Total Ankle Replacement
Evolution of the Technology and Future Applications

John J. Yu, M.D., and Steven Sheskier, M.D.

Abstract
Total ankle arthroplasty was developed to reduce pain and retain motion of the ankle joint in patients with osteoarthritis much like its total hip and knee counterparts. Orthopaedic surgeons are well equipped to evaluate and treat patients with end-stage hip or knee arthritis; however, the management of patients with ankle arthritis represents a challenge to both general orthopaedic surgeons and to the foot and ankle surgeons to whom these patients are often referred. Although techniques for both hip and knee arthroplasty have evolved to provide long-term pain relief and functional improvement, neither ankle arthrodesis nor arthroplasty has demonstrated comparably favorable outcomes in long-term follow-up studies. Early ankle arthroplasty designs with highly constrained cemented components were abandoned due to unacceptably high failure rates and complications. While arthrodesis is still considered the “gold standard” for treatment of end-stage ankle arthritis, progression of adjacent joint arthritis and diminished gait efficiency has led to a resurgence of interest in ankle arthroplasty. Long-term outcome studies for total ankle replacement found excellent or good results in 82% of patients who received a newer generation ankle device compared with 72% if undergoing ankle fusion. Continued long-term follow-up studies are necessary, but total ankle arthroplasty has become a viable option for surgical treatment of ankle arthritis.

Anatomy and Biomechanics
The bony anatomy, ligaments, and joint capsule guide and restrain movement between the talus and the mortise so that the talus has a continuously changing axis of rotation as it moves from maximum dorsiflexion to maximum plantar flexion relative to the mortise. The talus and mortise widen slightly from posterior to anterior. Thus, when the talus is plantar flexed, its narrowest portion sits in the ankle mortise and allows rotator movement between the talus and mortise. When the talus is maximally dorsiflexed, the tibiofibular syndesmosis spreads, and the wider portion of the talar articular surface locks into the ankle mortise, allowing little or no rotation between the talus and the mortise. When compared to the other weightbearing joints of the lower extremity, the ankle has significantly less contact area than the hip or knee; 350 mm² versus 1,100 mm² for the hip and 1,200 mm² for the knee under 500 N of load. While the knee is subjected to forces estimated at 3 times body weight, the ankle is subjected to 5.5 times body weight with normal ambulation. In contrast to the articular cartilage of the knee, which ranges from 1 mm to 6 mm, the ankle articular surface is uniformly thinner, ranging 1.0 to 1.7 mm.

Osteoarthritis of the Ankle Joint
Clinical experience and published reports of the treatment of ankle OA indicate that primary ankle OA is rare and that secondary ankle OA, which develops after ankle fractures or ligamentous injury, is the most common cause of ankle OA.

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The ankle joint is subjected to more weightbearing force per square centimeter and is more commonly injured than any other joint in the body, but the prevalence of symptomatic arthritis at the ankle is approximately 9 times lower than that at the knee and hip. Approximately 6 to 13% of all cases of OA involve the ankle joint. With respect to surgical treatment for end-stage arthritis, total knee arthroplasty is performed 24 times more frequently than ankle arthroplasty and arthrodesis combined. Trauma or abnormal ankle mechanics are the most common causes of degenerative changes; less common are inflammatory arthropathies, hemochromatosis, infection, neuropathic arthropathy, and tumor.

While the incidence of severe ankle arthritis is clearly less than the hip or knee, the effects of symptomatic end-stage ankle arthritis on patient quality of life is significant. In a multi-center study comparing 130 patients with end-stage hip arthritis versus 130 patients with end-stage ankle arthritis, SF-36 scores for both groups were substantially lower than that for the population mean, by approximately two standard deviations. The mental and physical disability associated with end-stage ankle arthrosis is at least as severe as that associated with end-stage hip arthrosis.

Management

In the early stages of ankle arthritis, nonoperative management can provide relief for patients. Nonsteroidal anti-inflammatory drugs, corticosteroid injections, ankle-foot orthoses, and a simple lace-up ankle support brace can all provide symptomatic relief. In addition, weight loss and lifestyle modification may also benefit ankle arthritis patients. Less invasive surgical techniques, including ankle arthroscopy, can provide temporary relief. However, it has limitations. Arthroscopic debridement is not recommended for patients with advanced arthritis, significant joint-space narrowing, marked fibrosis, or mechanical deformity. Debilitating posttraumatic arthritis is the most common indication for arthrodesis and is widely considered the gold standard. Arthrodesis is also indicated for pain and deformity secondary to previous infection, osteochondral defects, osteonecrosis of the talus, osteoarthritis, inflammatory arthropathies, and rheumatoid arthritis.

Ankle fusion results are predictable with consistent pain relief once fusion is achieved. In most cases, good and excellent intermediate-term results are reported for modern arthrodesis techniques. Long-term reliability, however, is questioned because ankle fusion has been associated with premature arthritis, pain, and dysfunction of the adjacent hindfoot joints. Waters and coworkers reported a 16% decrease in gait velocity, 3% increase in oxygen consumption, and 10% decrease in gait efficiency after ankle fusion. In a long-term follow-up study of 23 patients evaluated over an average of 22 years after tibiotalar arthrodesis, Coester and associates demonstrated progressive degenerative changes of ipsilateral subtalar (91%), talonavicular (57%), and tarsometatarsal (41%) joints. The progressive arthritis in these joints led to ipsilateral foot pain and limitations in ambulation and activities of daily living. Pseudoarthrosis rates approach 50% in some studies, and appropriate position for fusion is often difficult to obtain in cases with bone loss.

With fusion results being adequate but not optimal, surgeons have tried to replicate the success of the hip and knee arthroplasty into the ankle joint. End-stage ankle arthritis rarely occurs in isolation; any intra- and extra-articular pathologic conditions that may require additional surgery.
(i.e., subtalar arthrodesis) and affect the outcome must be determined before surgery. The preoperative Canadian Orthopaedic Foot and Ankle Society end-stage ankle arthritis classification distinguishes isolated ankle arthritis (type 1), ankle arthritis with intraarticular varus or valgus deformity, hindfoot instability or a tight heel cord (type 2), ankle arthritis with hindfoot deformity, tibial malunion, midfoot abduction or adduction, supinated midfoot, plantar flexed first ray, etc. (type 3), and types 1 to 3 plus subtalar, calcaneocuboid, or talonavicular arthritis (type 4).8 When applied to the patient’s clinical and radiographic picture, the classification helps to correctly assess intra- and extra-articular ankle and hindfoot deformities and facilitates the decision of whether fusion or arthroplasty is to be recommended. The ideal indication for TAR is a lightweight individual with a body mass index (BMI) ranging from 20 to 25 kg/m², little or no hindfoot deformity (i.e., varus or valgus), low demand, severe pain secondary to ankle arthritis, and preservation of more than two thirds of normal ankle range of motion. Patients with arthritis or previous arthrodesis of the adjacent joints (i.e., subtalar and talonavicular joint) are also considered good candidates for TAR because pantalar arthrodesis would be an undesirable alternative. However, only 10% to 20% of patients meet these criteria, and most TAR candidates have at least one or two relative contraindications.

Relative contraindications for TAR are a high activity level, BMI greater than 25 kg/m², coronal deformity greater than 15°, partial areas of avascular bone, traumatic bone loss, osteoporosis, poor motion, diabetics without angiopathy, or a history of previous infections. Absolute contraindications for TAR are Charcot arthropathy, active infection, vascular compromise, avascular necrosis of the talus, and significant peripheral neuropathy. The exact parameters regarding these contraindications are poorly supported by the literature and are left largely to the discretion of the surgeon.

Historical Total Ankle Replacement Designs

The first reported attempt to avoid fusion of an arthritic ankle was in 1913 when Eloesser performed ankle cartilage allograft transplantation.9 The first “total” ankle replacement was performed by Lord and Marrotte in 1970.10 Their prosthesis could be described as a reverse hip, with a long stem metallic component implanted into the tibia, articulat-
ing with a cemented acetabular cup in the calcaneus, after
the talus had been completely removed. The implant was
abandoned due to unsatisfactory results. The stimulus for
total ankle replacement in the last 40 years derived from
partial dissatisfaction with ankle arthrodesis and the success
of total hip and knee arthroplasties. Learning from failure,
surgeons continued to modify implant designs, moving from
constrained to less constrained, and from two- to three-
component mobile-bearing designs (Figs. 2 and 3).
Outcomes gradually improved, with survivorship rate of
approximately 80% at 10 years. Over the years, the use of
dolor methacrylate cement for implant fixation was
abandoned, whereas advancements in technology led to
improved metallic implant surfaces that could induce bone
ongrowth and reduce aseptic loosening. Current total ankle
replacement systems include various materials and shapes of
fixation elements. Pegs, long or short stems, and cylindrical
or rectangular bars have been used. Cobalt chromium alloy
is the current material of choice.
As a result of clinical failures of multiple cemented,
highly constrained devices, implant design has evolved to
allow for press-fit insertion, limited bone resection, as well
as less constrained components. The new implants have
been designed with attention to reproducing normal ankle
anatomy, joint kinematics, ligament stability, and mechanici-
al alignment. Two- or three-component designs are used to
allow for sliding and rotational motions at the ankle joint.
The development of a prosthesis that would accommodate
the three articulations of the ankle has proceeded in two
strategic directions.
The first is replacement of all three articulations (talo-
fibular, tibiotalar, and medial malleolar-talar) along with a
fusion of the distal tibiofibular syndesmosis. The second is
replacement of the superior articulation with hemiarthroplas-
ties of the medial and lateral malleolar articular surfaces.
The second generation implants (Agility™, Salto-Talaris,
INBONE™, Eclipse) are two component systems with a
polyethylene bearing surface incorporated into the talar or
tibial component.
In contrast, the third-generation designs incorporate a
third component: an independent polyethylene component,
the mobile-bearing meniscus. The three-component design
allows for flexion and extension at the talar-meniscal inter-
face with rotation and sliding at the tibiomeniscal interface.
Advantages of this design are improved congruency, multi-
planar motion, and minimal bone resection. Disadvantages
are the potential for dislocation of the mobile bearing, per-
sistent pain at the medial and lateral articulations, and the
necessity for a tight implant fit to prevent instability of the
mobile bearing. The STAR™ was recently approved by the
Food and Drug Administration (FDA) in 2009 as the first
meniscal-bearing ankle for use in the USA.
There are presently five arthroplasty designs that are
FDA approved for implantation plus one system in final
clinical trials in the USA. The INBONE™ Total Ankle, the
Salto Talaris Anatomic Ankle, and the Eclipse Total Ankle
Replacement have all been approved for less than 6 years.
The Mobility Total Ankle System is currently involved in
a double-blind FDA study versus the Agility™ Total Ankle
System. Due to the lack of published data supporting the

<table>
<thead>
<tr>
<th>Device (Manufacturer)</th>
<th>Components</th>
<th>Materials</th>
<th>Fixation</th>
</tr>
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<tbody>
<tr>
<td>Agility (DePuy, Warsaw, IN)</td>
<td>Two</td>
<td>Tib = titanium Tal - Co-Cr</td>
<td>Central Fins</td>
</tr>
<tr>
<td>INBONE (Wright Medical Technologies, Arlington, TN)</td>
<td>Two</td>
<td>Titanium Tal - Co-Cr</td>
<td>Tib = IM Stem</td>
</tr>
<tr>
<td>Salto Talaris (Tornier, Saint Ismier, France)</td>
<td>Two</td>
<td>Co-Cr Topped by cylinder Tal = pegs, hollow stem</td>
<td></td>
</tr>
<tr>
<td>Eclipse (Integra LifeSciences, Plainsboro, NJ)</td>
<td>Two</td>
<td>Co-Cr Tib = box Stem Tal = fin</td>
<td></td>
</tr>
<tr>
<td>STAR (Waldemar Link, Hamburg, Germany)</td>
<td>Three</td>
<td>Co-Cr Tib = box Stem Tal = fin</td>
<td></td>
</tr>
<tr>
<td>Mobility (DePuy International, Leeds, UK)</td>
<td>Three</td>
<td>Co-Cr Tib = stem</td>
<td></td>
</tr>
<tr>
<td>Buechel-Pappas (Endotec, South Orange, NJ)</td>
<td>Three</td>
<td>Titanium Tal = fin</td>
<td></td>
</tr>
<tr>
<td>HINTEGRA</td>
<td>Three</td>
<td>Co-Cr Tib = screws Tal = fin</td>
<td></td>
</tr>
<tr>
<td>BOX (Finsbury Orthopaedics, Leatherhead, Surrey, UK)</td>
<td>Three</td>
<td>Co-Cr Tib = bars Tal = pegs</td>
<td></td>
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survivorship and clinical outcomes for these four systems in the USA, it is difficult to determine their future significance.

**Evolution of the Total Ankle Replacement and their Outcomes**

Current popular ankle arthroplasties (Table 1) have two common features: all are porous coated for bone ingrowth, and almost all components are made of a titanium alloy with a cobalt chrome-polyethylene articulation.

Ankle arthroplasty implants of the first decade (1970s) were relatively constrained, consisting of two components: one made of metal and one of polyethylene fixed with polymethyl methacrylate cement (Fig. 2). Because clinical results were far from satisfactory, newer designs were introduced. The one fundamental modification, compared with the early era implants, is namely the “meniscus,” made of UHMWPE in most prostheses (with the exception of the TNK ceramic-metallic ankle arthroplasty). Some prostheses, although consisting of three components (tibial, talar, and polyethylene), act as two-component implants. In the Agility, TNK, INBONE, Eclipse, and ESKA ankle implants, the meniscus is fixed to the tibial component and has no independent movement (fixed-bearing). However, other modern prostheses consist of three separate components (tibia, talus, mobile meniscus). Therefore, modern total ankle replacement prostheses are classified as three-component versus two-component implants and fixed-bearing and mobile-bearing implants. The development of mobile-bearing implants was based on the concept that incongruent surfaces in constrained joint replacements lead to high local stresses and pressures and therefore increase UHMWPE wear. Mobile-bearing implants combine congruence with minimally constrained components to enable the soft tissues to control physiologic motion at the joint. Furthermore, polymethyl methacrylate cement fixation, which was common practice in the early era of total implant ankle replacement, was abandoned, and the next generation implants are inserted without polymethyl methacrylate cement. Improved biomaterials that enhance bone ongrowth and thus prosthesis fixation are being manufactured, and cementless fixation in total ankle replacement is the gold standard at present.

Another parameter in the prosthesis design is the length of the tibial stem. BP-type implants have adopted a relatively long tibial stem, requiring the tibial component to be inserted through an anterior tibial window. Other designers, based on the fact that the bone strength, especially at the distal tibia (and to a lesser extend in the talus), decreases below the surface and becomes less resistant to compressive loading, advocated the use of shorter pegs, rather than a stem. Kofoed, the designer of the STAR prosthesis, noted that only the most distal 1 cm to 1.5 cm of the tibia is solid subchondral bone; above this level, the bone marrow is loose and fatty, not suitable for implant fixation. This applies to the design of the Agility, STAR, HINTEGRA, and BOX prostheses, which do not have a stem for tibial component fixation.

**Two-Component Ankle Replacement Designs**

**INBONE Total Ankle System**

The INBONE and INBONE II Total Ankle Systems (Wright Medical Technology, Arlington, TX), formerly known as the Topez Total Ankle Replacement System, has a relatively

<table>
<thead>
<tr>
<th>Two Components</th>
<th>Three Components</th>
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<tbody>
<tr>
<td>Agility (DuPuy/Ace, Warsaw, IN; 1985)</td>
<td>STAR (Walademar Link, Hamburg, Germany; 1978)</td>
</tr>
<tr>
<td>TNK (Kyocera, Kyoto, Japan; 1996)</td>
<td>Buechel-Pappas (Endotec, South Orange, NJ; 1989)</td>
</tr>
<tr>
<td>INBONE (Wright Medical Technologies, Arlington, TN; 2005)</td>
<td>Ramses (Fournitures Hospitalieres, Mulhouse, France; 1996)</td>
</tr>
<tr>
<td>Salto Talaris (Tornier, Saint Ismier, France; 2006)</td>
<td>Salto (Tornier, Saint Ismier, France; 1997)</td>
</tr>
<tr>
<td>Eclipse (Integra LifeSciences, Plainsboro, NJ; 2007)</td>
<td>Eska (Eska Implants GmbH, Lubeck, Germany; 1995)</td>
</tr>
<tr>
<td>AES (Biomet, Dordrecht, The Netherlands; 1996)</td>
<td>Albatros (Groupe Lepine, Lyon, France; 1995)</td>
</tr>
<tr>
<td>HINTEGRA (Integra LifeSciences/Newdeal, Lyon, France; 2002)</td>
<td>Mobility (DePuy International, Leeds, UK; 2005)</td>
</tr>
<tr>
<td>OSG (Corin, Cirencester, UK; 2005)</td>
<td>BOX (Finsbury Orthopaedics, Leatherhead, Surrey, UK; 2005)</td>
</tr>
<tr>
<td>Taric (Implant Cast, Buxtehude, Germany; 2006)</td>
<td>Van Straten (Argomedical, Gifhorn, Germany; 2006)</td>
</tr>
<tr>
<td>ARGE (Medizintechnik, Hannover, Germany; N/A)</td>
<td>AlphaMed Ankle (AlphaMed Medizintech Fisch GmbH, Lassnitzhoehe, Austria; N/A)</td>
</tr>
</tbody>
</table>

long modular intramedullary stem to allow tibial fixation. The stem consists of small, interconnecting pieces and can be built-up piece-by-piece. UHMWPE is fixed on the tibial tray. It received FDA approval in 2005. A recent publication presented the use of the INBONE prosthesis as a salvage procedure for revision to failed Agility total ankle replacements in five patients. The long stem raises concerns regarding transmission of forces into the tibial metaphysis leading to loosening of the prosthesis.

Agility Total Ankle Replacement

The Agility (DePuy, Warsaw, IN) is the most widely reported two-component implant. This implant allows space between the medial and lateral gutters to absorb rotational forces (the talar component can slide from side-to-side). Its implantation requires fusion of the syndesmosis, and this has proved to be a source of potential problems. Furthermore, implantation of the Agility total ankle replacement requires more bone resection, possibly compromising future revision options. In terms of ankle kinematics, this semiconstrained design does not replicate normal ankle motion, because the ankle slides from side-to-side during rotation and dorsiflexion and plantarflexion motion. It was the only Food and Drug Association (FDA)-approved ankle implant in the USA until 2006 and has been in continuous clinical use for more than 20 years. The designers of the implant published their results in 1998 with a failure rate (revision or arthrodesis) of 6.6% in 686 cases from 1995 to 2004, compared with 11% in 132 total ankle replacements from 1984 to 1994. Other surgeons have reported less favorable outcomes. A recent systematic review of the literature revealed that 9.7% of 2,312 ankle replacements had failed after a weighted mean follow-up of 22.8 months. The failure rate was 15.8%, however, in 234 prostheses followed for longer (weighted mean of 6.6 years) in a systematic review published in 2010.

The ESKA Ankle Prosthesis

This two-component cementless prosthesis (polyethylene attached to the tibial component) was designed and used in Germany (ESKA, Lubeck, Germany) and is implanted through a lateral approach. Most foot and ankle specialists are more familiar with anterior ankle approaches and would not adopt the ESKA implant. According to the developer of the prosthesis, none of the implants followed for 1 to 5 years had failed: (85%) of 20 total ankle replacements followed for 5 to 10 years were in situ, whereas 8 (67%) of 12 total ankle replacements remained in situ after 10 to 15 years. No results from independent centers have been reported.

Eclipse Total Ankle Replacement

The Eclipse (Integra LifeSciences, Plainsboro, NJ) was FDA approved in November 2006 but does not seem to be in regular clinical use in the USA. It can be implanted from a medial or lateral approach. Currently, only a few implants have been inserted. The bone cuts, guided by extramedullary instruments, are cylindrical and are thought to minimize bone resection while optimizing bone-to-implant interface. The developers of the Eclipse believe that by avoiding an anterior incision, which is required for nearly all TARs, they avoid crossing the angiosome of the anterior skin of the ankle and thereby hope to avoid postoperative skin complications. Potential problems include malleolar fixation, length of time to union, and possible delayed union or nonunion of the malleoli. Although the Eclipse has been approved for use by the FDA, it has only been inserted by a few surgeons.

The TNK Prosthesis

Takakura introduced this prosthesis (Nara, Japan), fixed with or without cement, in Japan in 1975 (early version). The first- and second-generation implants were associated with high aseptic loosening rates, and biomaterials were modified. The third generation (current) implant provided better outcomes. The developer’s team recommended cemented talar component fixation in rheumatoid patients. Unfavorable clinical and radiographic outcomes in Japanese rheumatoid patients were reported in two studies. It is currently the only total ankle replacement prosthesis with alumina ceramic components.

RAMSES Ankle Replacement

The RAMSES (Laboratoire Fournitures Hospitalieres, Heimsbrunn, France) was developed in 1989 in France by the Talus Group. They changed from using polymethyl methacrylate cemented implants (1989 to 2000) to cementless fixation in 2000. A 16.4% failure rate and a 61% radiolucency rate, after 10 to 14 years of follow-up in 73 ankles, using the polymethyl methacrylate cemented version has been reported. Concerns about the Ramses ankle implant are the wide talar bone resection, compromising future revision options, and the thin tibial loading platform (long-term fatigue possible).

Three-Component (Mobile-Bearing) Ankle Replacement Designs

BP-Type Designs

The BP prosthesis (Endotec, Orange, NJ; and Wright-Cremascoli Orthopedics, a division of Wright Medical Technologies, Peschiera Borromeo, Italy) evolved from the LCS prosthesis and was the predecessor of many modern implants (e.g., the Mobility, Ankle Evolutive System, Zenith and CCI Evolution prosthesis). It consists of three components (metal talus and tibia, separated by a mobile-bearing UHMWPE “meniscus”) providing unconstrained motion with LCS on the bearing surfaces, allowing also inversion and eversion. This prosthesis has further evolved in biomaterials and design. In their initial series of 40 total ankle replacements, the developers used a “shallow-sulcus” design, producing 70% good-to-excellent results after 2 to 20 years (mean, 12 years). A “deep-sulcus” design used in 75 ankles after 1990 revealed 88% good-to-excellent results after 2 to 12 years (mean: 5 years). Doets and colleagues
reported 90% survivorship at 12 years in 74 BP (deep sulcus) implants, and San Giovanni and colleagues\(^{35}\) reported 93.4% survivorship at 8 years. A review article reported an overall 12% failure rate after weighted mean follow-up of 6.3 years in 253 BP ankle replacements performed in several centers (including the developers’ series).\(^{13}\) Practically, the BP prosthesis is no longer marketed and has been replaced by its successors. One concern regarding BP-type implants (implants having a tibial stem) is the need for an anterior tibial cortical window for insertion of the component, although it has not caused prosthesis failures according to the published studies. The main concern for tibial stems is that they rely for their fixation stability on the supramalleolar bone, which is loose and fatty and a less stable location to fix a prosthesis.\(^{36}\) In the tibia and talus, bone strength rapidly decreases below the surface and is more apparent in the tibia compared to the talus.\(^{37}\)

**The Mobility Total Ankle System**

The Mobility Total Ankle System (De Puy, Warsaw, IN) is a more recently developed BP-type prosthesis, designed by a team of experienced ankle arthroplasty surgeons (Chris Coetzee in the USA, Pascal Rippstein in Switzerland, and Paul Wood in the UK). Unlike the BP prosthesis, the talar component of the Mobility Total Ankle System does not replace the medial and lateral surfaces of the talus. Two of the designers have published results from their own series. A failure rate of 2.1% in 233 arthroplasties, at a mean 33-months follow-up, with a postoperative complication rate of 8.6% and reoperation rate of 7.7%, was reported by Rippstein’s and Coetzee’s teams and a 94.6% survivorship rate at 4 years by Wood.\(^{38}\) Use of the prosthesis was documented in the New Zealand\(^{41}\) and the Swedish Arthroplasty Registers.\(^{42}\)

**The STAR**

The STAR (Waldmar Link, Hamburg, Germany; SBi, Morrisville, PA) is at present one of the most widely used total ankle replacements. The first two-component STAR, metal-on-polyethylene cemented implant designed by Kofoed in 1978, was modified in 1986 when a mobile-bearing (meniscus) UHMWPE was introduced.\(^{39}\) Two anchorage bars on the tibial component are meant to enhance fixation strength. The longitudinal ridge on the talar component is congruent with the distal surface of the mobile meniscus. The prosthesis allows dorsiflexion and plantar flexion, but no talar tilt, whereas the flat tibial surface of the meniscus allows rotation. Another modification was the bioactive surface coating for cementless fixation in 1990 and a double coating addition in 1999 to enhance bone ongrowth ability. Kofoed\(^{40}\) reported a 95.4% survival rate for the uncemented design (1990 to1995), which has not been reproduced by others. Wood and colleagues reported in his series of 200 total ankle replacements an 80% survivorship at 10 years,\(^{41}\) similar to Karantana and colleagues who found 84% survivorship at 8 years.\(^{42}\) In a systematic literature review published in 2010, a 13% failure rate in 344 STAR implants, followed for a weighted mean of 6.3 years, was reported. A systematic review of published results on 2088 uncemented STAR prostheses revealed a pooled 71% survivorship rate at 10 years.\(^{43}\) A Swedish group of surgeons\(^{42}\) reported a 98% prosthesis survivorship at 5 years using 58 double-coated STAR prostheses, markedly better than the single-coated prosthesis used in earlier years.\(^{42}\) Surgeons’ experience influenced results. The STAR is the first mobile-bearing, three-component ankle marketed in the USA. A recent publication of the first long-term STAR prosthesis survivorship data from the USA revealed a 90% survival rate at 10 years.\(^{45}\) A potential issue with the STAR prosthesis is the lack of circumferential bone support of the tibial component, making it prone to sinking in the distal tibia cancellous bone and possibly to periarticular ossification.\(^{41}\)

**The Ankle Evolutive System**

The Ankle Evolutive System (Biomet, Dordrecht, The Netherlands) is a cobalt chromium three-component ankle prosthesis with hydroxyapatite coating, similar to the BP ankle prosthesis but with some modifications (modular tibial stem, hemireplacement of the medial and lateral “gutters”). Given the high rates of aseptic loosening\(^{45-48}\) it was withdrawn from the market.

**HINTEGRA Total Ankle Arthroplasty**

The HINTEGRA (Newdeal SA, Lyon, France) total ankle arthroplasty prosthesis, a three-component mobile-bearing implant (flat tibial component, UHMWPE meniscus, convex conic talus with a smaller medial radius), designed by Hinterman, has been in clinical use since 2000.\(^{49,50}\) It relies on minimal bone resection to allow placement of the prosthesis in the very distal, better-quality cancellous subchondral bone. The talar and tibial components have ventral shields to allow screw placement, although the current trend is not to use screws for fixation because they could lead to loosening of the prosthesis during the initial phase of osteointegration. Side borders on the talar component should prevent dislocation of the polyethylene.\(^{49,50}\) The anterior tibial flange aims to reduce postoperative heterotopic ossification and soft tissue adherence. The designer of the prosthesis reported a relatively high complication rate of 14% (39 complications in 278 implantations and 13 failures) in his earlier case series (prostheses implanted before 2000), whereas the failure rate dropped after 2003. Overall survivorship in 340 primary total ankle replacements at 6 years was 98.2%, being 97.9% for the talar component and 98.8% for the tibial component.\(^{49,50}\)

**Salto Talaris Anatomic Ankle Prosthesis**

The Salto (Tornier, Saint Ismier, France) is a newly designed version of the three component mobile bearing implant, used in clinical practice since 1997 in Europe and approved for marketing by the FDA in 2006. It is fixed without polymethylmethacrylate cement, by a hollow fixation plug on the tibial side. Titanium plasma spray technology is used
on the tibial and talar implants. The tibial surface of the UHMWPE is flat and fits the congruent surface of the talar component with a sulcus, allowing varus-valgus motion in the coronal plane. Medial impingement is prevented by a medial metallic tibial rim, whereas a UHMWPE implant on the fibula replaces the talofibular joint. 51 Results from the developer’s group in France showed an 85% survivorship at 8.9 years. 52 An independent series showed an estimated 87% 5-year survivorship. 53

Most published reports related to total ankle arthroplasty have a fair to poor-quality level of evidence. Comparative studies with a fair to good-quality level of evidence suggest that total ankle arthroplasty provides equal pain relief and possibly improved function compared to ankle arthrodesis. On the basis of the current literature, survivorship of total ankle arthroplasty implants, when measured as the retention of metal components, ranges from 70% to 98% at 3 to 6 years and from 80% to 95% at 8 to 12 years. A successful return to low-impact, recreational sporting activities is possible after total ankle arthroplasty. Most commonly, patients participated in swimming, cycling, and fitness and weight-training.

There are currently no published prospective randomized controlled clinical trials comparing ankle arthroplasty to tibio-talar arthrodesis. However, a 2009 study published in Foot and Ankle International showed non-inferiority of the STAR™ versus ankle fusion in a non-randomized multicenter design.

In a recent meta-analysis, Haddad and coworkers aggregate results of 10 studies of arthroplasty and compared them to 39 studies of arthrodesis. Total ankle arthroplasty resulted in a 78% implant survival rate at 5 years and 77% survival rate at 10 years. There was a 7% revision rate, with loosening subsidence accounting for the majority (28%) of cases. In addition, 1% of patients ultimately underwent below the knee amputation. In comparison, arthrodesis resulted in a 10% nonunion rate with a 9% revision rate, the vast majority (65%) as a result of nonunion. Amputation rate for the arthrodesis group was 5%. Intermediate outcomes were similar between the two groups. The investigators concluded that both procedures yield satisfactory results, and the data suggest equivalence between the procedures.

**Discussion**

Earlier implant designs failed because ankle arthroplasty took its cues from hip and knee arthroplasty and did not take into consideration the kinematics of the ankle and hindfoot joints during gait. Cement fixation, although it had long-term success in knees and hips, did not prove to be of similar benefit in ankles and has largely been abandoned in favor of efforts to enhance osteointegration and reduce contact stresses at the bone-implant interface. After learning from failures, designs for total ankle replacement have combined congruence and stability with minimally constrained components allowing the soft tissue and ligaments to balance the motion of the ankle joint. Three component mobile bearing designs have allowed for more acceptable results. The only long-term report in the USA for a mobile three component device revealed that the STAR prosthesis showed 90% survivorship at 10 years.

However, despite the increased popularity in total ankle replacements, several key questions remain to be answered, such as will the functional outcomes of total ankle arthroplasty surpass those of ankle arthrodesis? Will the motion attained following total ankle arthroplasty protect the ipsilateral subtalar joint complex from arthritis? What will be the survival rates of the newer ankle replacements? Further long-term studies are required to answer these questions as well as determination of the ideal patient and comparisons between various types of implant systems.

**Disclosure Statement**

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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