanism of injury to the forefoot in car crashes. *Traffic Inj Prev*. 2005;6:156–169.

12. Richter M, Wippermann B, Thermann H, et al. Plantar impact causing midfoot fractures result in higher forces in Chopart's joint than in the ankle joint. *J Orthop Res*. 2002;20:222–232.

13. Mulier T, Reynders P, Sioen W, et al. The treatment of Lisfranc injuries. *Acta Orthop Belg*. 1997;63:82–90.

14. Richter M, Wippermann B, Krettek C, et al. Fractures and fracture dislocations of the midfoot: occurrence, causes and long-term results. *Foot Ankle Int*. 2001;22:392–398.

15. Teng AL, Pinzur MS, Lomasney L, et al. Functional outcome following anatomic restoration of tarsal-metatarsal fracture dislocation. *Foot Ankle Int*. 2002;23:922–926.

16. Saltzman CL, Nawoczenski DA. Complexities of foot architecture as a base of support. *J Orthop Sports Phys Ther*. 1995;21:354–360.

17. Song J, Hillstrom HJ, Secord D, et al. Foot type biomechanics. Comparison of planus and rectus foot types. *J Am Podiatr Med Assoc*. 1996;86:16–23.

18. Wadsworth DJ, Eadie NT. Conservative management of subtle Lisfranc joint injury: a case report. *J Orthop Sports Phys Ther*. 2005;35:154–164.

19. Rattanaprasert U, Smith R, Sullivan M, et al. Three-dimensional kinematics of the forefoot, rearfoot, and leg without the function of tibialis posterior in comparison with normals during stance phase of walking. *Clin Biomech (Bristol, Avon)*. 1999;14:14–23.

20. Tome J, Nawoczenski DA, Flemister A, et al. Comparison of foot kinematics between subjects with posterior tibialis tendon dysfunction and healthy controls. *J Orthop Sports Phys Ther*. 2006;36:635–644.

21. Wilken J. *The Effect of Arch Height on Tri-planar Foot Kinematics During Gait, in Physical Rehabilitation Science*. Iowa City: The University of Iowa; 2006;94.

22. Hunt AE, Smith RM, Torode M, et al. Inter-segment foot motion and ground reaction forces over the stance phase of walking. *Clin Biomech (Bristol, Avon)*. 2001;16:592–600.

23. Gazdag AR, Cracchiolo A 3rd. Rupture of the posterior tibial tendon. Evaluation of injury of the spring ligament and clinical assessment of tendon transfer and ligament repair. *J Bone Joint Surg Am*. 1997;79:675–681.

24. Hodge MC, Bach TM, Carter GM. Novel Award First Prize Paper. Orthotic management of plantar pressure and pain in rheumatoid arthritis. *Clin Biomech (Bristol, Avon)*. 1999;14:567–575.

25. Burns J, Crosbie J, Hunt A, et al. The effect of pes cavus on foot pain and plantar pressure. *Clin Biomech (Bristol, Avon)*. 2005;20:877–882.

26. Rao S, Nawoczenski D, Baumhauer J. Shoe inserts alter plantar loading and functional outcomes in patients with midfoot arthritis. *Foot Ankle Int*. 2007. In review.

27. Jannink M, van Dük H, Ijzerman M, et al. Effectiveness of custom-made orthopaedic shoes in the reduction of foot pain and pressure in patients with degenerative disorders of the foot. *Foot Ankle Int*. 2006;27:974–979.

28. Mann RA, Prieskorn D, Sobel M. Mid-tarsal and tarsometatarsal arthrodesis for primary degenerative osteoarthrosis or osteoarthrosis after trauma. *J Bone Joint Surg Am*. 1996;78:1376–1385.

29. Bert JM, Gasser SI. Approach to the osteoarthritic knee in the aging athlete: debridement to osteotomy. *Arthroscopy*. 2002;18(9 suppl 2):107–110.

30. Mukherjee D, Nissen SE, Topol EJ. Risk of cardiovascular events associated with selective COX-2 inhibitors. *JAMA*. 2001;286:954–959.

31. Pleimann JH, Davis WH, Cohen BE, et al. Viscosupplementation for the arthritic ankle. *Foot Ankle Clin*. 2002;7:489–494.

32. Saltzman CL, Johnson KA, Goldstein RH, et al. The patellar tendon-bearing brace as treatment for neurotrophic anthropathy: a dynamic force for monitoring study. *Foot Ankle*. 1992;13:14–21.

33. ACFAOM. *Prescription Custom Foot Orthoses Practice Guidelines of the American College of Foot and Ankle Orthopedics and Medicine*. In: Jarett B, Bernstein D, eds. Bethesda, MD: The American College of Foot and Ankle Orthopedic Medicine; 2004. Available online at: http://64.176.45.146/pg1103.pdf.

34. Pletka J, Cavitt A, Baumhauer J. *Carbon Foot Plates in the Non-Operative Treatment of Midfoot Arthritis*. Boca Raton, FL: Eastern Orthopedic Association; 2006.

35. Komenda GA, Myerson MS, Biddinger KR. Results of arthrodesis of the tarsometatarsal joints after traumatic injury. *J Bone Joint Surg Am*. 1996;78:1665–1676.

36. Jung HG, Myerson MS, Schon LC. Spectrum of operative treatments and clinical outcomes for atraumatic osteoarthritis of the tarsometatarsal joints. *Foot Ankle Int*. 2007;28:482–489.

37. Bibbo C, Anderson RB, Davis WH. Complications of midfoot and hindfoot arthrodesis. *Clin Orthop Relat Res*. October 2001;391:45–58.

38. Berlet GC, Davis WH, Anderson RB. Tendon arthroplasty for basal fourth and fifth metatarsal arthritis. *Foot Ankle Int*. 2002;23:440–446.

39. Shawen SB, Anderson RB, Cohen BE, et al. Spherical ceramic interpositional arthroplasty for basal fourth and fifth metatarsal arthritis. *Foot Ankle Int*. 2007;28:896–901.

40. Arntz CT, Hansen ST Jr. Dislocations and fracture dislocations of the tarsometatarsal joints. *Orthop Clin North Am*. 1987;18:105–114.

41. Suh JS, Amendola A, Lee KB, et al. Dorsal modified calcaneal plate for extensive midfoot arthrodesis. *Foot Ankle Int*. 2005;26:503–509.

42. Marks RM, Parks BG, Schon LC. Midfoot fusion technique for neuroarthropathic feet: biomechanical analysis and rationale. *Foot Ankle Int*. 1998;19:507–510.

43. Alberta FG, Aronow MS, Barrero M, et al. Ligamentous Lisfranc joint injuries: a biomechanical comparison of dorsal plate and transarticular screw fixation. *Foot Ankle Int*. 2005;26:462–473.

44. Jinks C, Jordan K, Croft P. Osteoarthritis as a public health problem: the impact of developing knee pain on physical function in adults living in the community: (KNEST 3). *Rheumatology (Oxford)*. 2007;46: 877–881.

45. Kuo RS, Tejwani NC, Digiovanni CW, et al. Outcome after open reduction and internal fixation of Lisfranc joint injuries. *J Bone Joint Surg Am*. 2000;82-A:1609–1618.

46. Myerson MS, Fisher RT, Burgees AR, et al. Fracture dislocations of the tarsometatarsal joints: end results correlated with pathology and treatment. *Foot Ankle*. 1986;6:225–242.

47. Sangeorzan BJ, Veith RG, Hansen ST Jr. Salvage of Lisfranc's tarsometatarsal joint by arthrodesis. *Foot Ankle*. 1990;10:193–200.

48. Ly TV, Coetzee JC. Treatment of primarily ligamentous Lisfranc joint injuries: primary arthrodesis compared with open reduction and internal fixation. A prospective, randomized study. *J Bone Joint Surg Am*. 2006;88:514–520.

49. Arntz CT, Veith RG, Hansen ST Jr. Fractures and fracture-dislocations of the tarsometatarsal joint. *J Bone Joint Surg Am*. 1988;70:173–181.