Total Ankle Replacement, Then and Now: A Review

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Abstract

Total ankle replacement (TAR) for treating end-stage osteoarthritis of the ankle joint has been evolving since the early 1960s. Increased understanding of the biomechanics and kinematics of the foot and ankle, postoperative results of implant use, and advances in technology have led to improved implant designs and treatment outcomes. The current study reviews associated historical perspectives, kinematics, biomechanics, patient selection, imaging procedures, modern surgical techniques, postoperative complications, and comparison studies with arthrodesis to help evaluate TAR in successfully treating osteoarthritis of the ankle joint. Although arthrodesis remains the gold standard for treatment, findings of new studies have suggested that TAR may be comparable in outcomes, gait mechanics, and complications.

Introduction

Dr. Carrol Larson performed the first TAR in 1962 at the University of Iowa.[1] The patient was a painter, physically active, and worked at a John Deere factory. Findings of radiographs were used to create and guide implantation of a vitallium mold of the surface of his talus. Follow-up of the patient was not reported until 33 years later, which noted an American Orthopedic Foot and Ankle Score of 85 of 100, moderate range of motion, slight limp, and rare pain.[1] Although TAR was being performed as early as the 1960s, the designs of associated implants and treatment outcomes were not fully documented until the later part of the 20th century.

Several studies published between the1970s and 1980s investigated the effectiveness of TAR in treating ankle osteoarthritis.[2-5] In 1973, Lord and Marotte[2] reported an average 5-year follow-up of 25 patients who underwent TAR, in which twelve TAR were unsuccessful and seven patients (3%) were satisfied with the treatment. During this period, most first-generation implants involved 2-component, cemented, and constrained or unconstrained designs (Table 1).[3,4] The tibia implant was usually polyethylene and concave, and the talus implant was a metal alloy with a convex shape. Complications were frequently reported and included aseptic loosening, osteolysis with cyst development, subsidence in mechanically unstable bone after larger bone resections to allow for cementing, and low intrinsic stability resulting in mechanical failure.[3,4] Contraindications to TAR were soon defined by Newton[5] and included history of infection, varus or valgus deformity greater than 20°, ligamentous instability, avascular necrosis of the talus, nonunion of prior fusion, and rheumatoid arthritis with long-term steroid use.

Table 1. Creators of implants used in the first generation of total ankle replacements[a,b]

Years of total ankle replacement	Creator of used implants
1970s-1980s	Mayo Clinic
1970s-1980s	Imperial College of London Hospital Prosthesis
1976	Thompson-Richard
1975	Richard Smith
1970s	Newton Ankle Implant
1970s	Irine Ankle TAR (Howmedica)
1973	St Georg-Bucholtz
1973	Conaxial (Beck-Steffee) Ankle Prosthesis

[a] Kirkup[3]
[b] Wynn and Wilde[4]

In the late 1970s and middle 1980s, treatment results of arthrodesis appeared more promising than those of TAR.[6,7] Demottaz et al[6] compared TAR treatment outcomes at the Mayo Clinic between use of six different implants, including an in-house design, with an average follow-up of 15 months. Most of the implants (88%) showed progressively increased loosening. The study concluded that arthrodesis was the procedure of choice in treating osteoarthritis of the ankle. Additionally, an editorial[7] published in 1985 within *The Journal of Bone and Joint Surgery (British Volume)* noted that, "clearly the answer to the question of replacing the ankle joint using current techniques must be 'no'."

To help understand the effectiveness of TAR in treating osteoarthritis of the ankle, the current review highlights kinematics, biomechanics, patient selection, imaging, surgical procedure, modern techniques, complications, and comparison studies with arthrodesis.

Kinematics and Biomechanics

Since the early 1980s, technological advances in biomechanics have allowed researchers to better reproduce the physiological function and kinematics of the ankle, thus improving TAR implant design and positively affecting clinical outcomes.

In the ankle, the bony and ligament structures create a dynamic & highly congruent joint.[8] The average cartilage thickness is 1.6 mm, whereas that of the knee is 6 mm to 8 mm thick. Removal of the subchondral plate decreases compressive resistance by 30% to 90%. There is a changing instant center of rotation owing to the shape of the talar trochlea, known as being polycentric and poly-radial, which combines rolling and sliding motions.[9] The tibiotalar articulating surface contributes 70% anterior-posterior stability, 50% inversion-eversion stability, and 30% internal-external rotation stability. The ankle has a load-bearing surface of 11 cm^2 to 13 cm^2, with a vertical load of about 5 times and 10 times the body weight during gait and running, respectively.

An important key for successful TAR is allowing for rotational forces while maintaining the stability of the joint and its components. Yamaguchi et al[10,11] examined a 2-component implant and found no difference in weight-bearing and non–weight-bearing kinematics concerning ankle range of motion. The kinematic patterns observed (eg, internal rotation during plantar flexion) were the same as those in naturally positioned ankles, although an overall decrease in range of motion was noted. Surface incongruity and hinging note on 2D and 3D imaging were not observed on static radiographs more than 40% of the time. Reproduced kinematics, in which the joint surface was replaced with a non-anatomic shape, suggested ankle motion may also be guided by extraarticular structures. Success of the arthroplasty depends on how successful designs can dissipate these rotational forces while maintaining the stability of the joint. The kinematics may seem normal, but the stress across the implant is not.

TAR reproduces muscle torque across the joint, which never equals that of an uninjured leg.[12] There is about 83% and 86% dorsiflexion and plantarflexion recovery, respectively. The percentage noted may be promising for rehabilitation, function, and short-term outcomes but potentially misleading for implant survival (with current designs).

Pedobarography is the study of pressure fields acting between the plantar surface of the foot and a supporting surface. Common measurements include maximum force, contact time, peak pressure, contact area, and center of pressure index. Hintermann and Valderrabano[13] examined the use of 148 Hintegra implants with pedobarographic measurements and found a normal plantar pressure distribution and normal line of center of pressure in 78.1%. Using similar measurements, Valderrabano and Hintermann[14] used the STAR prosthetis in treating 65 patients and noted that, at an average 3.5-year follow-up, about 53% of patients had normal plantar pressure distribution while walking. Although the studies did not assess the clinical ramifications of the findings, the long-term altered mechanics across an implant could affect loosening and adjacent joint pathological features. Pedobarographic measurements are useful for preoperative planning in treating complex deformities and evaluating for TAR.

Patient Selection

In the experience of the author, patients who successfully undergo TAR are typically associated with the following descriptions:

- Aged 60 years or older
- Participate in low-demand physical activities (hiking, biking, swimming, golfing)
- No considerable medical comorbidities
- Do not smoke
- Normal body mass index
- Healthy bones
- Well aligned and stable hindfoot
- Healthy soft tissue (no previous operative procedure)
- Well preserved preoperative ankle range of motion
- Reasonable expectations; should not expect notable improvements in range of motion

Imaging

Radiographs should include anteroposterior views with weight and lateral views of the foot and ankle. Clinicians should identify co-existing degenerative joint diseases and other deformities (eg, flat foot). The supramalleolar and inframalleolar ankle alignment should be assessed using the hindfoot alignment view, which accurately assesses heel position in relation to long axis of the leg.[15] The beam is angled at 20° toward the floor, with the medial border of the foot parallel to the beam. A computed tomography scan can help assess bony defects and joint congruency.

Surgical Approach

The traditional approach is anterior, between the tibialis anterior and extensor digitorum tendons. An alternative lateral approach has been described for specific implants, which involved an oblique osteotomy of the distal fibula and is repaired at the end of the operation.[16] If varus and valgus deformities can be surgically corrected with realignment procedures, then TAR is not contraindicated for treatment.

Modern Designs

In the last few decades, implant designs for TAR have evolved (Table 2). Implants have more conservative and bone-sparing cuts, elimination of bone cement to reduce aseptic loosening, biologic interfaces, and increased surface area of metallic components to decrease subsidence.[17,18] The FDA approved five 2-component designs in the US: Agility (DePuy Synthes, Warsaw, IN), Salto (Tornier, Bloomington, MN), INBONE (Wright Medical Group, Memphis, TN), Eclipse (Kinetikos Medical, Carlsbad, California), and Zimmer (Zimmer Trabecular Metal, Zimmer, Warsaw, IN). The STAR implant (Stryker, Mahwah, New Jersey) is the only 3-component design approved for use in the US.

In 2005, Stengel et al[19] published a systematic review meta-analysis of the efficacy of TAR using meniscal (mobile) bearing implants with 3-component designs. Eighteen studies were reviewed, totaling 1086 patients. The results indicated a significant functional improvement and slight increase in ankle range of motion compared with preoperative reports. There was an overall 5-year survival of 91%, with 1.6% deep infection, 14.7% impingement, and 6.3% ankle fusion. Of those patients with impingement, only a small fraction had it revised.

Complications

Studies have shown that TAR can be a technically challenging procedure for surgeons.[20] Performing at least 21 TAR between 2003 and 2009 was considered "high volume." These surgeons have reported considerable decreases for patients in postoperative complications, medial malleolus fractures, length of hospital stay, and hospital charges.[20]

Table 2. Modern designs of implants used in total ankle replacement and results of related studies

Implant name: details	Study (year)	Study variables	Study results
Agility: 2-component; most used implant US	Knecht et al[21] (2004)	126 patients, 132 ankles, 2-13.5 year FO	33 patients died at mean 9-year FO; > 90% of 67 patients with clinical FO satisfied; 89 of 117 ankles with radiograph FO had radiolucency around components
	Kopp et al[22] (2006)	41 patients, 43 ankles, 4-year FO	97% of 38 patients with clinical FO satisfied and would undergo again;98 29 of 40 ankles with clinical FO had radiolucency
Beuchel-Pappas: 3-component; none US	Buechel et al[23] (2014)	Group one: 38 patients, 40 ankles, 2-20 year FO. Group two: 74 patients, 75 ankles, 2-12 year FO	Group one (shallow-sulcus design): 74% survivorship at 20-year FO; Group two (deep-sulcus design): 92% survivorship at 12-year FO
STAR: 3-component; only FDA-approved mobile-bearing ankle prosthesis in US	Kerkhoff et al[24] (2016)	124 patients 134 ankles 7.5-10 year FO	78% survivorship at 10-year FO; 15% of ankles unsuccessfully treated; 10.4% had multiple fractures; 60% had benign osteolytic cyst; > 50% had benign heterotopic ossification
Zimmer: 2-component, semi-constrained, new	Tan et al[17] (2016)	19 patients 20 ankles 12-22 month FO	No fibular complications, but had 2 plates removed for symptomatic hardware; no complications at 12-month FO.

FO, follow-up; US, United States; FDA, Food and Drug Administration.

Progressive designs have some of the same problems as noted with first-generation implants; however, improvements are considerable. For example, although osteolysis and radiolucencies have been common problems,[21-24] the following design changes to adjust these issues include coated metals, smaller bone cuts, congruent components, and attention to detail of alignment and orientation of components. One should have a low threshold to surgically revise the ankle. Medial and lateral malleolar fractures and tendon lacerations have also been reoccurring concerns.[21-24]

Accurate component position is difficult to obtain, yet failure to do so may severely affect treatment outcomes.[25] Low-volume centers have shown lower survival of components.[26] The talus is the most difficult to position because of its constantly changing center of rotation. One study showed that talus malrotation lead to significantly increased peak pressure, decreased contact area, and increased rotational torque; all of which were contributors to component failure, loosening, and polyethylene fracture.[27] Malposition also affects ligament balance and tension, which can have harmful effects.

Wound-healing complications and infection pose a notable threat to successful TAR. Studies have reported such complications up to 20%.[28] Proper patient selection is important to avoiding these problems. Assets include meticulous and skilled techniques for handling soft tissue, hemostasis, and multi-layered closure. Postoperatively, obligate elevation can be essential for successful treatment. If a patient experiences a large dehiscence, surgeons have typically created a local skin graft using the extensor digitorum brevis.[29]

Preoperative malalignment (>15°) can also lead to unsuccessful treatment. Patients who underwent TAR with this level of malalignment had 10 times more frequent edge loading postoperatively.[27] The 8-year survivorship of patients who underwent TAR was reported at 48% with varus or valgus incongruence noted preoperatively, whereas the survivorship was 90% for patients with a neutrally positioned ankle with osteoarthritis.[30]

If the subchondral plate is removed from the talus or the tibia, there is a decrease in compressive resistance of the bone.[31] Implant subsidence is caused by insufficient bone ingrowth, insufficient bone stock, mal-loading, over-stuffing, or over-stressing with high level of activity. Most of these issues can be treated surgically. If performing a revision TAR, use of bone graft and larger components, cement, and staging the revision to allow the graft to take first have been helpful. If performing a revision with arthrodesis, physicians should preserve the height of the ankle with iliac crest autograft or femoral head allograft.[32]

Use of polyethylene in TAR has been reported with some complications. Fracture and wear are consistent concerns. Ultra-high-molecular-weight polyethylene (known as UHMWPE) has less use in TAR owing to the risk of fracture with mobile-bearing 3-component implants.[33] Cross-linking the polyethylene can reduce its mechanical properties and decrease toughness, ductility, tensile strength, and fatigue strength. Polyethylene wear has been comparable to that in a posterior stabilized total knee arthroplasty, with similar particle size and concentration.[34]

Total Ankle Replacement Versus Arthrodesis

Tibiotalar arthrodesis has been the gold standard for treating symptomatic end-stage osteoarthritis of the ankle. Historically, reports of the procedure have shown high fusion rates, low failure and complication rates, and significant improvement in clinical outcomes. The comparison of TAR and arthrodesis has been considerably researched.[35-41]

In 2007, SooHoo et al[35] performed a retrospective review on postoperative outcomes of 4705 arthrodesis and 480 TARs. Patients treated with TAR showed a significantly increased risk of device-related infection and major revision. Overall, TAR major revision rates by 1 year postoperatively were 9% and 5 years, 23%. Patients treated with arthrodesis had an increased rate of subtalar fusion at 5 years compared to those treated with TAR.

Four years later, Courville et al[36] reported the outcomes of a 60-year hypothetical cohort of patients with end-stage ankle osteoarthritis treated with either TAR or arthrodesis. The study used quality adjusted life years (QALY) as a generic measurement for disease burden, in which one QALY was equivalent to 1 year in perfect health. The study found that TAR cost $20,200 more than arthrodesis but had 1.7 more QALY than arthrodesis. The authors concluded that although the implants were costly and patients required lengthier follow-up, TAR remained a more cost-effective alternative to arthrodesis.

In 2007, Haddad et al[37] systematically reviewed relevant studies published between 1990-2004 (49 total; 10 on TAR, 39 on arthrodesis). A total of 852 and 1262 patients underwent TAR and arthrodesis, respectively. The mean American Orthopedic Foot and Ankle Score for TAR was 78.2, whereas that of arthrodesis was 75.6. The 5-year and 10-year survival for TAR was 78% and 77%, respectively. Rate of revision TAR was 7% (vs 9% for arthrodesis, with nonunion being the most common reason). About 1% of patients in the TAR group underwent below-knee amputation (vs 5% for arthrodesis). The study concluded that “intermediate outcomes of [total ankle replacement] appear to be similar to ankle arthrodesis, though ultimately the data is sparse. It should be noted this study while well conducted is rather outdated and survivorship numbers are reported as much better in the more recent literature."

The debate on whether to perform TAR or arthrodesis continues with a more recent study in 2016.[38] It is the first randomized control trial comparing TAR to arthrodesis, currently in data collection and based out of the United Kingdom. The goal is to enroll 328 patients aged 50 to 85 years with end-stage ankle osteoarthritis. The primary outcome measure is patient-reported validated outcomes throughout the first postoperative year. Secondary outcomes include quality of life scores, complications, revision, and reoperation.

Overall, arthrodesis remains the gold standard for treating end-stage ankle osteoarthritis; however, patient indicators for choosing TAR (performed with technical skill) should be considered. More studies have been published that reveal improved gait mechanics and better patient outcomes with TAR than arthrodesis.[39] Yet other recent articles have noted adjacent joint osteoarthritis after symptomatic arthrodesis may not be as frequent as once thought.[40] The debate will clearly continue for some time. Thanks to the advent of 3D printing technology, TAR has moved toward involvement of patient-specific implants such as the Prophecy INBONE and Infinity (Wright Medical Group, Memphis, TN) implants.[41] The effect of these implants on TAR has yet to be determined.

Conclusion

TAR has proven to be a challenging yet successful operative procedure to help patients with symptomatic end-stage ankle osteoarthritis. Although mechanical and technical difficulties with the procedure may challenge surgeons, researchers, and patients, improvements and breakthroughs in implant design are constant. Careful patient selection and technical skill can help minimize the risks and improve outcomes of patients treated with TAR.

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Conflict of Interest

The author reports no conflicts of interest.

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