Nonmedicinal therapy in the management of ankle arthritis
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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 end stage 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

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 plantarflexion 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]. Ankle arthrodesis 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 concurrent 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 resorption [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 Kofoid 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.

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**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).

Nonmedicinal therapy for ankle arthritis Rao et al.5


51 Cracchiolo A 3rd, Deorio JK. Design features of current total ankle replacement: 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.


6 Rehabilitation medicine in rheumatic diseases


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