Current Reviews in Musculoskeletal Medicine (2018) 11:546–557
https://doi.org/10.1007/s12178-018-9525-9

FOOT AND ANKLE TRAUMA (G MOLONEY, SECTION EDITOR)

Management of Posttraumatic Ankle Arthritis: Literature Review

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Published online: 16 October 2018

Abstract

Purpose of Review Trauma is the principle cause of osteoarthritis in the ankle, which is associated with significant morbidity. This review highlights the current literature for the purpose of bringing the reader up-to-date on the management of posttraumatic ankle arthritis, describing treatment efficacy, indications, contraindications, and complications.

Recent Findings Recent studies on osteoarthritis have demonstrated variability among anatomic locations regarding the mechanisms and rates of development for posttraumatic osteoarthritis, which are attributed to newly discovered biological differences intrinsic to each joint. Regarding surgical management of posttraumatic ankle arthritis, osteochondral allograft transplantation of the talus, and supramalleolar osteotomies have demonstrated promising results. Additionally, the outpatient setting was found to be appropriate for managing pain following total ankle arthroplasty, associated with low complication rates and no readmission.

Summary Management for posttraumatic ankle arthritis is generally progressive. Initial treatment entails nonpharmacologic options with surgery reserved for posttraumatic ankle arthritis refractory to conservative treatment. Patient demographics and lifestyles should be carefully considered when formulating a management strategy, as outcomes are dependent upon the satisfaction of each set of respective criteria. Ultimately, the management of posttraumatic ankle arthritis should be individualized to satisfy the needs and desires, which are specific to each patient.

Keywords Posttraumatic · Ankle · Arthritis · Osteoarthritis · Treatment

Background

Osteoarthritis (OA) is a growing health concern that affects approximately 27 million people in the USA and is associated with a $185 billion annual cost burden [1]. A host of associated risk factors have been identified and shown to act with codependence to generate diverse pathomechanisms (Table 1). OA arising from trauma, also known as posttraumatic osteoarthritis (PTOA), comprises around 12% of all OA and develops nearly 10 years earlier than of primary OA [2]. However, the proportion of OA secondary to trauma varies by anatomic location, accounting for over 90% regarding the ankle joint and only 2 to 10% for the hip and knee [2–6]. Any event that compromises the articular surface of the ankle joint has potential to develop posttraumatic ankle arthritis (PTAA). Trauma may occur directly or indirectly by way of injury to the surrounding structural elements, which stabilize the ankle (i.e., ligaments, tendons, and bones). Both tissue injury incurred in the acute setting and the resultant structural abnormalities in the ankle contribute to the development of ankle instability and joint surface incongruity; the two primary mechanisms responsible for the loss of articular cartilage, bone remodeling, and degenerative changes which define OA. Alteration of ankle biomechanics, in turn, alters the mechanical loading of the ankle joint, which ultimately produces a mechanically driven degenerative remodeling process [6, 7].

PTAA most frequently involves the talocrural joint and primarily results from rotational ankle injuries involving bony fracture and ligamentous sprain [8]. Unlike primary OA, which primarily affects older adults, PTAA predominates in

This article is part of the Topical Collection on *Foot and Ankle Trauma*

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Table 1 Predisposing risk factors for osteoarthritis

Risk factor	Comment
Advanced age	0.1% prevalence in ages 25–34 [2, 3] 80% prevalence in ages > 55 [2, 3]
Female sex [4, 5]	Relative risk of 2.6 [5] Higher rates of rapid structural damage [6]
Obesity/metabolic syndrome	One of the strongest modifiable risk factors [5, 6] Repetitive overloading of cartilage ➔ chondrocyte oxidant-dependent mitochondrial dysfunction ➔ disruption of chondrocyte anabolic responses to mechanical stimuli ➔ cartilage destabilization [7]
Higher bone mineral density	Especially related to hip OA in older women [8–10] Conflicting evidence in regard to the relationship between estrogen replacement therapy and OA
Occupation	
Sports activities [11]	Recreational parachuting (ankle) Ballet dancing (talar joints) Soccer (ankle, talar joints) Football (foot/ankle)
Trauma	Unilateral amputation via increased contralateral weight bearing stress [12, 13]
Physical exercise [14–16]	Neuroanatomically normal joints at increased risk with sedentary activity level and repetitive, high-impact activities Neuroanatomically abnormal joints at increased risk with repetitive, low-impact activities
Proprioceptive deficits (neuroarthropathy)	Diabetic neuropathic arthropathy via diabetes mellitus ➔ peripheral neuropathy ➔ decreased proprioception ➔ ligamentous laxity ➔ increased joint ROM ➔ instability ➔ minor trauma ➔ altered architecture ➔ asymmetric weight bearing ➔ focal trauma
Genetics	
Acromegaly	
Calcium crystal deposition disease	
Deformity	

the younger population, progressing more rapidly with a variable time of progression.

Patients typically experience increased joint pain and stiffness as the severity worsens, eventually leading to end-stage ankle arthrosis, which is one of the leading causes of chronic disability in North America [9]. Research on PTAA is sparse in comparison to other joints, with many treatment modalities lacking high quality studies to delineate their appropriateness and efficacy [10, 11]. This review aims to bring the reader up to date with current PTAA management by highlighting the most recent literature regarding treatment options and their respective efficacies, indications, contraindications, and complications.

Etiology

PTAA is thought to arise from injuries which pathologically alter ankle biomechanics, resulting in ankle joint incongruity, malalignment, and dislocation. Intra-articular fractures and high-grade ankle sprains are among the most commonly reported traumatic mechanisms. Other pathomechanisms and predisposing risk factors are outlined in Table 2.

Clinical Presentation

Patients with PTAA often present with the classic symptoms of primary OA such as joint stiffness, inflammation, swelling, reduced range of motion, disability, and pain exacerbated with increased activity. However, the pattern and character of each PTAA presentation is dependent upon injury acuity and severity as well as any associated risk factors (Table 2). Acute injuries which go on to develop PTAA are often mild to severe in character and associated with a relatively noninflammatory synovitis (< 2000 cells/mm^3). Additional clinical signs and symptoms related to PTAA are described in Table 3.

Diagnosis

Early diagnosis of PTOA has been shown to increase the likelihood of modifying the disease course [12]. Clinical examination (Table 3) and radiographic imaging are used to diagnose PTAA. Weight-bearing radiographs with AP, lateral, and mortise views are generally recommended for initial imaging. PTAA may be evidenced on radiography via joint space narrowing, osteophytes, and subchondral bone sclerosis

Table 2 Injury patterns associated with posttraumatic ankle arthritis

Injury	Comment
Dislocations	
Articular surface impaction	
Malleolar fracture	
Ankle ligament and capsular injuries	Severe sprain is one of the most common inciting injuries related to PTAA
Intra-articular fractures • Tibial plafond fracture • Talus fracture	One of the most common inciting injuries related to PTAA [17, 18] Over 50% of fractures involving the tibial plafond go on to develop OA [17, 18]
Tibial shaft fracture	May occur secondary to malalignment deformities (e.g., planovalgus, cavovarus)
Severe combined fractures	

[13]. During radiologic assessment, associated findings may include malalignment, arthritis in adjacent joints, and implanted hardware. Advanced imaging techniques such as computerized tomography (CT) and magnetic resonance imaging (MRI) may be employed in the acute setting to diagnose soft tissue pathology or preoperatively for surgical planning. MRI has demonstrated significant benefit for diagnosing ligamentous injury, subchondral edema, and cartilage injury, which portend the development of PTOA (Fig. 1) [14–16].

Management

Nonsurgical

Management of PTAA should fall within the context of each patient, producing outcomes which correlate to individualized goals. Nonsurgical options are generally preferred in the initial management of patients with PTAA. However, disease severity and patient goals may warrant a more aggressive approach to treatment.

Mild PTAA is treated conservatively, targeting modifiable risk factors related to the pathogenesis. Of the conservative options, nonpharmacologic therapies are suggested for initial treatment, such as weight management, exercise, braces, orthoses, and assistive devices (Table 3). Though proven

Table 3 Clinical signs and symptoms of posttraumatic ankle arthritis

Symptom	Comment
Subjective	
Pain	Diffuse > focal
	Dull ache or sharp in character
	Insidious onset
	Variable intensity and duration
	Exacerbated by increased joint movement, particularly when weight bearing
	Improved with initial movement, rest, and joint immobilization
	Night pain (more common with end-stage arthritis)
Swelling	Most frequent at the end of the day and after prolonged weight bearing activity
Stiffness	Most common after prolonged inactivity
	Exacerbated by progression of disease
	Improved with movement
	Decreased ankle motion
Objective	
Appearance	Swelling secondary to osteophytosis ± joint edema*
	Atrophy of adjacent muscles
	Joint deformity
	Positive talar tilt
	Angular deformity
Range of motion	Pain at the end of dorsiflexion and/or plantarflexion*
	Difference in ROM of passive plantar flexion between the injured and contralateral ankle, suggestive of obstructive anterior ostophytosis*
	Crepitus
	Muscle weakness
Palpation	Joint line tenderness

*Statistically significant for early OA in the TCJ and TNJ [19]

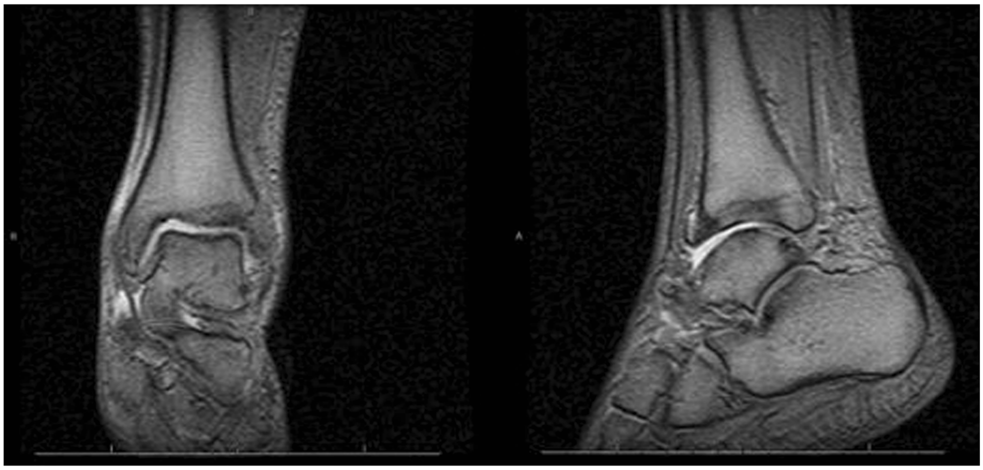

Fig. 1 Osseous structures: subchondral cysts are present and are described below. Soft tissues: circumferential soft tissue swelling is present, particularly over the malleoli. Articular surfaces: a moderate joint effusion is seen in the tibial talar joint with minimal fluid in the subtalar joint. There is advanced arthrosis of the tibial talar joint with denuding of the articular surface cartilage and subchondral cyst formation in the distal tibia and across the talar dome with subtle mechanical remodeling of the talar dome. Bulky osteophytic ridging is seen anterior distally as well. This bulky osteophytic ridging may be somewhat restrictive in dorsiflexion. There is advanced arthrosis of the tibial talar joint characterized by joint space and bulky anterior osteophytic ridging. Ligaments: thickening of the anterior tibiofibular and anterior talofibular ligaments suggesting residua from prior sprain

effective in managing PTAA, pharmacologic agents are suggested as second-line or adjunct therapies given their side effect profiles (Table 4).

Intra-articular injection of glucocorticoid (GC) with or without anesthetic is a popular treatment option for ankle OA as well as for other forms of arthritis throughout the body. This treatment option is often employed when PTAA is refractory to the aforementioned conservative modalities. Generally, the wide variability in reported efficacy may be attributed to the equally variable success rate of needle positioning—30–80%—when solely using manual palpation for guidance [25, 26]. Employing ultrasound to guide injections has increased the upper limit of the needle positioning success rate—32–97%—and decreased the rate of complications related to manual error [25]. Bioimpedance-based needle guidance is a newer methodology regarding GC injections [27]. This technology functions by detecting the presence of synovial fluid upon needle contact and relaying real-time feedback to the provider [28••]. A level II study by Halonen et al. assessed the efficacy of bioimpedance-based needle guidance for intra-articular injections in 80 joints in patients with inflammatory arthritis [28••]. The authors concluded this methodology to be efficacious in ease of use, improving needle placement (particularly in small joints), and safety profile.

Viscosupplementation (VS) has gained traction in the treatment of PTAA as well as in the overall management of OA. A level II study by Murphy et al. demonstrated efficacy regarding injections of hyaluronic acid (HA) VS as an adjunctive treatment for symptomatic ankle arthritis using pre- and posttreatment Foot and Ankle Outcome Scores [29••]. Further, a recent systematic review of VS in ankle OA determined this treatment modality to have good efficacy in improving patient functionality scores; though, not significantly better than other nonoperative modalities [30••]. Higher-quality randomized controlled trials will be necessary prior to developing any definitive recommendations for HA in treating PTAA.

Although alternative therapies such as acupuncture, traditional Chinese medicine, and transcutaneous nerve stimulation have been implemented for managing PTAA, these methods were not included in this review due to insufficient evidence.

Surgical

Arthroscopic Debridement and Microfracture Arthroscopic debridement and microfracture of the ankle is indicated among patients with mild PTAA with osteochondral lesions (OCLs) less than 15 mm in diameter [31]. This procedure works by stimulating fibrocartilage development by penetrating the subchondral plate followed by the introduction of serum factors that ultimately lead to scar tissue growth. Due to both technical ease and favorable outcomes, this procedure has been gaining popularity for the treatment of talus OCLs [17, 32–34].

Postoperative management consists of range of motion exercises beginning postoperative day 2 with partial weight bearing and crutches for 6 weeks [18]. Loading activities are permitted after 3 months and athletes can return to sport after 6 months [18].

The outcomes for arthroscopic debridement and microfracture have been favorable at short- and long-term follow-up. In a study of 105 patients with talar OCLs treated with arthroscopic debridement and microfracture, all 73 patients with OCL diameter less than 15 mm who underwent the

Table 4 Conservative management options for posttraumatic ankle arthritis

Nonpharmacologic
Activity modification, weight loss, physical therapy (e.g., exercise, heat/cold therapy)
Shoe modification (Orthotics, Comfort shoes with a single rocker sole**)
Assistive devices: cane, walker, knee scooter
Ankle bracing (OTC vs. custom)
Pharmacologic
Anti-inflammatory medications (Oral NSAIDs, Topical NSAIDs)
-Avoid use of selective and nonselective NSAIDs in patients with CVD.
-Avoid routine use of NSAIDs in patients who are concurrently taking low-dose ASA as cardioprotective prophylaxis
-Avoid use of oral NSAIDs in patients with diabetes mellitus, especially if complicated by CVD or kidney disease
Acetaminophen
Nutritional supplements: nutraceuticals (chondroitin sulfate*, glucosamine), vitamin D, diacerin, avocado soybean unsaponifiables*, fish oil*
-Limited studies have shown oral glucosamine to be safe in patients with DM [20]
Corticosteroids (oral, injection)
-GC injections are absolutely contraindicated in the presence of local infection, bacteremia, fracture, joint prosthesis, tumor, achilles or patellar tendinopathy, and history of allergy to any of the injectable components [21]
-Associated with a transient (usually 1–2 days) elevation in blood glucose levels secondary to increased insulin-resistance
-Insufficient data exists to characterize the effects of GC injections regarding location, dose, and formulation [21]
-Corticosteroid flare is among the most commonly reported adverse effects, with a rate of 2–50%; although, studies have assessed various formulations of GC with nonsteroid solutions (e.g., balanced pH with bicarbonate) and found no differences in occurrence rates [21].
Duloxetine

*Minor effect on mild OA symptoms [22••, 23]

**Can improve gait and pain symptoms [24••]

procedure had successful outcomes, where success was defined as fulfilling three of the following four criteria defined prior to the start of study: (1) more than 50% improvement in VAS score for pain during daily activities, (2) more than 50% improvement in VAS score for pain during exercise, (3) an AOFAS score that was increased by at least 30 points, and (4) a Roles and Maudsley score of 1 or 2 [19]. A systematic review of 7 studies with 299 ankles by Donnenwerth et al. found that good to excellent outcomes can be achieved consistently in greater than 80% of patients undergoing this procedure [35].

Though further studies are necessary to evaluate the true efficacy of this treatment, arthroscopic debridement and microfracture is a safe and effective method in treating mild PTAA, particularly in patients with small OCLs.

Osteochondral Allograft Transplantation Osteochondral allograft (OCA) transplantation is indicated for young active patients presenting with osteochondral lesions (OCLs) refractory to conservative management. This procedure involves the transplantation of fresh OCA to replace existing articular lesions and has the advantage of transferring viable chondrocytes with optimal matching of graft and lesion to allow a stable bone-to-bone healing process. OCA transplantation has thus been utilized for a variety of OCLs, primarily of the knee and ankle [36–39]. Various studies have shown its effective clinical application on the talus, particularly among younger individuals without contraindications such as varus and valgus malalignment greater than 10°, obesity, ankle joint instability, and underlying vascular disease [20, 37–39].

Postoperative management consists of nonweight bearing for 6 weeks followed by protected ambulation in a cam boot while encouraging progressive increase in range of motion exercises for the subsequent 6 weeks [21]. Patients are then permitted to transition to a regular shoe with an ankle brace as tolerated [21].

The overall outcomes of OCA transplantation of the talus have shown to be excellent. A recent systematic review of 5 studies with 91 ankles by VanTienderen et al. showed that at a mean follow-up of 45 months, 66.7% improved in AOFAS scores and reported a decrease in pain VAS scores by a mean of 62.0% [22••]. However, this procedure has been shown to have high failure and reoperation rates, particularly among older, less active patients [22••, 23]. The same study by VanTienderen et al. showed that failure and reoperation rates after OCA transplantation of the ankle were 13.2% and 25.3%, respectively, when failure was defined as postoperative graft nonunion or resorption, or persistence of symptoms leading to subsequent arthrodesis or arthroplasty [22••]. A study by Gaul et al. further reported long-term outcomes of 20 patients who underwent revision OCA transplantation and showed a failure and reoperation rates of 30% and 50%, respectively [24••].

Though relatively high rates of failure and reoperation, considering the more invasive nature of treatment alternatives such as arthrodesis and arthroplasty, OCA transplantation is an effective treatment option, particularly for carefully selected young active patients.

Joint Distraction Arthroplasty Joint distraction arthroplasty for PTAA, though controversial, is indicated in highly motivated candidates with refractory pain, appropriate joint alignment, and preservation of motion (> 20 degrees) whom do not want to proceed with either ankle arthrodesis or total ankle arthroplasty (TAA) [40]. Concomitant extra-articular deformity, either in the distal tibia or the hind foot, is not an absolute contraindication providing steps that are taken to address the deformity before the distraction procedure [41]. Relative contraindications include concomitant complex regional pain syndrome, inflammatory arthritides, infection, neuropathic joint, low functional demands, and stiffness (< 20 degrees ROM). Patients with stiffness should be guided toward TAR or fusion as distraction arthroplasty has not been shown to reliably increase ROM [42].

Joint distraction is thought to optimize the body's own regenerative capacity and function via mechanical unloading of the diseased joint [43, 44]. Evidence suggests that cartilage regeneration most reliably occurs in a mechanically unloaded, well-aligned limb [45, 46]. However, the exact biological mechanism remains poorly understood and human studies have shown varying results. Distraction is thought to relieve pain, preserve range of motion, and delay or potentially reverse PTA [42, 47••]. Decrease in joint reactive forces, an increase in proteoglycan synthesis, recruitment of mesenchymal stems cells, and decrease in subchondral sclerosis are all thought to occur with this technique [48, 49]. In addition to joint unloading with external fixation, osteophyte removal, microfracture, soft-tissue release, and deformity correction are undertaken as needed depending on the pathology of each patient. Although the use of biological augmentation is left to the surgeon's discretion, many advocate for the use of bone marrow aspirate concentrate (BMAC) from the iliac crest. Injection is done prior to distraction of the joint and has been shown to be a promising strategy to promote cartilage regeneration [44, 50–53].

Postoperative management may involve additional distraction at follow-up, which is determined via surgeon's preference. Patients are encouraged to weight bear on crutches and open the hinge mechanism for active ROM exercises in regular intervals. The distraction device is then applied for 8–12 weeks maximum [44, 54].

Outcomes following joint distraction arthroplasty have shown variable results. In a study by Marijinissen et al., 111 patients with an average age of 42.7 years and minimum follow-up of 2 years demonstrated a decrease in pain and disability score from 67% and 68% to 38% and 36%, respectively. The majority of failures occurred within the first 5 years of follow-up with 17% of patients failing in the first 2 years and an additional 37% in the following 3 years [47••]. In a smaller study by Tellisi et al., 91% of the patients reported pain improvement at 30 months follow-up with the mean AOFAS score improving from 55 preoperatively to 74 postoperatively [42]. Despite 100% of the patients having pin-site infections during their treatment, only 2 of the 23 patients went on to receive a fusion procedure [43]. A randomized trial by Saltzman et al. compared 36 patients who underwent distraction arthroplasty with a hinge to those without a hinge via ROM during ring external-fixation. Two years after the frame was removed, hinge application did not correlate with better ROM, although overall clinical scores were better in the hinge group [55••]. In this study, 28% of patients had either a medial calcaneal or deep peroneal nerve injury. Intema et al. demonstrated a decrease in AOS pain and disability score with distraction and showed that subchondral bone remodeling correlated with clinical outcome [48]. In a follow-up study to Saltzman's original study with the same cohort of patients, the nonhinge group demonstrated superior results at an average follow up of 8.3 years. In this cohort, 16 of 36 patients failed treatment, half of whom eventually underwent ankle fusion [56••]. A level IV study with 96 patients by Zhang et al. compared outcomes between distraction arthroplasty alone vs. distraction arthroplasty combined with arthroscopic microfracture for PTAA. Ultimately, the authors determined the combined treatment to be superior regarding improvement of functional ability, pain, and radiologic appearance related to PTAA [57••].

Overall, results are variable in the literature regarding distraction arthroplasty. Advantages associated with this technique include a minimally invasive approach and lack of required internal fixation, facilitating future reconstructive procedures. However, further studies are required to assess outcomes of TAR or arthrodesis after distraction. Additionally, analyses of outcomes in patients with moderate PTAA are necessary as most studies currently involve patients with severe arthritis who would have otherwise been candidates for fusion. One of the major limiting factors of distraction arthroplasty is the need for stringent follow-up and meticulous postoperative regimens.

Supramalleolar Osteotomy Supramalleolar osteotomy is a joint-preserving procedure reserved for eccentric cartilage loss secondary to excessive varus or valgus malalignment. It has been well documented that changes in pressure and force transfer across the ankle joint occur in response to ankle malalignment, occurring in both the coronal and sagittal plane. The degree of supramalleolar varus or valgus will have significant impacts on the force transduction across the joint surface [58, 59]. The resulting focal static and dynamic overload within the joint causes rapid degeneration of the joint surface [58, 60]. Beyond varus or valgus malalignment, ankle joints are further classified into congruent or incongruent deformities. Congruency is based off tibiotalar tilt, with 4° or less considered congruent, and greater than 4° considered incongruent [61, 62].

Supramalleolar osteotomies are performed to realign the mechanical axis and thus redistribute the joint loading force in the ankle, with the goal of delaying or stopping the degenerative cascade [63••, 64, 65].

Indications for supramalleolar osteotomy are asymmetric valgus or varus osteoarthritis with at least 50% preserved tibiotalar joint surface. Contraindications include elderly patients with hindfoot instability not correctable with ligament reconstruction. Further contraindications consist of those patients with severe vascular or neurologic conditions of the affected extremity, inflammatory arthritides, and active infection.

An advantage of the medial opening wedge osteotomy is the ability for gradual correction, with simultaneous correction of the sagittal plane deformity via distraction and subsequent allograft implantation. One of the drawbacks is the potential need for an additional approach should the patient need a fibular osteotomy. Conversely, the lateral closing wedge offers the ability to readily access the fibula, circumvent the need for allograft insertion, increase the inherent stability of the construct, and avoid medial soft tissue compromise [66, 67].

For valgus ankle correction, most recommend a medial closing wedge osteotomy with the aim again of 2–4° of varus overcorrection of the joint surface. The addition of a fibular osteotomy through a separate lateral incision is required if reduction of the talus is blocked by fibular malunion. Medial opening wedge osteotomy can be considered as well, however, is contraindicated with poor medial soft tissue envelope. The medial cortex is also weaker than lateral and may fall into over correction.

Once supramalleolar correction is obtained, remaining malalignment and instability must be addressed. Additional surgical correction of contracture of the subtalar joint, posterior tibial tendon contraction, hindfoot malalignment, lateral ligament instability, and peroneus brevis insufficiency must all be considered. Loss of alignment correction may result if these pathologies are not adequately addressed with adjunctive procedures [63••, 64, 68]. Delayed union or nonunion can result from lack of appropriate fixation or excessive weight bearing in the early postoperative phase.

The most recent studies assessing supramalleolar osteotomies demonstrate promising results. This includes short- to mid-term outcomes regarding survival rates and clinical outcomes. A study of 18 patients by Takakura et al. showed that most patients reported a substantial improvement in both functional performance and pain. Of the 18, only 3 patients had "fair" results which the authors attribute to under correction of the deformity and end-stage arthritis [69]. Cheng et al. again showed that patients generally showed good to excellent results following low tibial osteotomy for both OA and PTOA [70]. Pagenstert reported outcomes at a mean of 5 years on 35 consecutive patients showing improvement in pain and function for the majority, although 10 patients required a revision of some sort including 3 TAAs [65]. Barg et al. showed that clinical improvement is seen in most patients despite the lack of radiographic appearance of anatomic talar tilt reduction, suggesting that the clinical outcomes are not based solely of perfect anatomical radiographic reduction [63••]. Kim et al. analyzed outcomes after varus ankle correction and bone marrow stimulation showing that overall there was an improvement in VAS and AOFAS scores at 27.4 months [71••]. Nuesch et al. compared gait biomechanics and quality of life score in healthy controls to patients undergoing realignment surgery for asymmetric ankle arthritis at a minimum of 7 years postoperatively. The authors showed that between patients and controls, the overall quality of life score did not differ despite differences in gait biomechanics. Of note, the pain subscore was significantly increased in patients undergoing realignment surgery [72••].

Arthrodesis (Fusion) Arthrodesis is one of the mainstay surgical techniques for managing end-stage PTAA. While the current literature shows similar outcomes with total ankle replacements, certain factors significantly affect the outcomes for each procedure such as medical co-morbidities, age, activity level, surgical expectations, coexisting hindfoot pathology, and soft tissue compromise. Arthrodesis is indicated for PTAA refractory to conservative management with persistent ankle-joint pain and stiffness and significantly restricted function.

There are numerous techniques for ankle arthrodesis that have been described, each with their own advantages and disadvantages. As advances in arthroscopic equipment and design have increased so has the popularity of arthroscopic-assisted ankle arthrodesis. The advantages of this technique are the preservation of soft tissue envelope thus maintaining the natural biologic milieu for bony healing. The union rate is similar to that of open techniques, with the expected decrease in wound related complications. However, if there is co-existing deformity, then this technique is not preferred. Greater than 15° of coronal varus or valgus deformity is a contraindication to arthroscopic assisted ankle arthrodesis, and another technique should be considered [73, 74, 75••]. Outcomes for arthroscopic assisted arthrodesis in the nondeformed ankle with appropriate soft tissue envelope are promising. Townshend et al. showed that arthroscopic arthrodesis compared to the open technique had a decreased hospital length of stay, similar 1-year union rates, and overall better clinical outcomes at 2 years postoperatively [75••]. Furthermore, Obrien et al. showed decrease blood loss and tourniquet times and similar union rates at 1 year postoperatively compared to open procedures [76]. Mini-arthrotomy is a variation of the arthroscopic assisted arthrodesis and offers similar advantages to the arthroscopic version, namely preserved biologic healing potential and decreased wound complications [77, 78]. Cadaveric studies show that the mini-arthrotomy technique compared to open procedures protect the major blood supply to the fusion sites, thus theoretically optimizing fusion biology [79]. Again, coronal deformity greater than 15° is difficult to address with the mini-arthrotomy technique, and if present should push toward the open technique. However, some authors have described the ability to correct deformity with wedge resections [78, 80].

Several open techniques for ankle arthrodesis have been described in the literature including the lateral transfibular and lateral fibular sparing techniques. The former described by Mann et al. uses the fibula as an autograft source to supplement fusion [81]. However, some authors argue that removing the fibula destabilizes the ankle causing higher rates of nonunion [80, 82, 83]. Proponents for leaving the fibula in-situ argue that it allows one to assess rotation of the ankle and position of the ankle in the mortise and acts as a buttress for valgus deformity in cases of delayed bony fusion. Smith et al.

looked retrospectively at the fibular-sparing technique in 38 patients at an average follow-up of 28 months showing good results with 93% union at 12 weeks postoperatively, 86% patient satisfaction, and no revisions for malalignment [84••].

Another popular technique is the use of open anterior plating to either supplement screw fixation or as the sole fixation technique for ankle arthrodesis. Anatomic compression arthrodesis with multi-planar screw fixation alone has the benefits of preserving bony anatomy, but construct stiffness depends on the position and orientation of the screws in addition to the quality of the patient's native bone and biology [83, 85–87]. For tibiotalar fusion, two to three screws are typically placed in the inferolateral aspect of the base of the talar neck with trajectory toward the tibiotalar joint and into the tibia. For tibiofibular fusion, two screws are placed on the posterolateral aspect of the fibula with trajectory toward the anteromedial tibia. With well-executed screw fixation, some studies have demonstrated union rates as high as 99%. Anterior plating augmentation improves construct stiffness by decreasing micromotion at the fusion site leading to fusion rates above 90% [88–92]. This technique is particularly helpful in patients with bone loss or poor bone stock in which more rigid fixation is warranted. The anterior approach to the ankle allows for better visualization of the joint surface and allows subsequent triple arthrodesis if necessary due to the maintenance of the medial and lateral malleoli. Literature shows good outcome with anterior plating augmentation, and low complication rates. Guo et al. performed a retrospective study of 10 patients showing 90% fusion at 15 weeks, no postoperative wound complications, with all patients reporting an improvement in pain [90]. In another study looking at the use of an anterior T-plate, authors showed a 94% fusion rate in 33 consecutive patients, the authors did report on two tibial stress fractures that occurred, but healed without complication, and four patients that had superficial surgical site infections [93]. Plaas et al. showed 100% fusion rate and 93% patient satisfaction rate with the use of a double-plate system [92]. If these methods fail and persistent ankle nonunions exist, then one can consider utilizing an external compression arthrodesis with a circular external fixator. This is usually reserved for patients who failed arthrodesis with associated talar osteonecrosis, soft-tissue compromise, infection, or severe deformity [94, 95]. Union rates range from 84 to 100% [94, 96, 97].

Total Ankle Replacement (Arthroplasty) Total ankle arthroplasty (TAA) is a safe and effective alternative to ankle arthrodesis in the treatment of PTAA [98••, 99, 100]. Absolute contraindications to TAA include active infections, Charcot arthropathy and peripheral vascular disease [101]. Cigarette smoking is a relative contraindication due to evidence showing increased wound complication rates, which leads to higher reoperation rates in patients after TAA and poorer patient-reported outcomes [101, 102]. In the past decade, the number of TAAs have increased secondary to improved implant design and short- to mid-term outcomes [101, 103].

Implants for TAA are currently in their third generation and have been improved upon [99, 101]. Earlier generation implants had lower patient satisfaction rates and numerous complications due to lack of consideration for the surrounding soft tissue [99, 103]. Currently, there are cementless fixed implants (two-part implant, e.g., Salto Talaris) and mobile implants (three-part implant, e.g., Scandinavian Total Ankle Replacement (STAR)) [98••].

Recent studies have addressed multiple areas of consideration surrounding TAA such as: surgeon experience, requirement of inpatient management, ankle arthrodesis (AA) versus TAA, fixed versus mobile implants etc. In one such study, Borenstein et al. found that outpatient management of patients undergoing TAA resulted in low (1.5%) infection and wound breakdown rates and that outpatient pain management was appropriate with no patients requiring readmission for pain control [104••].

TAA is a technically demanding procedure and requires adequate expertise to allow patients the best surgical outcomes [105, 106]. Surgeons with higher volume/expertise had lower complications rates, lower cost of care and reduced hospital length of stay/readmission rates compared to surgeons with lower volume/expertise [105, 106].

In a study by LaMothe and colleagues using multiple state-wide databases, TAA outcomes were evaluated showing promising results for newer generation implants, which showed a greater than 90% survivorship at 5 years, however, the risk of 90-day readmission was associated with a score of at least 2 on the Charlson-Deyo Index, which uses ICD-9-CM diagnosis codes to assesses 17 specific comorbidities to calculate a medical comorbidity score for each patient. Fixed and mobile bearing implants have shown positive results when analyzing patient-reported outcomes such as pain, functionality, physical and mental health, lower complication rates, and excellent mid- to long-term survivorship [100, 104, 107••, 108–114].

Wound breakdown is one of the major complications of TAA. The lateral approach TAA is a method that can be used when there are significant pre-existing anterior wound complications [115]. This lateral approach can reliably correct alignment especially through the fibular osteotomy; however, this may result in more complications [116]. In a study by Gross and colleagues, there were similar rates of wound complications in patients with diabetes, coronary artery disease and smoking [116]. In a similar study of patients with obesity, a risk factor believed to be the cause of increased complications after TAA, Gross showed that obese patients can safely undergo TAA and despite having lower functional outcomes initially, their functional and pain scores continue to improve [117]. Schipper et al.

showed that the use of compression dressing led to a reduction in wound complications and a higher rate of healed wounds 3-months postoperatively [118].

Despite significant improvement in TAA and increased use in the past two decades, selection of TAA for treatment of PTAA should be on an individual basis for each patient. Patient comorbidities, current level of function, desired outcome and surgeon expertise should all play a role in deciding when to perform TAA. Future studies with longer follow-up will elucidate further the reliability of the current generation of implants.

Ankle arthrodesis (AA), though considered by many to be the treatment of choice for ankle arthritis, results in reduced mobility of the ankle joint and increased complication rates such as adjacent joint degenerative changes compared to TAA. TAA, however, allows conservation of mobility at the ankle but has been associated with higher rates of revision [99, 119]. Studies ultimately suggest that the decision of AA versus TAA should be made on an individual patient basis, taking into account all patient considerations [99, 119]. Certain criteria must be satisfied before considering an arthroplasty, including (1) soft tissue envelope adequacy, (2) perfusion adequacy, (3) absence of neuropathy, and (4) ability to correct the deformity. Additionally, TAA may be considered in certain cases of avascular necrosis, such as those which are amenable to restoration via revascularization and creeping substitution TAR [120]. Satisfaction of these criteria affords further discussion, including the pros and cons related to each treatment thereof. Factors which strengthen the argument for fusion include obesity, diabetes, labor-intensive employment, and patient desire for a single operation. Factors which favor replacement include adjacent joint arthritis and/or a stiff foot, bilateral ankle arthritis, lower demand patients, and patients whose desired activities or work require ankle motion (wearing boots, frequent crouching, walking on uneven ground or hills). Within this context, a well formulated conversation may be had with the patient, ultimately allowing for their autonomous and informed decisions regarding treatment.

Conclusions

Management for PTAA is generally progressive. Initial treatment entails nonpharmacologic options including patient education, exercise, weight management, and assistive devices. Acetaminophen is the pharmacologic therapy of choice for symptomatic OA with topical and oral nonsteroidal anti-inflammatory agents as second-line therapies. PTOA refractory to first- and second-line therapies may be managed with tramadol with consideration given to duloxetine. Intra-articular injections are appropriate for step-up therapy, though additional evidence is required to establish a standard for frequency, dose, and formulation. Surgical management is reserved for advanced PTAA refractory to conservative treatment. Patient demographics and lifestyles should be carefully considered when formulating a management strategy, as outcomes are dependent upon the satisfaction of each set of respective criteria. Ultimately, the management of PTAA should be individualized to satisfy the specific needs and desires of each patient.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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