Total ankle arthroplasty in end-stage ankle arthritis

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Abstract Recent advancements in ankle prosthesis design, combined with improved surgical techniques for correction of coronal plane deformity and ligamentous balancing, have led to a resurgence of interest in total ankle arthroplasty for the treatment of end-stage ankle arthritis. Although ankle arthrodesis has long been considered the gold standard treatment for ankle arthritis, recent studies have shown that patients who undergo total ankle replacement have equivalent pain relief and improved function, when compared with patients with an ankle fusion. The purpose of this review is to summarize the indications, advantages, disadvantages, and clinical outcomes of some of the more commonly used modern prostheses for total ankle arthroplasty.

Keywords Ankle arthritis · Total ankle arthroplasty · Total ankle replacement · Mobile bearing · Fixed bearing

Introduction

Ankle arthritis can be a significant source of pain and disability for patients. Individuals with end-stage ankle arthritis experience equivalent levels of pain and limitation to their activities of daily living as patients with end-stage hip arthritis [1]. Moreover, end-stage ankle arthritis can result in similar perceptions of quality of life for a patient as end-stage kidney disease or congestive heart failure [2]. Primary osteoarthritis of the ankle is relatively uncommon. The most common cause of end-stage ankle arthritis is prior ankle fracture or ankle instability as a result of prior ligamentous injury to the ankle [3]. With posttraumatic arthritis constituting approximately 70 % of all end-stage ankle arthritis, inflammatory arthropathy is the second leading cause, with a reported incidence of 12 % [3].

Ankle arthrodesis has long been considered the gold standard treatment for ankle arthritis. Early attempts at total ankle arthroplasty in the 1970s were fraught with high rates of osteolysis, significant tibial and talar bone loss, component loosening, and wound complications [4–7]. This played a large role in the abandonment of ankle replacement in favor of ankle arthrodesis for the treatment of end-stage ankle arthritis.

Successful ankle arthrodesis has been shown to result in relief of pain and return to activities of daily living. However, fusion of the ankle joint will require compensatory motion in the adjacent joints during gait [8]. Long-term studies have demonstrated that joints of the hindfoot adjacent to the ankle will degenerate and develop arthritis following ankle arthrodesis. Fuchs et al. reported that 50 % of patients will have significant limitations to their activities of daily living 20 years after ankle arthrodesis because of arthritis, which

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develops primarily in the subtalar joint, but also in the talonavicular, calcaneocuboid, and midfoot [9]. In addition, Buchner and Sabo showed significant stiffness in the joints adjacent to the ankle 9 years after ankle arthrodesis and found that clinical outcomes were directly correlated with the range of motion available in the remaining joints of the foot [3, 10].

Recent advancements in prosthesis design, combined with a better understanding of ligamentous balancing and component alignment, have renewed interest in total ankle replacement as an alternative to ankle arthrodesis. With modern prostheses, total ankle arthroplasty has been shown to result in equivalent pain relief and improved function, when compared with ankle arthrodesis [11, 12••]. In addition, there is early evidence to suggest that adjacent joint degeneration is mitigated by ankle arthroplasty, when compared with ankle arthrodesis [13, 14•].

Current generation implants can be divided between fixed-bearing and mobile-bearing designs. In fixed-bearing prostheses, the polyethylene component is fixed to the metallic tibial component, whereas in a mobile-bearing prosthesis, the polyethylene component is positioned between the metallic components of the tibia and talus, thus creating two articulating surfaces. The purpose of this article is to review the indications, advantages, disadvantages, and clinical outcomes of some of the more commonly used modern prostheses for total ankle arthroplasty.

Patient evaluation and indications for total ankle arthroplasty

The evaluation of a patient with ankle arthritis for possible ankle arthroplasty begins with obtaining a consultation with a foot and ankle trained orthopaedic surgeon with experience in ankle replacement. Weight-bearing radiographs of the ankle and foot, including a hindfoot alignment view, are necessary to evaluate the extent of disease in the ankle and to examine adjacent joints of the hindfoot for degenerative changes. Weight-bearing radiographs are also necessary to identify malalignment in the ankle and foot, which will need to be taken into consideration during preoperative planning. Computed tomography or magnetic resonance imaging can be used to better determine the extent of subchondral cyst formation and evaluate for avascular necrosis of the talus or tibia. During initial consultation, patients may also be evaluated as candidates for other joint-preserving procedures, such as supramalleolar osteotomy, fresh allograft transplantation, and distraction arthroplasty.

Total ankle arthroplasty is indicated in patients with end-stage ankle arthritis who have sufficient bone stock available in the tibia and talus to support a prosthesis. Patients with associated arthritic changes in adjacent joints of the hindfoot

and midfoot are ideal candidates. Contraindications include active infection in the ankle, poorly controlled diabetes, neuropathic arthropathy, and avascular necrosis in the tibia or talus with subchondral collapse. Relative contraindications include peripheral vascular disease, peripheral neuropathy, poor soft tissue envelope, and a history of tobacco use. Patients should have failed appropriate nonoperative management, which may include activity modification, nonsteroidal antiinflammatories, intra-articular corticosteroid injections, bracing, and physical therapy.

Successful ankle arthroplasty is more dependent upon preoperative planning, proper surgical technique, and ligamentous balancing than upon the type of prosthesis that is chosen for implantation. However, there are cases when certain patients may be better served with one type of prosthesis over another. Those instances will be highlighted as each prosthesis is discussed individually.

INBONE® total ankle system

The INBONE® Total Ankle System (Wright Medical Technologies, Arlington, TN) is the first prosthesis to use intramedullary referencing for placement of the tibial component. Initially approved by the U.S. Food and Drug Administration in 2005, a second generation of the prosthesis was introduced in 2010. It is a stout, fixed-bearing prosthesis that utilizes stem fixation for the tibial and talar components to better distribute stresses at the bone–implant interface (Fig. 1). Both the tibial and talar components are made of cobalt–chromium with a titanium plasma spray coating. The current version of the INBONE® total ankle has a talar component with a central sulcus, thus providing additional coronal stability. Our indications for an INBONE® total ankle arthroplasty include patients with moderate-to-severe ligamentous instability of the ankle; large, incongruent ankle coronal plane deformities; moderate-to-severe sagittal angular deformity, as well as anterior or posterior talar subluxation relative to the tibia; and moderate-to-severe talar wear as evidenced by a flat-top talus. In addition, we utilize the INBONE® prosthesis as our primary prosthesis in the obese patient and for revision total ankle prosthesis.

The principal advantage of the INBONE® total ankle replacement is the constraint it provides at the tibiotalar articulation. Stresses transferred from the prosthesis to the bone–implant are mitigated by the increased surface area achieved by the stemmed component of the tibia and talus, as well as a talar component with a surface area that is 1.5 to 2 times larger than other FDA-approved talar components [15, 16]. Moreover, there is modularity available in the tibial component that allows for improved coverage in the anteroposterior plane and better cortical contact with the distal tibia. Placement of the talar component requires a flat cut

Fig. 1 Preoperative (a) and postoperative (b) anteroposterior radiographs of the ankle, demonstrating a patient with end-stage ankle arthritis with valgus deformity who underwent total ankle arthroplasty with the INBONE prosthesis

on the talus, which allows for minimal bone resection, especially in cases where there is significant wear on the talus or in cases of revision ankle arthroplasty.

The INBONE® requires the surgeon to drill a hole from the plantar aspect of the foot, through the calcaneus and talus, and into the tibia. The 6-mm hole is designed to pass anterior to the posterior facet of the subtalar joint; however, it creates an additional hole in the talus, which may act as a stress riser. In addition, it creates a communication between the subtalar joint and the underside of the talar prosthesis, which may contribute to cyst formation at the bone–implant interface. Lastly, passage of the drill across the subtalar joint places the artery of the sinus tarsi and the artery of the tarsal canal at risk. These vessels provide the majority of the blood supply to the talus, and injury to these vessels may place the talus at risk for avascular necrosis postoperatively.

To date, there are few reports on the outcomes of the INBONE® total ankle. Adams et al. reported on the results of a consecutive series of 194 patients who underwent primary total ankle arthroplasty with the INBONE® prosthesis. At a mean follow-up of 3.7 years, they noted significant improvement in pain, function, and patient-reported outcome scores [17•]. In addition, they reported an overall survivorship of 93.8 %, with a 10.3 % incidence of reoperation and a 6.2 % incidence of revision of the metallic components [17•]. Devries et al. summarized their results for 14 patients who underwent revision total ankle arthroplasty from the Agility total ankle replacement (DePuy Orthopedics, Inc, Warsaw, IN) to the INBONE® prosthesis [18]. Although they were able to demonstrate successful revision of the ankle replacement, they noted a complication rate of

64.3 %, which included two failures and four patients who developed component subsidence and persistent pain [18]. In conclusion, early to midterm follow-up of the INBONE® total ankle is promising; however, further studies with longer term follow-up are necessary to determine implant survivorship and patient factors that may predispose to early failure. Although revision total ankle arthroplasty is possible with the INBONE® prosthesis, complications in this setting are common.

Salto Talaris total ankle arthroplasty

The Salto Talaris total ankle arthroplasty (Tornier US, Edina, MN) is an anatomically designed, fixed-bearing prosthesis available in the United States since 2006 (Fig. 2). The Salto Talaris is a fixed-bearing design that is based on the initial mobile bearing design that is used outside of the United States—known as the Salto Total Ankle. The evolution of the fixed-bearing design came about after a radiological study assessed postoperative polyethylene motion and observed very little motion of the mobile bearing [15]. Both the tibial and talar components are made from a cobalt–chromium alloy. The talar component is conical in shape, with two different radii of curvature to match the normal morphology of the talus. The lateral facet of the talus is resurfaced. Fixation of the talar component is achieved by a central peg. The tibial component utilizes a central keel for fixation.

A unique feature of this fixed-bearing implant is that the trial tibial component can rotate on the tibia to find its ideal rotation. The trial tibial component has a highly polished

Fig. 2 Preoperative (a) and postoperative (b) mortise radiographs of the ankle showing a patient with end-stage varus ankle arthritis who underwent total ankle arthroplasty with the Salto Talaris implant

base allowing it to articulate freely with the distal tibial cut. Taking the ankle through a range of motion allows the implant to find its proper position. In practice, the tibial component is constrained by the malleoli, and significant rotation is achieved only after resecting a portion of the malleoli. Although there is some modularity between the components, the tibia and talus can differ only by one size. In addition, there are instances when the geometry of the tibial component will not allow for contact of the prosthesis with the anterior and posterior cortical rim of the distal tibia.

Results for the Salto Talaris total ankle arthroplasty have been encouraging thus far. In the U.S., Schweitzer et al. reported on the largest known cohort of patients treated with a Salto Talaris ankle replacement [19•]. They followed 67 patients clinically and radiographically for a minimum of 2 years. Implant survival was 96 % at a mean follow up of 2.81 years. Three patients developed aseptic loosening of the tibial component, and two of those patients required revision of the tibial component [19•]. Longer-term results are available from the Salto mobile-bearing prosthesis used in Europe. Bonnin et al. looked at midterm outcomes of 93 Salto total ankle replacements and noted an implant survivorship of 95 % [20]. More recently, Bonnin et al. published a follow-up report examining the long-term outcomes of the Salto total ankle arthroplasty and noted a survivorship of 85 % at a mean follow-up of 8.9 years [21]. Even though there is not an abundance of literature specifically relating to the Salto Talaris TAA system used in the U.S., the short-term survivorship and functional improvement reported thus far are promising.

S.T.A.R.

The Scandinavian Total Ankle Replacement (S.T.A.R.) has been FDA approved for use since 2009. The first generation prosthesis, developed in 1986, used a three-piece cemented design and has evolved to the only uncemented, mobile-bearing total ankle arthroplasty approved for use in the U.S. today. The S.T.A.R. is unique, since it utilizes a mobile-bearing meniscus theoretically allowing axial rotation, translation, as well as dorsiflexion and plantarflexion of the artificial ankle joint (Fig. 3).

Features of the S.T.A.R. include a cobalt–chromium alloy tibial component with titanium plasma spray coating allowing bony ingrowth to occur. A trapezoidal shape and two barrels are employed to increase bone contact and stability, while the surface articulating with the polyethylene is flat and highly polished, allowing the polyethylene component to glide. This ankle uses a highly cross-linked polyethylene that is also flat along its top surface to conform to the tibial component, while the talar side of the polyethylene is

Fig. 3 Preoperative (a) and postoperative (b) mortise radiograph of the ankle of a patient with rheumatoid arthritis with minimal coronal deformity who underwent a S.T.A.R. total ankle replacement

curved to match the smooth curved surface of the talus. A sagittal groove runs through the center of the polyethylene, which matches a fin in the talus in order to confer medial-to-lateral stability. The polyethylene is square to minimize impingement on the malleoli. The talar component is also made of a cobalt–chromium alloy with titanium plasma spray coating and resurfaces the medial and lateral facets of the talus.

The principal advantage of the S.T.A.R. prosthesis is its mobile-bearing design. By allowing motion in flexion, extension, and rotation, it minimizes the stress that is transmitted to the bone–implant interface. However, because the polyethylene is not fixed to either the tibia or the talus, the prosthesis can translate and create edge loading of the polyethylene insert. This can lead to increased polyethylene wear and osteolysis [22••]. In addition, because the implant is less constrained than fixed-bearing implants, it does not confer the same stability for coronal plane deformities. The prosthesis is ideally suited for lower demand patients, with minimal preoperative deformity, who present with significant adjacent joint arthritis in the hindfoot and midfoot. Patients with inflammatory arthropathy are also excellent candidates for a S.T.A.R. prosthesis.

Recent studies have shown that patient-reported outcomes are significantly improved after successful implantation of the S.T.A.R., with long-term survival rates of 70.7 %–90 % at 10-year follow-up [22••, 23•, 24]. Early results in one large, multicentered study comparing S.T.A.R. total ankle with tibiotalar arthrodesis showed equivalent pain relief, with superior function in the ankle replacement group [12••]. Gait studies conducted following S.T.A.R. ankle replacement have shown more normal gait patterns, as compared with historical studies of the effects of ankle fusion. In addition, increases in cadence, stride length, and ankle range

of motion have been observed, when compared with preoperative measures [25].

Complication rates reported in the literature vary widely and consist of wound complications, aseptic loosening, coronal plane malalignment, malleolar fractures, and subsidence. Implantation of the S.T.A.R. total ankle arthroplasty is a technically demanding procedure. Authors have reported a steep learning curve associated with this procedure and have reported improving outcomes as their experience with the procedure increases [26]. One must use caution in interpreting reported results of the S.T.A.R., since earlier designs used a single coating of hydroxyapatite, as well as first-generation instrumentation. Successful total ankle replacement requires strict attention to correct coronal plane alignment, since errors can lead to much higher rates of aseptic loosening, when compared with hip or knee replacement [27].

Zimmer Trabecular Metal total ankle

The newest total ankle arthroplasty system to become available in the U.S. is the Zimmer Trabecular Metal Total Ankle system (Fig. 4). This total ankle system is designed to accurately reproduce the ankle anatomy and joint kinematics with minimum bone resection. The Zimmer Trabecular Metal Total Ankle is a fixed-bearing prosthesis.

The prosthesis utilizes trabecular metal technology, which is designed to simulate the architecture of normal cancellous bone. Bobyn et al. have shown that trabecular metal has up to 80 % porosity, thus increasing the potential for bony ingrowth [28]. The potential for bony ingrowth is a unique feature, as compared with other prostheses that rely upon

bony ongrowth for fixation at the bone–implant interface. The prosthesis also has a highly cross-linked polyethylene insert, which may improve the wear properties of the polyethylene and decrease osteolysis.

Another unconventional feature of the Zimmer total ankle arthroplasty is the surgical approach for implantation. The anterior approach to the ankle is the current approach for all other total ankle systems on the U.S. market. The Zimmer Trabecular Metal Total Ankle, however, uses a lateral transfibular surgical approach to implant the prosthesis. This requires an osteotomy of the fibula. This approach allows the surgeon to perform curved cuts on both the tibia and the talus, thus placing the metallic prosthesis perpendicular to the trabeculae of the tibia and talus. This may improve the transfer of forces from bone to implant and decrease the shear forces at the bone–implant interface. The transfibular approach, however, can be considered a disadvantage. The fibula has to be repaired at the end of the surgery and has to heal before the patient can resume full activity. In addition, it is more challenging for the surgeon to achieve appropriate ligamentous balance and decide upon the correct size of polyethylene when performing the surgery from a lateral approach and without repairing the lateral ligaments and fibula. Similar to the INBONE® prosthesis, the Zimmer total ankle uses an external frame to maintain the foot in a plantigrade position and assist with alignment of the total ankle components. The Zimmer Trabecular Metal Total Ankle was introduced in the fall of 2012, and there are no published results of survivorship or outcomes to date.

Conclusion

Ankle arthroplasty can relieve pain and improve function for patients with end-stage ankle arthritis. Current ankle prostheses can be divided into fixed-bearing and mobile-bearing designs. However, to date, there are no comparative studies demonstrating the superiority of one type of ankle replacement over another. Early-to-midterm results of modern ankle prostheses are promising; however, further research is necessary to determine long-term implant survivorship and need for reoperation.

Compliance with Ethics Guidelines

Conflict of Interest Constantine A. Demetracopoulos, James P. Halloran, Paul Maloof, Samuel B. Adams, Jr., and Selene G. Parekh declare that they have no conflict 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.

Fig. 4 Postoperative anteroposterior (a) and lateral (b) radiograph of a total ankle arthroplasty using the Zimmer Trabecular Metal Total Ankle

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