INTRODUCTION

Total ankle arthroplasty (TAA) is becoming a popular alternative to ankle arthrodesis for the treatment of end-stage ankle arthritis. Although almost abandoned because of high failure rates with historical prostheses, modern implants are demonstrating a dramatic improvement in clinical outcomes and survivorship. Additionally, pain subscores and functional outcomes are equal to and may exceed those of ankle arthrodesis.1 Likewise, TAA has been shown to be cost-effective compared to ankle arthrodesis.2,3

This chapter summarizes the results of modern TAA, with special attention to patient-specific factors and implant design. However, with more than 40 different implant designs and a myriad of outcome measures, direct comparison among reports of survivorship can be difficult. Additionally, confounding variables such as a prolonged learning curve for surgeons implanting TAA and changes in prosthetic designs and operative techniques make it difficult to sort out the reasons for success or failure. Likewise, the term “failure” is not used universally. In general, failure is defined as removal of one or both metal components with subsequent revision ankle arthroplasty or conversion to ankle arthrodesis. In some survivorship analyses, polyethylene meniscal bearing exchange and other reoperations are included as failures. However, reoperation in TAA does not imply failure. In fact, some repeated surgery for relieving impingement, improving alignment, bone grafting cysts, and/or exchanging the polyethylene component is anticipated to prolong implant survival.

META-ANALYSES AND SYSTEMATIC REVIEWS

The vast majority of TAA studies are case series reporting results of a single implant. However, there have been a limited number of meta-analyses performed to summarize the outcomes of TAA with multiple prostheses. Most studies examined in TAA meta-analyses fail to meet methodological standards, lack key data elements, and contain variability in operative procedures, evaluation tools, and reporting of outcomes. Therefore, generalizations about TAA outcomes derived from meta-analyses of the existing body of literature for TAA are difficult to make in a reliable manner.

Gougoulias et al.4 identified 13 eligible studies comprising 801 mobile-bearing and 304 fixed-bearing prostheses. Including only results of current TAA designs, the authors noted that functional outcome scores improved in all studies and there was no superiority of one prosthesis over another. An important point raised in this study was that residual pain was common after TAA, ranging from 27% to 60%. More importantly, chronic pain was present in patients with clinically and radiographically acceptable implants and sometimes prompted conversion to arthrodesis.5,6

Stengel et al.7 identified 18 eligible studies of mobile-bearing TAAs with a mean follow-up of 44.2 months (range, 35.9 to 52.4 months). Using pooled data of outcome measures with 100-point scoring, they demonstrated a mean improvement of 45.2 points following TAA. A secondary surgery was performed in 12.5% of patients and arthrodesis was necessary in 6.3% of patients. They reported a 5-year survivorship of 90.6 (based on only six studies that actually reported survivorship data). The vast majority of reported results were for one particular design, and the authors did not identify differences in performance ratings when comparing that design against the other prostheses analyzed.

The systematic review by Haddad et al.8 of both TAA and ankle arthrodesis deemed 10 studies with 852 TAAs (both mobile-bearing and fixed-bearing designs) and 59 studies with 1,262 ankle arthrodeses eligible for systematic review. The mean American Orthopaedic Foot & Ankle Society (AOFAS) scores were 78.2 and 75.6 points for TAA and ankle arthrodesis, respectively, with mean subscores of pain, function, and alignment for TAA being 34.5, 37.4, and 9.4 points, respectively. For TAA studies with patient assessment that includes details of excellent, good, fair, and poor, mean results of meta-analysis were 38%, 30.5%, 5.5%, and 24%, respectively. These percentages were also calculated as a ratio of the number of patients with a particular outcome divided by the total number of patients reporting outcome: 48/92 (52.2%) excellent, 28/92 (30.4%) good, 4/92 (4.3%) fair, and 12/92 (13.0%) poor. In studies lacking such detail for TAA, good results were noted in 388/482 (80.5%) and poor results were observed in 94/482 (19.5%). With respect to the low patient satisfaction, their analysis included results of one study of a fixed-bearing two-component prosthesis9 that fall far below those of most studies of TAA.
including other studies of the same prosthesis. Likewise, their overall reported survivorship was lower than those reported in other meta-analyses. This is secondary to low implant survival reported in two studies. One of these studies was by Anderson et al. reporting a 5-year survivorship of 70% in a series of Scandinavian total ankle replacement (STAR) implants. The authors of that study acknowledged that their results and survivorship were negatively influenced by a so-called learning curve and an incomplete inventory of talar component sizes for their initial cases. Furthermore, the prosthesis they used did not consistently have the titanium spray, which is currently used on the mobile-bearing prosthesis that they were investigating. Likewise, the comparative study by Kofoed and Lundberg-Jensen included now abandoned early cemented and un cemented versions of the same mobile-bearing prosthesis.

Zhao et al. performed a systematic review on the available literature of STAR prostheses. They identified 16 studies representing 2,088 implants with a mean follow-up of 52 months. The mean AOFAS and Kofoed scores were 77.8 and 76.4 points, respectively. The pooled 5- and 10-year survival rates were 85.9% and 71.1%, respectively. This systematic review also included the study by Anderson et al., which reported a survivorship of 70% at 5 years and 60.4% at 10 years. The top three reasons for implant failure were aseptic loosening (5.2%), malalignment (1.7%), and deep infection (1.0%).

**JOINT REGISTRIES**

The advantages of joint registries in analyzing outcomes include analysis of large numbers of operative procedures, analysis of outcomes of a large number of surgeons with varied experience levels, the ability to study surgeon-, hospital-, and region-specific trends in practices, and uniform evaluation tools to facilitate comparisons.

In 2007, 18 surgeons from 18 hospitals reported their results extracted from New Zealand’s National Joint Registry. Only two surgeons had performed more than 25 TAAs. New Zealand’s registry included 292 TAAs performed in 183 patients, with 7% failures at a mean follow-up of 28 months. Only two prostheses, one two-component fixed-bearing implant (58%) and one three-component mobile-bearing implant (22%), were used. Overall 5-year survival was 86%, with the majority of failures being due to aseptic loosening.

A larger registry from Sweden included 531 primary mobile-bearing TAA implants (492 patients) reported between 1993 and 2005. Seventy-three percent of the TAAs had been performed by three surgeons in four hospitals. The 19% reported revision rate in this patient cohort is subject to a learning curve, with the busiest three surgeons noting an improvement in implant survivorship of 70% and 86% for the first 90 and second 132 TAAs, respectively. Most revision surgeries were due to the high number of technical errors and aseptic loosening, with nearly all cases of aseptic loosening occurring with the earlier design of the STAR prosthesis.

In a follow-up study of the Swedish Ankle Register, Henricson et al. reported on 780 prostheses implanted between 1993 and 2010. The overall 5-year survival rate was 81% and the 10-year survival rate was 69%. Interestingly, the 10-year survival rate was 72% for patients with rheumatoid arthritis (RA), 68% for patients with osteoarthritis (OA), and 66% for patients with posttraumatic arthritis. The survival rate was significantly lower for the single-coated STAR prosthesis implanted between 1993 and 1999. There was no significant difference in survival rates among the other prostheses (Ankle Evolutive System [AES], Buechel-Pappas, CCI, Hintegra, Mobility, and double-coated STAR). Aseptic loosening was the most common reason for revision and it was mainly a problem with the single-coated STAR.

The Norwegian Arthroplasty Register includes 257 primary TAAs in 245 patients (mean age 58 years) with an average follow-up of 4 years. Meaningful data from this database are for an early version of the STAR mobile-bearing prosthetic design (1996 to 2002) and a modern version of the same prostheses (2000 to 2005). As noted by other authors, fewer revisions due to aseptic loosening of the tibial component were performed in the modern prostheses when compared to the earlier design.

The authors report a 5- and 10-year survivorship of 89% (modern) and 76% (early), respectively. These calculations include the outdated cemented two-component versions of a mobile-bearing prosthetic design that is no longer used. Altogether, 21 revisions were performed in 216 mobile-bearing implants. Six were for aseptic loosening; five occurred with the early design versus only one for the modern design. These authors defined revision as reoperation and did not designate removal of a metal component or conversion to arthrodesis as the end point for their overall survivorship analysis as is commonly reported in other studies. Recalculation of this registry’s survivorship without the six polyethylene exchanges and three other reoperations without removal of the metal components would make this study’s survivorship data consistent with those from other studies of modern TAA.

Outcomes of 515 primary mobile-bearing TAAs included in the Finnish Arthroplasty Register were published in 2010. Three centers each performed 100 TAAs or more, 4 centers performed between 10 and 50 TAAs, and 10 centers accounted for less than 10 TAAs each. Five-year survival was 83% with any reason for revision surgery as the end point and 95% isolating aseptic loosening as the end point. Their analysis of results failed to show a measurable difference in implant survival rates between high- and low-volume hospitals. Relative to the outcomes derived from the other Scandinavian national joint registries, the Finnish report suggests a high rate of ligamentous instability. Despite the majority of metal implants being well-fixed to bone, several TAAs showed ligamentous instability, which the authors attribute to the learning curve for TAA and persistent ligament attenuation secondary to preoperative deformity.

**TAA RESULTS BASED ON PATIENT-SPECIFIC FACTORS**

**ETIOLOGY OF ANKLE ARTHRITIS**

Multiple etiologies of ankle arthritis have been described. The majority of ankle arthritis is posttraumatic in nature. Posttraumatic ankle arthritis includes both ankle fracture and nonfracture traumatic conditions such as repetitive ankle sprains. In fact, studies indicate that approximately 51% to 80% of patients who underwent TAA had posttraumatic conditions.
as the primary etiology of ankle arthritis.25-27 Other common causes include inflammatory conditions such as RA and degenerative arthritis that cannot be attributed to any specific trauma. Less commonly, TAA has demonstrated efficacy for patients with gouty arthritis28 and those with joint destruction secondary to hemochromatosis.29 Results of TAA based on etiology are mixed. The skewed posttraumatic etiology of ankle arthritis and low sample sizes of RA and primary OA are the contributing factors.

According to some authors, results of TAA are less favorable and complication rates are higher in patients with posttraumatic arthritis than in those with OA and inflammatory arthritis.25,27,30-32 In a 10-year follow-up study of 780 implants in the Swedish Ankle Register, Henricson et al.19 demonstrated a greater survival rate for patients with RA compared to OA and posttraumatic arthritis, although this was not significant. Rippstein et al.,25 in a study of 233 TAAs, 123 of which were for posttraumatic arthritis and 36 of which were for RA, reported no significant difference with respect to improvement in AOFAS scores and reduction in pain compared to patients with posttraumatic arthritis. Alternatively, in a slightly smaller study of 158 TAAs with a subset of 127 performed for patients with posttraumatic arthritis, Giannini et al.27 found no significant difference in AOFAS ankle–hindfoot scale scores, range of motion (ROM), or radiographic measurements at a mean follow-up of 38 months. One possible reason for these findings is that TAA for posttraumatic arthritis is frequently performed in a relatively younger patient population and patients who have undergone prior surgery to the ankle.17,18,22,33 Finally, one registry and a meta-analysis suggest a trend of lesser implant survivorship for inflammatory arthritis when compared to OA.12

**AGE**

The mean age of patients receiving TAA consistently ranges from 50 to 60 years.4,7 Several investigations of TAA suggest that implant survivorship and functional outcomes are less favorable in younger patients.7,17,18,34 In a study of 303 TAAs in 305 patients, Spirt et al.34 reported 5-year implant survivorship of 74% and 89% for patients under and over the age of 54, respectively. These authors also calculated that patients with a median age of 54 years or less had a 1.45-times greater risk for reoperation and a 2.65-times greater risk of implant failure than patients over the age of 54. Nonetheless, Kofoed and Lundberg-Jensen15 demonstrated, in a comparative study of a mobile-bearing prosthesis, including early-generation cemented and uncemented TAAs, that TAA survivorship was comparable for patients under and over 50 years of age. One TAA registry reported that a lower age at the time of TAA was associated with increased risk of revision.18 Data from 780 patients in the Swedish Ankle Register demonstrated that women younger than 60 years who suffered from OA or posttraumatic arthritis had a significantly higher risk of revision than patients older than 60 years.25

**WEIGHT**

Few studies report or analyze patient weight. One study reported on the body mass index (BMI) of 90 patients.35 They found no significant change in mean BMI at 6 months, 1 year, 2 years, and 3 years postoperatively despite significant improvement in Ankle Osteoarthritis Scale scores and Short Form (SF)-36 Physical Component scores. The authors did not correlate BMI at the time of surgery and outcome scores or complications.

**PREOPERATIVE DEFORMITY**

One of the goals of TAA is to return the ankle to physiologic alignment. The magnitude of deformity that can be corrected at the time of TAA is unknown. Commonly, coronal plane deformity exceeding 10° to 15° is reported as a relative contraindication to TAA.11,20,21,26-28 Doets et al.30 reported an increased failure rate with a preoperative deformity of more than 10° in the coronal plane. On the contrary, Hobson et al.35 compared patients with preoperative deformity of less than 10° to a group with coronal plane deformity of 11° to 30° and found no difference in ROM, complication rate, and survival rate. Sagittal plane deformity, typically with relative anterior translation of the talus to the tibia, may also result in persistent postoperative deformity, subluxation and edge loading of the polyethylene, osteolysis, and potential early implant failure.25

**THE SUBTALAR JOINT**

Although necessary in select cases of TAA, subtalar arthrodesis may lead to diminished TAA survivorship in younger, high-demand patients.22 Even with equal pain subscores, efficacy outcomes of TAA with subtalar arthrodesis will be inferior to those for isolated TAA, since outcome scoring for the ankle includes hindfoot ROM.40,41

**SIMULTANEOUS IMPLANTATION**

There are minimal reports on TAA in the setting of concomitant arthroplasty. Barg et al.46 reported on 23 patients who underwent bilateral simultaneous TAA because of severe bilateral symptoms. The authors compared this group to 26 patients of similar age, gender, and BMI who underwent unilateral TAA during the same time period. Patients who underwent bilateral replacement had a significantly longer hospital stay and were slower to demonstrate postoperative improvement, yet at 2-year follow-up, there was no difference in the magnitude of improvement in pain, AOFAS ankle–hindfoot scores, and SF-36 scores. The authors concluded that simultaneous bilateral TAA provides significant pain relief and functional improvement comparable to unilateral TAA. In a follow-up study of these same patients plus an additional three patients who underwent bilateral TAA, Barg et al.47 reported results at a median of 5 years.
TAA RESULTS BASED ON PROSTHESIS

There are few studies directly comparing the various prosthetic TAA designs. The majority of reports are level IV descriptive case series about a single prosthetic design, many of which are reports by the designer of the prosthesis. These case series often employ different methodologies, outcome assessments, and survivorship analyses, making direct prosthesis comparison difficult. The authors provide a summary of individual prosthesis results based on larger scale studies or ones that contribute substantially to the literature.

ANKLE EVOLUTIVE SYSTEM

AES (Transystem, France) is a three-part unconstrained mobile-bearing cementless prosthesis. Prior to 2005, the design was cobalt–chrome with a porous and hydroxyapatite coating. After 2005, the components were porous coated with titanium and hydroxyapatite.

Early reported results of this prosthesis were promising. Morgan et al. reported on 45 patients at a mean follow-up of 57.8 months. Their survivorship analysis demonstrated 94.7% survivorship at 6 years. Only two patients required revision: one required revision of the tibial component for aseptic loosening and one underwent tibiocalcaneal arthrodesis for a stress fracture of the talus. The mean postoperative AOFAS score was 88.1. Nine patients demonstrated radiographic osteolysis with two of these patients demonstrating subsidence of the talar component. Owing to stabilization in symptoms, none of these patients underwent subsequent procedures. At the final follow-up, all patients demonstrated neutral ankle alignment except for one patient who was in 10° of varus. However, prior to the final follow-up, nine patients underwent realignment procedures because of edge loading. Similarly, in a study of 93 AES TAs, the 5-year survivorship was 90%. There were seven revisions due to loosening, infection, and fracture.

However, although functional outcome scores were on par with other implant designs, high rates of interface cysts were reported. Besse et al. reported on a prospective radiographic assessment of 50 AES implants with a minimum of 2-year follow-up. They reported a tibia–implant interface cyst (more than 5 mm) rate of 62% and a talus–implant interface cyst rate of 43%, and recommended preventative subsidence intervention by bone grafting. Kokkonen et al. reported on 38 AES prostheses with a mean follow-up of 28 months. In 50% of the implants, osteolysis occurred in the periprosthetic bone area. The 2-year survival rate was 79%. Likewise, in a study of 130 AES implants, osteolytic lesions were radiographically apparent in 37% of ankles. In a subgroup survivorship analysis of the two different implant coatings, the authors found a 3.1-times higher risk of osteolysis in implants with the titanium and hydroxyapatite dual coating than in those with the hydroxyapatite-only coating. In July 2012, the United Kingdom’s Medicines and Healthcare Products Regulatory Agency (MHRA) issued a recall of this device.

AGILITY

The Agility total ankle system (DePuy, Warsaw, IN) is a semi-constrained two-component design, and until 2005 it was the only prosthesis approved by the US Food and Drug Administration. This prosthesis is unique in that it requires syndesmotic fusion. Pyevich et al. reported early promising results on 86 TAAs at a mean follow-up of 4.8 years (range, 2.3 to 12.3). Thirty seven of the ankles experienced delayed or nonunion of the syndesmosis at final follow-up. Nonunion of the syndesmosis was associated with tibial component migration. Twelve tibial and nine talar components had migrated. However, at the time of the report, only five (6%) ankles had to be revised.

In a retrospective analysis of 42 Agility implants with a median follow-up of 8 years (range, 0.5 to 11 years), Criswell et al. reported a revision rate of 39% and an overall reoperation rate of 68%. Kaplan–Meier analysis demonstrated a cumulative 9-year survival rate of 62% with failure as the end point. The average VAS pain score on a scale of 1 to 10 for the patients who retained their implants was 4. Additionally, the authors report less than favorable results of a mailed-in Foot and Ankle Ability Measure (FAAM) in the same population. The authors concluded that TAA had high revision and reoperation rates and patients who retained their implants had only moderate pain relief and function. However, these types of conclusions illustrate the importance of larger studies across multiple implant designs.

BOLOGNA–OXFORD

The Bologna and Oxford Universities (BOX, Finsbury Orthopaedics Ltd, Leatherhead, UK) is a three-part prosthesis with cast cobalt–chrome–molybdenum alloy metal components and an interposed polyethylene meniscal bearing.

In an early result study, Giannini et al. reported on 51 BOX ankles at a mean follow-up of 29.7 months. The authors found a significant correlation between bearing movement and improvement in postoperative ankle dorsiflexion and plantar flexion. There was also a significant improvement of the AOFAS.
ankle–hindfoot score at most recent follow-up. There was only one failure, in a patient with Charcot–Marie–Tooth disease that went on to successful ankle arthrodesis. In another study, Biondi et al.\textsuperscript{38} reported on 62 BOX implants with a mean follow-up of 42.5 months (range, 24 to 71). They reported significant improvement in both AOFAS and VAS pain scores at final follow-up. The reported 5-year survivorship was 91.9%.

Giannini et al.\textsuperscript{27} reported on 158 BOX implants at a mean follow-up of 17.7 months (range, 6 to 48). They demonstrated significant improvement in AOFAS ankle–hindfoot scores at 12, 24, 36, and 48 months after surgery. There were two cases of metal component revision occurring at 2 and 3 years postoperatively. A formal survivorship analysis was not performed, but after more than 4 years of follow-up, 96.1% of the prostheses remained functional.

**HINTEGRA TOTAL ANKLE SYSTEM**

The Hintermann total ankle system (Newdeal, Lyon, France/Integra, Plainsboro, NJ) is a mobile-bearing three-component system.

Hintermann et al.\textsuperscript{39} reported on 122 Hintegra prostheses with a mean follow-up of 18.9 months (range, 1 to 3 years). At final follow-up, 83 (68%) ankles were pain-free and 102 (83.6%) patients were satisfied with the surgery. Eight (6.6%) ankles were revised for loosening of one of the components (4), impingement (2), dislocation of the meniscal component (1), and residual pain and stiffness (1). A formal survivorship analysis was not calculated.

A retrospective study on 317 Hintegra replacements was performed by Barg et al.\textsuperscript{40} This cohort was followed for 53.2 ± 18.4 months. They demonstrated significant improvement in pain, AOFAS ankle–hindfoot score, and ankle ROM at final follow-up. This was a radiographic study of alignment of the center of the talar component with respect to the long axis of the tibia, and therefore, survivorship and complications were not discussed. It is important to mention that patients with the talar centered under the long axis of the tibia experienced significantly greater improvement in pain, AOFAS ankle–hindfoot scores, and ankle ROM postoperatively than did those with the talar centered anterior or posterior to the long axis of the tibia.

**SALTO TOTAL ANKLE PROSTHESIS**

The Salto total ankle prosthesis is a mobile-bearing design with dual titanium and hydroxyapatite coatings on the components.

Bonin et al.\textsuperscript{25} reported on 93 Salto implants with a mean follow-up of 35 months (range, 24 to 68 months). Of note, two patients with Salto implants during the study time period were not included because the implants were removed for residual pain without evidence of aseptic loosening. The authors report a survivorship at 68 months of 98% (favorable scenario) and 94.9% (unfavorable scenario). A Kaplan–Meier survival analysis was not performed.

Bonin et al.\textsuperscript{2} reported on 87 prostheses in 85 patients with a mean follow-up of 8.9 years. There were six cases of implant removal and conversion to arthrodesis. Additionally, there were five cases of polyethylene exchange (one of these cases also had a tibial component exchange). All exchanges occurred in patients in which a 3-mm polyethylene component was used. Eight patients required reoperation for symptomatic osteolytic cysts. Radiographic subsidence was noted with one tibial component and two talar components. None of these patients required additional surgery. The AOFAS ankle–hindfoot scores significantly improved at final follow-up.

Schenk et al.\textsuperscript{63} reviewed the available data on 218 patients at a mean follow-up of 32.8 months (range, 12 to 65). They reported significant improvement of AOFAS ankle–hindfoot and VAS pain scores at 1-year follow-up. The scores did not continue to improve after 1 year. As mentioned earlier, they reported significantly greater improvement in AOFAS and VAS pain scores in patients with RA compared to posttraumatic arthritis. There were five failures of the metal components at a mean of 27 months after surgery and one polyethylene exchange, but this was replaced at the time of infection irrigation and debridement. On the basis of functional radiographs, they reported significant increase in plantar flexion, dorsiflexion, and total ROM at latest follow-up.

A smaller study of 58 Mobility replacements demonstrated a 4-year survivorship rate of 84% for the tibial or talar components.\textsuperscript{26} When polyethylene exchange was included, the 4-year survivorship was 79%. Likewise, in another small study of only 30 TAAs, the 5-year survivorship was 87.6%.\textsuperscript{61}

Recently, a prospective, multicenter, independent, nonin- ventor study was published on 88 Mobility implants followed for a mean of 40 months (range, 30 to 60 months).\textsuperscript{2} The AOFAS ankle–hindfoot score improved from a mean of 38.2 points preoperatively to 74.8 points postoperatively. The authors do not mention if this change was significant. The Kaplan–Meier survival analysis demonstrated a 5-year cumulative survival of 89.6% and a 4-year survival of 88.4%. These numbers represent 10 failures. One patient underwent conversion to arthrodesis for component malpositioning and edge loading and another underwent a transfibial amputation for chronic pain syndrome. Of the eight patients who underwent revision of the components, six were for aseptic loosening of the tibial component, one was for talar component migration, and one was for deep infection. Bone–implant interface abnormalities were identified in 33 (43%) ankles with retained prostheses. The authors concluded that these results do not match those of designer surgeons and may more accurately reflect survivorship.
SCANDINAVIAN TOTAL ANKLE REPLACEMENT

The STAR (Small Bone Innovations, Inc., Morrisville, PA) is a mobile-bearing three-component implant that is used worldwide and is the only mobile-bearing design currently available in the United States. It is the most widely published on prosthesis, and therefore the discussion will be limited to the larger sample size and long-term follow-up studies.

A systematic review of 16 studies and a total of 2,088 STAR prostheses was performed. The mean follow-up for these prostheses was 52 months. The compiled data demonstrated an overall 5-year survival rate of 85.9% and a 10-year survival rate of 71.1%. The overall failure rate was 11.1%. The authors associated aseptic loosening, malalignment, and deep infection as the top reasons for implant failure.

One study analyzed the medium-term results of 200 STAR prostheses with a mean follow-up of 88 months (range, 60 to 156). Twenty-four ankles were revised for unreported reasons. Survivorship analysis indicated a 93.3% survivorship rate at 5 years and 80.3% at 10 years.

Mann et al. prospectively reported on 84 STAR prostheses with a mean follow-up of 9.1 years (range, 2.6 to 11). The AOFAS ankle–hindfoot score significantly improved from 42.7 points preoperatively to 81.9 points postoperatively. There were two cases of aseptic loosening and three cases of subsidence, all requiring conversion to fusion. There were four additional cases of implant failure that were revised to TAA. Calculated survivorship analysis was 96% at 5 years and 90% at 10 years.

Brunner et al. recently published their long-term results of the STAR prosthesis. The study was an observational one of 77 consecutive single hydroxyapatite-coated STAR implants. Sixty-two ankles were available for evaluation. However, all ankles (n = 77) were included in the survivorship and revision rate analyses. Revision of at least one of the metallic components was performed in 29 (38%) ankles. Of these cases, only the talar component was revised in 28 ankles, both components were revised in 25 cases, and one patient underwent arthrodesis. The Kaplan–Meier survival analysis revealed a survival rate of 70.7% at 10 years and 45.6% at 14 years. The main reasons for revision were aseptic loosening, subsidence of the talar component, and progressive cyst formation. Patients who underwent component revision were significantly younger than those without revision surgery. Ankle arthritis etiology and sex were not associated with prosthesis revision. The majority of failures were related to problems at the bone–prosthesis interface, and the authors hypothesize that the single hydroxyapatite coating may partially resorb over time, weakening the interface. The 33 ankles that were not revised were followed for a mean of 12.4 years (range, 10.8 to 14.9) postoperatively. The mean AOFAS score demonstrated significant improvement and 26 patients (27 ankles) were satisfied or very satisfied.

ALTERNATIVES TO ASSESSING TAA OUTCOMES

The vast majority of TAA studies report outcomes based on revision rate and survivorship analysis. However, other outcome aspects may be just as important in assessing the success of TAA.

ACTIVITY LEVELS AND SPORTING ACTIVITY

The majority of TAA studies employ the AOFAS ankle–hindfoot score to report outcomes. This score is heavily weighted to assess pain (40% of the score) and therefore may not be the best measure to assess improvement in function after TAA. Alternatively, other outcome measures that have been used to better assess activity level after TAA include the Activities Rating Scale, the FAAM, the Foot Function Index, the International Physical Activity Questionnaire, and the University of California, Los Angeles (UCLA) Activity Scale.

Valderrabano et al. evaluated 152 mobile-bearing TAs clinically and by questionnaire at early follow-up. Seventy-six percent of the patients who underwent TAA for posttraumatic ankle arthritis reported 83% good-to-excellent results, with mean AOFAS ankle–hindfoot scores improving from 36 to 84 points. Those patients active in sports before the operation tended to be active in sports after TAA. Most commonly, patients participated in hiking, biking, and swimming.

The UCLA activity scale and Activities Rating Scale were used in a study of 155 TAs, with early-to-intermediate follow-up of two mobile-bearing implant designs. Sixty-five percent of patients reported subjective improvement in sports ability after TAA; however, no differences were found in objectively pre- and postoperative sports participation, number of different sports, or frequency of weekly sporting activity. The most common sporting activities were cycling, swimming, and fitness/weight training. Using the International Physical Activity Questionnaire, they also calculated that 79% of patients met current guidelines for health-enhancing physical activity.

Bonnin et al. evaluated 179 mobile-bearing TAs clinically and by means of a self-administered questionnaire at a mean follow-up of 53.8 months. On the basis of an 82% response rate, the authors concluded that 76% of patients rated their ankle as normal or nearly normal and returned to light recreational activities and that nonimpact sport is generally possible, but that impact sports or strenuous recreational activities are rarely possible.

PROGRESSION OF ADJACENT JOINT ARTHRITIS

Several studies note development or progression of subtalar or talonavicular arthritis after TAA. Wood et al. in evaluating 167 TAs in 156 patients, reported progression of subtalar OA in 25 ankles (15%). Knecht et al., in reviewing 117 fixed-bearing TAs with a minimum follow-up of 2 years, noted that 22 (19%) had progressive subtalar arthritis and 17 (15%) had progressive talonavicular arthritis. Mann et al. observed and noted no radiographic progression of hindfoot arthritis at 10-year average follow-up in 44 of 55 (88%) mobile-bearing TAs; none of the remaining patients with progression of hindfoot arthritis were symptomatic. SooHoo et al., using the California’s hospital discharge database, identified 480 TAs over a 10-year study period and suggested that the subtalar arthrodesis rate at 5 years after TAA was 0.7%. These studies suggest that TAA does not fully protect the adjacent hindfoot from development or progression of arthritis.
ALIGNMENT
Survivorship is diminished when optimal TAA alignment is not achieved. Several authors describe soft tissue balancing and adjunctive procedures for the ankle and hindfoot to allow for correction of deformity in the coronal plane. Kofoed described a technique of intra-articular correction to realign severe ankle valgus with TAA that is similar to an intra-articular correction of the knee for severe genu valgum. Bonnin et al. described correction of severe varus with a comprehensive medial soft tissue release similar to that performed for the genu varum knee. The authors add that the medial release technique typically obviates the need for lateral ligament reconstruction, a technique frequently described for TAA in varus ankles. Alternatively, a sliding medial malleolar osteotomy has been described in patients with varus malalignment. Mild-to-moderate preoperative anterior translation of the talus within the ankle mortise appears to correct well with TAA, even with mobile-bearing designs.

RADIOGRAPHIC OUTCOMES
The majority of the implants contributing to these survivorship curves have satisfactory radiographic appearance with regard to periprosthetic lucencies, loosening, settling, or subsidence. Minor, stable component settling, particularly the talar component, within the first year after TAA, has been observed by several investigators and is thought to allow the prosthesis to find its ideal position. Several studies report implant migration, subsidence, or radiolucencies based on serial radiographs but few attempt to correlate the lucencies with outcomes. The presence of lucencies or subsidence does not necessarily mean component failure. Stable lucencies are often asymptomatic. Progressive lucencies or cysts may be bone grafted with successful implant retention, provided the implant is well-fixed at the time of reoperation.

Periarticular heterotrophic ossification (HO) has also been reported after TAA, but its significance with regard to outcome is unknown. Bronner et al. reported a 91% HO rate but could only weakly (insignificantly) correlate HO to AOFAS ankle–hindfoot score, pain, and ankle ROM.

SUMMARY
Modern TAA can provide patients with significant improvement in alignment, pain, quality-of-life measures, and subjective function. Although there are some outliers, implant survivorship, designating the end point as removal of a metal component, ranges from approximately 70% to 98% at 3 to 6 years and from 70% to 95% at 8 to 12 years. The vast majority of TAA studies report early- to midterm outcomes, and longer-term follow-up is needed. Additionally, survivorship after TAA depends on many patient and implant factors and without uniform outcome measures being applied to all studies, comparison of results from the different case series is challenging.

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