Nonmedicinal therapy in the management of ankle arthritis

Smita Rao[a,c], Scott J. Ellis[b], Jonathan T. Deland[b] and Howard Hillstrom[c]

[a]Department of Physical Therapy, New York University, [b]Department of Foot and Ankle Surgery, Orthopedics, Hospital for Special Surgery and [c]Leon Root, M.D. Motion Analysis Laboratory, Hospital for Special Surgery, New York, New York, USA

Correspondence to Howard Hillstrom, PhD, Director, Leon Root, M.D. Motion Analysis Laboratory, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, USA
Tel: +1 212 606 1507; fax: +1 212 774 7859; e-mail: HillstromH@HSS.edu HSS web site: www.hss.edu Lab web site: www.hss.edu/rehab-motion-analysis.asp

Current Opinion in Rheumatology 2010, 22:000–000

Purpose of review
The incidence of ankle osteoarthritis has increased in recent years, in part, secondary to vehicular trauma. This review describes conservative and operative intervention strategies along with current research related to the management of ankle osteoarthritis.

Recent findings
Self-reported physical function in patients with ankle osteoarthritis is equivalent to or worse than that of patients with endstage kidney disease, congestive heart failure, or cervical-spine pain and radiculopathy. Nonoperative-intervention strategies such as assistive devices, orthoses, and viscosupplements are frequently used in this clinical population. However, limited objective data are available examining outcomes following nonoperative intervention. Ankle fusion serves as a standard-surgical treatment for end-stage ankle osteoarthritis. The limitations of ankle fusion include prolonged immobilization, a relatively high risk of nonunion, and adjacent joint arthritis. Increasing evidence supports the safety and efficacy of total-ankle arthroplasty (TAA). Current (third generation) TAA prostheses feature cementless design and ligament preservation with reduced bone resection and improved instrumentation.

Summary
Limited objective evidence exists to guide clinical decision-making related to nonoperative choices such as assistive devices, orthoses, and viscosupplements. Outcomes from prospective clinical trials indicate that newer total ankle-arthroplasty designs provide substantial pain relief in patients with end-stage ankle osteoarthritis.

Keywords
ankle, osteoarthritis, tibio-talar

Curr Opin Rheumatol 22:000–000

1040-8711

Introduction

Osteoarthritis of the ankle affects 1–4% of the adult population [1,2]. The low incidence of ankle osteoarthritis is surprising considering the small articular contact area compared with the knee, in conjunction with the high loads sustained during standing, walking, and running. The relative rarity of ankle osteoarthritis has been attributed to increased stiffness and the greater capacity for repair shown by ankle-articular cartilage [3].

In recent years, the increasing incidence of ankle osteoarthritis has been linked with vehicular trauma [4,5]. Plantar impact sustained during restrained vehicular trauma combined with general aging-related changes may contribute to the development of ankle osteoarthritis. Consistent with this theory, epidemiological reports confirm that trauma is the most common cause of ankle osteoarthritis [6]. In a study of 406 ankles with end-stage osteoarthritis, Valderrabano *et al.* [7•] found that the underlying etiology in this cohort was posttraumatic ankle osteoarthritis in 78% of the cases, secondary arthritis in 13% of the cases, and primary osteoarthritis in 9% of the cases. Of the 78% cases of posttraumatic osteoarthritis, 62% were attributable to fracture events and 16% had ligamentous posttraumatic ankle osteoarthritis. Malleolar fractures (39%) and tibial plafond fractures were the two most common causes of posttraumatic ankle osteoarthritis [8]. Retrospective studies indicate that severity of the initial injury and adequacy of reduction may play a role in the development of ankle osteoarthritis [9]. However, more recent studies have questioned the role of anatomic fracture reduction in the development of posttraumatic ankle osteoarthritis [10,11]. Regardless of anatomic reduction, recent studies suggest that an osteochondral defect on the talar dome may progress to osteoarthritis [12,13].

Biomechanical considerations associated with ankle osteoarthritis

Biomechanical factors, including joint kinematics, kinetics, contact stress, and cartilage thickness may play a role in ankle-joint degeneration. The tibiotalar joint exhibits congruency at high loads and predominantly functions as a hinge joint in contrast to the knee, which functions as an unstable hinge that exhibits rolling, gliding, and rotation. The ankle sustains substantially higher contact stresses compared with the knee and hip, which may be due to its smaller contact area. At 500 N of load, the ankle has a contact area of 350 mm^2 as compared with 1100 and 1120 mm^2 for the hip and knee, respectively [14]. Furthermore, articular cartilage at the ankle is relatively thin (1–2 mm) compared with the knee (1–6 mm) [15,16].

Increased magnitude and directional gradients of contact stress have been used to evaluate the effect of ankle articular surface incongruity and joint instability [17]. McKinley *et al.* [18•] developed an in-vitro model that included a step defect in the tibiotalar-joint surface to simulate incongruity followed by posteriorly directed shear loads to invoke instability. Their results demonstrated that articular surface incongruity increased contact-stress gradients by 30%. Instability superimposed on articular incongruity led to an additional 60% increase in stress.

Effects on function

In-vivo studies indicate that patients with end-stage ankle osteoarthritis utilize an antalgic-loading pattern during walking. In addition, they exhibit aberrant-muscle function, joint kinetics, kinematics, and plantar pressures [19]. Substantial muscle atrophy has been observed, as evidenced by diminished isometric plantar flexion torque and reduced muscle cross-sectional area [20]. Using a novel subject-specific geometric model that combines MRI and dual fluoroscopy data, Kozanek *et al.* [21] found that subtalar-joint motion in the sagittal, coronal, and transverse planes occurs in the opposite direction in individuals with ankle osteoarthritis compared with controls. Horisberger *et al.* [22] noted that the affected foot in patients with ankle osteoarthritis sustained lower plantar pressures at the hindfoot compared with the nonaffected foot.

Burden of disease

Self-reported physical function in patients with ankle osteoarthritis quantified using the SF-36 was equivalent to or worse than that of patients with end-stage kidney disease, congestive heart failure, or cervical-spine pain and radiculopathy [23,24]. Recent reports also indicate that patients with ankle osteoarthritis report pain, diminished quality of life, and limited physical function, that is, as severe as that in patients with hip osteoarthritis [25]. Patients with ankle osteoarthritis are usually younger than those with knee or hip osteoarthritis [6]. The longer projected life span, combined with the substantial decrease in health-related quality of life, underscores the profound effect that ankle osteoarthritis has on patients' disability.

Nonmedicinal treatment choices in the management of ankle osteoarthritis

The primary aim of treatment is to provide pain relief. This may be attempted through the use of offloading strategies such as assistive devices [26]. A single point cane can decrease vertical loading by 11–25% [27,28]. Total contact casts, patellar tendon bearing braces, and removable walking boots have been shown to offload the foot [29,30]. However, they induce asymmetrical loading, and are often accompanied by poor patient compliance.

Ankle–foot orthoses

The goal of orthotic management in ankle osteoarthritis is to provide pain relief by maintaining talar alignment and limiting ankle motion during gait [31••]. Direct comparisons between brace designs in the form of a clinical trial are lacking. Experimental studies have assessed the effect of brace design on foot motion. The rocker sole and solid-ankle cushion-heel (SACH) decrease ankle and forefoot motion during walking and stair climbing [32]. Three brace designs (custom-molded ankle-foot orthoses, rigid hindfoot orthoses, and articulated hindfoot orthoses) were evaluated for their ability to control forefoot and hindfoot motion during walking in patients with ankle osteoarthritis. The rigid hindfoot orthoses provided selective restriction of ankle–hindfoot motion while allowing sufficient forefoot motion compared with the custom-molded ankle–foot orthoses. The articulated hindfoot orthoses were ineffective in restricting hindfoot motion [33]. Although ankle–foot orthoses may be effective, they may not be cosmetically acceptable. As an alternative, foot orthoses (shoe inserts), which can be used interchangeably in multiple pairs of shoes, have shown encouraging preliminary results in clinical populations with foot arthritis [34,35]. Clinical trials assessing alternative orthotic strategies for treating ankle osteoarthritis are needed.

Viscosupplementation

Few studies have used sodium hyaluronate (Hyalgan) and hyaluronic-acid injections in the treatment of ankle osteoarthritis, possibly because viscosupplements have not been approved for use in joints other than the knee [36••,37]. Salk *et al.* [38] conducted a small ($n = 20$), prospective, placebo-controlled, double-blind, randomized clinical trial assessing the efficacy and safety of intra-articular injections of sodium hyaluronate in the ankle with osteoarthritis. At 6-month follow-up, trends toward greater symptomatic improvement in the sodium-hyaluronate group compared with PBS control were noted.

A prospective case-series conducted in Europe has found positive preliminary findings with hylan G-F 20 (Synvisc) in patients with ankle osteoarthritis [39]. The investigators found that Hylan G-F 20 was effective at significantly reducing the pain associated with ankle osteoarthritis as soon as 7 days after injection and maintained this effect for up to 6 months. Further, the majority of patients (56%) responded adequately to a single injection. A recent prospective clinical trial compared 3 week hyaluronic-acid injections to 6 weeks of exercise therapy [40,41]. At 12-month follow-up, both groups showed significant pain relief and functional improvement, with no difference evident between groups.

Long term follow-up with attention to the pathophysiology of the joint are needed given that hyaluronic acid has been shown to clear the joint (in knee osteoarthritis) in as little as 1 week. Pain relief, however, may persist for 9 months. The efficacy of repeated injections after pain relief subsides is poorly understood at the ankle. The success of injections likely decreases with more advanced levels of arthritis.

Debridement, allograft transplantation, and distraction arthroplasty

Arthroscopic–ankle debridement provides short-term pain relief. A 5-year survival analysis indicates that this procedure is most effective in patients with ankle impingement [42]. Ankles with more advanced osteoarthritis progressed to have major surgery [42]. Data from a retrospective case series ($n = 29$) indicate that fresh osteochondral total ankle-allograft transplantation is associated with an extremely high rate of failure (69%). Though its indications are controversial, the total osteochondral allograft technique is reserved for patients who are too young for ankle replacement, have excellent range of motion, low BMI, normal-radiographic alignment, and who refuse arthrodesis [43]. Another technique that may be utilized in patients too young to consider joint salvage procedures is ankle-distraction arthroplasty [44]. Ankle distraction is achieved using an external fixator, which allows concomitant joint range of motion thought to enhance the generation of fibrocartilage. A recent retrospective review of 25 patients with ankle osteoarthritis found promising results, demonstrating that distraction arthroplasty affords substantial pain relief [44].

Arthrodesis

Ankle fusion still represents the most standard surgical treatment of advanced ankle osteoarthritis. Arthrodesis affords good-pain relief. However, the limitations of ankle fusion include prolonged immobilization, a relatively high risk of nonunion [45], adjacent-joint arthritis [46], and increasing difficulty with uneven terrain. In-vitro studies indicate that ankle arthrodesis increases contact stress at the talonavicular and calcaneocuboid joint [47]. In a study of 28 patients who all stated they were highly satisfied immediately after ankle fusion, 79% reported difficulty walking on uneven ground, and 64% reported aching around the ankle with prolonged standing or walking [48]. At 44 months follow-up, Thomas *et al.* [49] noted that patients with arthrodesis demonstrated reduced cadence and stride length accompanied by a diminished range of motion of the hindfoot and midfoot during walking.

Total-ankle arthroplasty

Initial failures with TAA designs have led to continued refinement. In particular, current third generation designs are cementless, retain medial and lateral ankle ligaments, and require minimal bone resection [50•]. Until the recent approval of the Scandinavian Total Ankle Replacement (STAR, Waldemar Link, Hamburg, Germany) in the United States, the FDA had only allowed the implantation of nonmobile-bearing prostheses. Those currently approved include the Salto Talaris (the nonmobile counterpart of the mobile bearing Salto implant used in Europe) Tornier (Saint Ismier, France), the INBONE (featuring stems for both the tibial and talar components, Wright Medical Technologies, Arlington, Tennessee, USA), and the Eclipse (Integra LifeSciences, Plainsboro, New Jersey, USA). The TAA design features and their rationale are presented in a recent comprehensive review [51•].

Encouraging results have been reported at short (6–12-month) and mid-term (3–10-year) follow-up for the Agility [52,53], Hintegra [54,55], Salto [56], and Buchel Pappas [57,58] TAA designs. In the summer of 2009, the Food and Drug Administration (FDA) approved the STAR. The Pivotal Study, approved as part of an investigational device exemption (IDE), evaluated the safety and efficacy of the STAR compared with ankle fusion in the treatment of patients with ankle osteoarthritis [59••]. A total of 606 TAA and 66 fusion patients were enrolled. At 24-month follow-up, only 10.6% STAR TAA patients required a secondary procedure indicating the relative safety of the procedure. Both the STAR TAA and fusion groups showed similar improvements in terms of pain, presence of a limp, and walking ability. The STAR TAA group showed significantly greater improvement in the level physical function and performing such tasks as negotiating stairs.

These positive findings of the safety and efficacy of third generation TAA designs have been confirmed by a recent systematic review of 13 studies (1105 ankles) [60••]. Gougoulias *et al.* [60••] reported that an overall 9.8% of ankle replacements required revision or conversion to ankle fusion at 5.2 years. Intraoperative complications include difficulty with alignment and fractures that may account for the steep learning curve associated with TAA [55]. Complications following the STAR TAA include polyethylene fracture [61] and wound complications [62].

The role of patient selection in the success of TAA is controversial. Recent reports have disputed the role of age, weight, and etiology [60••,63]. Though abnormal stresses due to ankle deformity theoretically lead to earlier implant wear and failure, TAA has been successful in patients with up to 30 degrees of hindfoot varus deformity [64,65]. Younger, heavier, and more active patients likely place more demand on ankle prostheses, but there is currently no agreement as to the absolute limit of age and weight for TAA.

Outcomes following total-ankle arthroplasty

Increasing evidence supports the notion that substantial pain relief follows TAA surgery [60••]. However, concomitant increases in recreational physical activity may be modest. At mid-term follow-up (3.7 years), a study assessing 101 patients with TAA noted significant improvements in self-reported outcomes, but only trends towards improved sport and recreational activity participation, underscoring the role of continued rehabilitation [66].

Further, a recent systematic review noted that there is limited evidence supporting the reliability, validity, and responsiveness of the most frequently used outcome instruments (e.g. the American Orthopaedic Foot and Ankle Society and Kofoed score) [67•]. Future studies may consider using the Foot and Ankle Abilities Measure, particularly because it has been developed and tested for use in patients with ankle osteoarthritis [68].

Recent studies have examined objective changes in joint kinematics and kinetics following TAA. A comparison of gait patterns quantified using ground reaction force, walking speed, and joint kinematics revealed that patients with ankle arthrodesis as well as TAA walk slower than matched controls. Patients with arthrodesis walked with longer step lengths, but less symmetry in ground reaction force compared with patients with TAA [69]. Self-reported outcomes and in-vivo measures of ankle-joint kinematics and kinetics suggest that patients with ankle osteoarthritis show an antalgic-walking pattern characterized by reduced walking speed, diminished range of motion, and reduced ankle power generation at push off [70,71]. Twelve months following TAA, patients show improvement in self-report outcomes accompanied by near-normal walking speed, and improvements in ankle-joint motion and power generation at push off [70,71].

Conclusion

The incidence of ankle osteoarthritis, which affects 1–4% of the adult population, has increased in recent years, in part secondary to motor vehicle trauma. Patients with ankle osteoarthritis are usually younger than those with knee or hip osteoarthritis. The longer projected life span, combined with the substantial decrease in health-related quality of life, underscores the profound effect that ankle osteoarthritis has on patients' disability. The primary aim of treatment is to provide pain relief, which may be attempted nonoperatively through the use of assistive devices and orthoses. Limited quantitative data in the form of clinical trials are available to guide clinical decision making in the management of early ankle osteoarthritis. Recent reports indicate the viscosupplements may provide symptomatic relief, however; long-term follow-up is lacking. Ankle fusion serves as a standard surgical treatment for advanced ankle osteoarthritis. Limitations of ankle fusion include prolonged immobilization, the relatively high risk of nonunion, adjacent joint arthritis, and poor functional improvement. The development of third generation TAA prostheses, whose design features include cementless fixation and ligament preservation with decreased bone resection, and improved instrumentation, has resulted in better safety and efficacy. Increasing evidence supports the substantial pain relief that follows TAA surgery. Superiority of one TAA design over another cannot be supported by existing data.

Acknowledgements

Howard Hillstrom acknowledges funding from the National Institutes of Health, the Elbow Research Fund, the HSS OA Initiative, and StrideRite.

We, the authors of this manuscript, affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript except as cited in the manuscript.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:
• of special interest
•• of outstanding interest
Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 000–000).

1 Peyron J. The epidemiology of osteoarthritis, in osteoarthritis. In: Moskowitz RW, Goldberg VM, Mankin HJ, editors. Diagnosis and Treatment. Philadelphia: WB Saunders; 1984. pp. 9–27.

2 Cushnaghan J, Dieppe P. Study of 500 patients with limb joint osteoarthritis. I. Analysis by age, sex, and distribution of symptomatic joint sites. Ann Rheum Dis 1991; 50:8–13.

3 Kuettner KE, Cole AA. Cartilage degeneration in different human joints. Osteoarthritis Cartilage 2005; 13:93–103.

4 Estrada LS, Alonso JE, McGwin G Jr, *et al.* Restraint use and lower extremity fractures in frontal motor vehicle collisions. J Trauma 2004; 57:323–328.

5 Saltzman CL, McIff TE, Buckwalter JA, *et al.* Total ankle replacement revisited. J Orthop Sports Phys Ther 2000; 30:56–67.

6 Saltzman CL, Salamon ML, Blanchard GM, *et al.* Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. Iowa Orthop J 2005; 25:44–46.

7 • Valderrabano V, Horisberger M, Russell I, *et al.* Etiology of ankle osteoarthritis. Clin Orthop Relat Res 2009; 467:1800–1806.
This study evaluated 390 patients with symptomatic osteoarthritis in terms of their etiology, clinical presentation, and radiographic data.

8 Horisberger M, Valderrabano V, Hintermann B. Posttraumatic ankle osteoarthritis after ankle-related fractures. J Orthop Trauma 2009; 23:60–67.

9 Lindsjo U. Operative treatment of ankle fracture-dislocations: a follow-up study of 306/321 consecutive cases. Clin Orthop Relat Res 1985; 199:28–38.

10 Wyrsch B, McFerran MA, McAndrew M, *et al.* Operative treatment of fractures of the tibial plafond: a randomized, prospective study. J Bone Joint Surg Am 1996; 78:1646–1657.

11 DeCoster TA, Willis MC, Marsh JL, *et al.* Rank order analysis of tibial plafond fractures: does injury or reduction predict outcome? Foot Ankle Int 1999; 20:44–49.

12 Zengerink M, Struijs PA, Tol JL, *et al.* Treatment of osteochondral lesions of the talus: a systematic review. Knee Surg Sports Traumatol Arthrosc 2009. [Epub ahead of print]

13 Schachter AK, Chen AL, Reddy PD, *et al.* Osteochondral lesions of the talus. J Am Acad Orthop Surg 2005; 13:152–158.

14 Kimizuka M, Kurosawa H, Fukubayashi T. Load-bearing pattern of the ankle joint: contact area and pressure distribution. Arch Orthop Trauma Surg 1980; 96:45–49.

15 Shepherd DE, Seedhom BB. Thickness of human articular cartilage in joints of the lower limb. Ann Rheum Dis 1999; 58:27–34.

16 Wan L, de Asla RJ, Rubash HE, *et al.* In vivo cartilage contact deformation of human ankle joints under full body weight. J Orthop Res 2008; 26:1081–1089.

17 Tochigi Y, Rudert MJ, McKinley TO, *et al.* Correlation of dynamic cartilage contact stress aberrations with severity of instability in ankle incongruity. J Orthop Res 2008; 26:1186–1193.

18 • McKinley TO, Tochigi Y, Rudert MJ, *et al.* The effect of incongruity and instability on contact stress directional gradients in human cadaveric ankles. Osteoarthritis Cartilage 2008; 16:1363–1369.
This study applied a novel in-vitro model to assess the effect of articular incongruity and joint instability on contact stress distribution.

19 Khazzam M, Long JT, Marks RM, *et al.* Preoperative gait characterization of patients with ankle arthrosis. Gait Posture 2006; 24:85–93.

20 Valderrabano V, von Tscharner V, Nigg BM, *et al.* Lower leg muscle atrophy in ankle osteoarthritis. J Orthop Res 2006; 24:2159–2169.

21 Kozanek M, Rubash HE, Li G, *et al.* Effect of posttraumatic tibiotalar osteoarthritis on kinematics of the ankle joint complex. Foot Ankle Int 2009; 30:734–740.

22 Horisberger M, Hintermann B, Valderrabano V. Alterations of plantar pressure distribution in posttraumatic end-stage ankle osteoarthritis. Clin Biomech (Bristol, Avon) 2009; 24:303–307.

23 Saltzman CL, Zimmerman MB, O'Rourke M, *et al.* Impact of comorbidities on the measurement of health in patients with ankle osteoarthritis. J Bone Joint Surg Am 2006; 88:2366–2372.

24 Agel J, Coetzee JC, Sangeorzan BJ, *et al.* Functional limitations of patients with end-stage ankle arthrosis. Foot Ankle Int 2005; 26:537–539.

25 Glazebrook M, Daniels T, Younger A, *et al.* Comparison of health-related quality of life between patients with end-stage ankle and hip arthrosis. J Bone Joint Surg Am 2008; 90:499–505.

26 Martin RL, Stewart GW, Conti SF. Posttraumatic ankle arthritis: an update on conservative and surgical management. J Orthop Sports Phys Ther 2007; 37:253–259.

27 Aragaki DR, Nasmyth MC, Schultz SC, *et al.* Immediate effects of contralateral and ipsilateral cane use on normal adult gait. PM R 2009; 1:208–213.

28 Youdas JW, Kotajarvi BJ, Padgett DJ, *et al.* Partial weight-bearing gait using conventional assistive devices. Arch Phys Med Rehabil 2005; 86:394–398.

29 DiLiberto FE, Baumhauer JF, Wilding GE, *et al.* Alterations in plantar pressure with different walking boot designs. Foot Ankle Int 2007; 28:55–60.

30 Keefer M, King J, Powell D, *et al.* Effects of modified short-leg walkers on ground reaction force characteristics. Clin Biomech (Bristol, Avon) 2008; 23:1172–1177.

31 •• John S, Bongiovanni F. Brace management for ankle arthritis. Clin Podiatr Med Surg 2009; 26:193–197.
This recent review describes commonly used orthotic devices, fabrication details and appropriate modifications for patients with ankle osteoarthritis.

32 Wu WL, Rosenbaum D, Su FC. The effects of rocker sole and SACH heel on kinematics in gait. Med Eng Phys 2004; 26:639–646.

33 Huang YC, Harbst K, Kotajarvi B, *et al.* Effects of ankle-foot orthoses on ankle and foot kinematics in patient with ankle osteoarthritis. Arch Phys Med Rehabil 2006; 87:710–716.

34 Rao S, Baumhauer JF, Becica L, *et al.* Shoe inserts alter plantar loading and function in patients with midfoot arthritis. J Orthop Sports Phys Ther 2009; 39:522–531.

35 Cho NS, Hwang JH, Chang HJ, *et al.* Randomized controlled trial for clinical effects of varying types of insoles combined with specialized shoes in patients with rheumatoid arthritis of the foot. Clin Rehabil 2009; 23:512–521.

36 •• Khosla SK, Baumhauer JF. Dietary and viscosupplementation in ankle arthritis. Foot Ankle Clin 2008; 13:353–361; vii.
This recent review provides an overview of dietary and viscosupplements used in patients with ankle osteoarthritis.

37 Sun SF, Chou YJ, Hsu CW, *et al.* Hyaluronic acid as a treatment for ankle osteoarthritis. Curr Rev Musculoskelet Med 2009; 2:78–82.

38 Salk RS, Chang TJ, D'Costa WF, *et al.* Sodium hyaluronate in the treatment of osteoarthritis of the ankle: a controlled, randomized, double-blind pilot study. J Bone Joint Surg Am 2006; 88:295–302.

39 Witteveen AG, Giannini S, Guido G, *et al.* A prospective multicentre, open study of the safety and efficacy of hylan G-F 20 (Synvisc) in patients with symptomatic ankle (talo-crural) osteoarthritis. Foot Ankle Surg 2008; 14:145–152.

40 Karatosun V, Unver B, Ozden A, *et al.* Intra-articular hyaluronic acid compared to exercise therapy in osteoarthritis of the ankle: a prospective randomized trial with long-term follow-up. Clin Exp Rheumatol 2008; 26:288–294.

41 Sun SF, Chou YJ, Hsu CW, *et al.* Efficacy of intra-articular hyaluronic acid in patients with osteoarthritis of the ankle: a prospective study. Osteoarthritis Cartilage 2006; 14:867–874.

42 Hassouna H, Kumar S, Bendall S. Arthroscopic ankle debridement: 5-year survival analysis. Acta Orthop Belg 2007; 73:737–740.

43 Jeng CL, Kadakia A, White KL, *et al.* Fresh osteochondral total ankle allograft transplantation for the treatment of ankle arthritis. Foot Ankle Int 2008; 29:554–560.

44 Tellisi N, Fragomen AT, Kleinman D, *et al.* Joint preservation of the osteoarthritic ankle using distraction arthroplasty. Foot Ankle Int 2009; 30:318–325.

45 Haddad SL, Coetzee JC, Estok R, *et al.* Intermediate and long-term outcomes of total ankle arthroplasty and ankle arthrodesis: a systematic review of the literature. J Bone Joint Surg Am 2007; 89:1899–1905.

46 Buchner M and Sabo D. Ankle fusion attributable to posttraumatic arthrosis: a long-term followup of 48 patients. Clin Orthop Relat Res 2003; 406:155–164.

47 Jung HG, Parks BG, Nguyen A, *et al.* Effect of tibiotalar joint arthrodesis on adjacent tarsal joint pressure in a cadaver model. Foot Ankle Int 2007; 28:103–108.

48 Muir DC, Amendola A, Saltzman CL. Long-term outcome of ankle arthrodesis. Foot Ankle Clin 2002; 7:703–708.

49 Thomas R, Daniels TR, Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. J Bone Joint Surg Am 2006; 88:526–535.

50 • Chou LB, Coughlin MT, Hansen S Jr, *et al.* Osteoarthritis of the ankle: the role of arthroplasty. J Am Acad Orthop Surg 2008; 16:249–259.
This review describes the surgical management of ankle osteoarthritis with particular emphasis on technique, TAA designs, and complications.

51 • Cracchiolo A 3rd, Deorio JK. Design features of current total ankle replacements: implants and instrumentation. J Am Acad Orthop Surg 2008; 16:530–540.
This is a comprehensive overview of TAA designs, underlying rationale, and summary of research findings to date.

52 Knecht SI, Estin M, Callaghan JJ, *et al.* The agility total ankle arthroplasty: seven to sixteen-year follow-up. J Bone Joint Surg Am 2004; 86-A:1161–1171.

53 Claridge RJ, Sagherian BH. Intermediate term outcome of the agility total ankle arthroplasty. Foot Ankle Int 2009; 30:824–835.

54 Hintermann B, Valderrabano V, Dereymaeker G, *et al.*, The HINTEGRA ankle: rationale and short-term results of 122 consecutive ankles. Clin Orthop Relat Res 2004; 424:57–68.

55 Lee KB, Cho SG, Hur CI, *et al.* Perioperative complications of HINTEGRA total ankle replacement: our initial 50 cases. Foot Ankle Int 2008; 29:978–984.

56 Bonnin M, Judet T, Colombier JA, *et al.* Midterm results of the Salto total ankle prosthesis. Clin Orthop Relat Res 2004; 424:6–18.

57 San Giovanni TP, Keblish DJ, Thomas WH, *et al.* Eight-year results of a minimally constrained total ankle arthroplasty. Foot Ankle Int 2006; 27:418–426.

58 Wood PL, Sutton C, Mishra V, *et al.* A randomised, controlled trial of two mobile-bearing total ankle replacements. J Bone Joint Surg Br 2009; 91:69–74.

59 Saltzman CL, Mann RA, Ahrens JE, *et al.* Prospective controlled trial of STAR
•• total ankle replacement versus ankle fusion: initial results. Foot Ankle Int 2009; 30:579–596.

This article is the first prospective multicenter trial comparing TAA to ankle fusion in the treatment of end-stage ankle osteoarthritis.

60 Gougoulias N, Khanna A, Maffulli N. How successful are current ankle
•• replacements? A systematic review of the literature. Clin Orthop Relat Res 2009. [Epub ahead of print]

This is a forthcoming systematic review that assesses indications, outcomes, and complications following TAA.

61 Scott AT, Nunley JA. Polyethylene fracture following STAR ankle arthroplasty: a report of three cases. Foot Ankle Int 2009; 30:375–379.

62 Karantana A, Hobson S, Dhar S. The Scandinavian total ankle replacement: survivorship at 5 and 8 years comparable to other series. Clin Orthop Relat Res 2009. [Epub ahead of print]

63 Valderrabano V, Hintermann B, Dick W. Scandinavian total ankle replacement: a 3.7-year average followup of 65 patients. Clin Orthop Relat Res 2004; 424:47–56.

64 Hobson SA, Karantana A, Dhar S. Total ankle replacement in patients with significant preoperative deformity of the hindfoot. J Bone Joint Surg Br 2009; 91:481–486.

65 Kim BS, Choi WJ, Kim YS, *et al.* Total ankle replacement in moderate to severe varus deformity of the ankle. J Bone Joint Surg Br 2009; 91:1183–1190.

66 Naal FD, Impellizzeri FM, Loibl M, *et al.* Habitual physical activity and sports participation after total ankle arthroplasty. Am J Sports Med 2009; 37:95–102.

67 Naal FD, Impellizzeri FM, Rippstein PF. Which are the most frequently used
• outcome instruments in studies on total ankle arthroplasty? Clin Orthop Relat Res 2009. [Epub ahead of print]

A systematic review of the literature, evalating 15 outcome instruments from 79 original studies.

68 Martin RL, Irrgang JJ, Burdett RG, *et al.* Evidence of validity for the foot and ankle ability measure (FAAM). Foot Ankle Int 2005; 26:968–983.

69 Piriou P, Culpan P, Mullins M, *et al.* Ankle replacement versus arthrodesis: a comparative gait analysis study. Foot Ankle Int 2008; 29:3–9.

70 Valderrabano V, Nigg BM, von Tscharner V, *et al.* Gait analysis in ankle osteoarthritis and total ankle replacement. Clin Biomech (Bristol, Avon) 2007; 22:894–904.

71 Ingrosso S, Benedetti MG, Leardini A, *et al.* GAIT analysis in patients operated with a novel total ankle prosthesis. Gait Posture 2009; 30:132–137.