Chapter 1

The Current Trend of Total Ankle Replacement

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Additional information is available at the end of the chapter

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Abstract

Total ankle replacement (TAR) was introduced for end-stage arthritis of the ankle joint in the 1970s. TAR is becoming the modality of choice and offers better mobility, improved gait, and reduces the development of subsequent subtalar joint arthritis when compared with ankle arthrodesis. To maintain the longest function of ankle replacements, the design of the prosthesis should allow for smooth and continuous interaction and normal gait. Improved operative techniques, the surgeon's experience, as well as appropriate patient selection can anticipate better outcomes. Deformities of the ankle and foot should be corrected before TAR is performed. Despite the functional limitations following the revision of TAR, the revision still offers a cost-effective alternative to ankle arthrodesis. The decision to treat with TAR depends on the surgeon's technique, as well as on the patient's condition.

Keywords: Ankle, Prosthesis, Kinematics, Replacement, Complication

1. Introduction

1.1. Back ground and history

Total ankle replacement (TAR) was introduced for end-stage arthritis of the ankle joint in the 1970s. Initial poor clinical results due to imperfect prosthesis design and our incomplete knowledge of the biomechanics of the foot and ankle limited the using of TAR. Despite high numbers of failures in early generations of ankle prostheses, there has been a continued and increasing interest in TAR for end-stage arthritis. Nowadays, scientists are working on fourth-generation ankle prostheses, which are characterized by three-part, mobile-bearing, uncemented design. The STARTM ankle prosthesis was one of these fourth-generation ankle prostheses, which was approved for use by the United States Food and Drug Administration (FDA) in May 2009. The clinical outcomes of TAR have been increasing in terms of progress.

Newer studies suggested that implant survival rates were 70% to 95% during follow-up periods that ranged from 2 to 12 years. TAR is increasingly used as an alternative to arthrodesis.

The ankle joint is subjected to more weight-bearing force per square centimeter and is more commonly injured than any other joint in the body. Approximately 6% to 13% of all cases of osteoarthritis (OA) involve the ankle joint. While the incidence of severe ankle arthritis is clearly less than that of the hip or knee, OA of the ankle is a main cause of disability, which impairs functional mobility and leads to poor quality of life. Unlike the hip and knee joints, in which the primary causes of degeneration are primary OA and inflammatory diseases, 70–80% of ankle arthritis is post-traumatic and the remaining cases are related to primary OA and rheumatoid arthritis [1, 2, 3].

The treatment options for severe ankle arthritis have changed during the past 10 to 15 years. Currently, treatment options include ankle arthrodesis and TAR. There remains considerable controversy surrounding the benefits of each procedure and treatment option, especially concerning the idea that patients might benefit from one approach more than the other. TAR has some disadvantages such as expensive cost, implant loosening, ankle instability, higher infection rate, and higher re-operation rate [6–9]. TAR remains a less satisfactory solution when compared to other joint replacements; however, TAR offers greater range of motion in the ankle with improved gait kinematics, reduced stress, and potentially causes less arthritis in adjacent joints [3]. In addition, with regards to cost-effectiveness analysis, TAR has better quality-adjusted life years when compared to arthrodesis, albeit at a higher cost [10].

In this chart, we will introduce the decision-making process of whether to use TAR or arthrodesis, as well as discuss the history of TAR, the characteristics of different prosthesis designs, their clinical outcome, and the complications and revisions associated with TAR.

2. Prosthesis design

Lord and Marotte introduced an inverted hip prosthesis as a disappointing solution for ankle replacement in 1970 [4]. The original first-generation TAP was non-anatomical, cemented, and restrictive. It is not surprising then that the original first-generation TAP prostheses are associated with severe osteolysis, component loosening, impingement, infection, and soft-tissue breakdown; this has led many surgeons to discredit this procedure. For these reasons, there has been a continuous effort to develop a safe, stable, and long-lasting ankle prosthesis that could replicate the complex anatomy of the ankle joint and better mimic ankle biomechanics.

Implant design played a large role in the effect of loading direction on the magnitude and direction of the joint's motion. Bone–implant displacements occurred along the directions expected on the basis of the implant interface geometries. Various ankle designs are available, including two-component and three-component systems [5]. After unacceptably high failure rates had been published for the first generation of implants [1–5], the second generation of implants achieved marked improvements in clinical outcomes [6–8]. Second- and third-

generation prostheses followed these first implants, and interest in this procedure has resurged in the past decade. These new designs include changes in the geometry and design of the components, as well as the use or non-use of polymethylmethacrylate bone cement, which is termed a two- or three-component design. The third-generation prosthesis is characterized by the non-use of cement, accurate anatomy, and better ROM of the ankle joint. Mobile-bearing implants are designed without constraint to reduce meniscal wear and to increase the longevity of the implant, which features mobile PE inlays. The stability of the bone–implant interface has been explored in an unconstrained, three-piece mobile-bearing implant using the concepts of implant migration and inducible displacement. Fixed-bearing designs, in contrast, are designed to increase stability, reduce micromotion at the bone–implant interface, and decrease bearing dislocation. In addition, the surgical instrumentation and technique are improved and redesigned for the new prosthesis.

The third-generation of ankle prostheses includes the HINTEGRA ankle (New deal, Lyon, France/Integra, Plainsboro, NJ, USA), the INBONE TAR implant (Wright Medical Technology, Arlington, TN, USA), the Agility prosthesis (DePuy Orthopaedic, Warsaw, IN, USA), the STAR prosthesis (Scandinavian TAR), the Mobility prosthesis (DePuy, Leeds, United Kingdom), and the Salto Talaris (Tornier, Edina, MN, USA).

2.1. HINTEGRA ankle prosthesis

The HINTEGRA prosthesis is a three-component, mobile-bearing ankle replacement with cobalt–chromium tibial and talar components [6]. The polyethylene mobile-bearing element provides axial rotation, physiological flexion, and extension mobility, and it also provides inversion and eversion stability [7, 8]. The HINTEGRA, which is a flat, anatomically shaped component, fully contacts the resected area with fixation of its tibial component. All inserted components have locking pegs on the talar component. The tibial component consists of a flat tray with raised spikes for bone fixation. The anterior side has a flange with holes for screw fixation. The talar component has medial and lateral walls and two fixation pegs; two screws may be used for added fixation, if appropriate. The ingrowth surface is plasma-sprayed titanium with a hydroxyapatite coat [9, 10]. Therefore, the HINTEGRA ankle prosthesis may be used for the treatment of major coronal plane deformities and as a salvage of failed ankle replacements.

2.2. INBONE ankle prosthesis

Amongst the third-generation ankle implants approved by the US FDA, the INBONE TAR implant employs a fixed-bearing design with a modular stem system for both the tibial and the talar components. The INBONE system features a technique that offers potential advantages in improved stem fixation and a unique intramedullary alignment system. It has a broader polyethylene component that conforms to the saddle ankle geometry, and it also provides a large surface area that spreads out stress gradients, leading to possible decreased wear [11]. A. Datir found that only the lateral talar component angle and the mean difference between the pre- and postoperative tibial slope had significant correlations with postsurgical outcomes in INBONE ankle replacement [11].

2.3. Agility ankle prosthesis

The Agility TAR System, which is almost exclusively without polymethylmethacrylate cement fixation, was the most commonly used implant in the United States from 1998 to 2007. The design process started in 1978, with prototype completion and cadaver implantation occurring in 1981 [12, 13]. It was first implanted in a patient in 1985 and subsequently marketed in 1992 as the "DePuy Alvine Total Ankle Prosthesis". From 1985 to 2007, the implant went through a total of four generations and seven phases of implant improvement [13, 14]. The US FDA has cleared it for use only with polymethylmethacrylate cement fixation [15]. The Agility prosthesis is a semi-constrained ankle replacement with a cobalt–chromium talar component, a titanium tibial component, and a fixed polyethylene bearing [16]. It is characterized by a tibial component, which provides a talar component with a larger surface area. The talar component of the Agility system was prone to shift forward and backward along the talar groove during plantar flexion–dorsiflexion loading, and it would also rock about its long axis in inversion–eversion loading. The ingrowth surface consists of cobalt–chromium sintered beads. Fixation on the tibial side is aided by syndesmotic arthrodesis. Fixation on the talar side is achieved with the use of a keel under a flat-cut component.

2.4. STAR ankle prosthesis

The STARTM ankle was first approved by the US FDA in 1998 [17]. It was a three-part, mobile-bearing, uncemented ankle replacement. The STAR prosthesis featured a cementless design with a plasma-sprayed titanium coat [18]. Fixation on the tibia was achieved with use of two barrels on the flat tibial component. The talar component was fixed with the use of two sidewalls and a fin on the inferior surface. The tibial component of the STAR was most susceptible to normal motion on the bone surface, especially in plantar flexion–dorsiflexion and inversion–eversion loading. On average, of the three loading directions, the internal–external rotation resulted in the smallest relative motions of both of the STAR components since the device allowed for unconstrained rotation about this axis [19].

2.5. Mobility ankle prosthesis

The Mobility prosthesis is a mobile-bearing ankle replacement with cobalt–chromium components on the tibial and talar sides, and it also features a sintered bead ingrowth surface [20]. The tibial component has a stem placed into the tibia with an anterior bone window. The talar component has two fins on the inferior surface; no sidewalls are present on the talar component. The talar cut has three surfaces. The prosthesis has not undergone design changes during the course of the study.

2.6. Salto Talaris Ankle prosthesis

The Salto Talaris TAP, with design and instrumentation based on the Salto mobile-bearing TAP, was approved for use by the US FDA in 2006. Although it is a fixed-bearing device, the instrumentation and component trialing incorporate a rotationally mobile tibial trial component that allows for self-alignment on the resected surface of the distal aspect of the tibia, which

is determined by the talar component. The final implant has a polyethylene insert that is rigidly fixed to the tibial component and does not allow for rotational or translational motion between the two surfaces.

3. Kinematics

Normal ankle kinematics attenuates ground reaction impact forces and impact loading on the subtalar joint. The importance of achieving normal ankle kinematics during stance is very important for both function of the ankle and long survivorship of the prosthesis. During a normal gait cycle, the talus has a continuously changing axis of rotation against the tibia as well as a gliding motion against the calcaneus, respectively. The talus and mortise widen slightly anatomically from posterior to anterior. Following talus plantar flexion, the narrowest portion of the talus sits in the ankle mortise and allows for rotational movement between the talus and mortise. When the talus is maximally dorsiflexed, the wider portion of the talar articular surface locks into the ankle mortise, allowing for little or no rotation between the talus and the mortise [21, 22].

Compared to a normal ankle, ankle OA shows a significant deficiency in triplanar ankle movement, the second active maximal vertical and maximal medial ground reaction force, sagittal and transverse ankle joint moments, and ankle joint power [2]. However, J.F. Baumhauer reported that ankle arthrodesis results in a normal gait postoperatively, especially when there is a normal subtalar joint and talonavicular joint [23].

S. Singer reported that TAR with first-generation TAP resulted in increasingly normal gait mechanics during sagittal joint motion, which was maintained, and it also resulted in more normal ankle kinematics when compared with those following arthrodesis [24]. The gait patterns of TAR with the third-ankle prosthesis more closely resembled normal gait during sagittal plane motion and dorsiflexion, and it also resulted in a normal range of tibial tilt when compared with the gait patterns of patients following arthrodesis [24]. Peak plantar flexor moment increased in arthrodesis patients and decreased in TAR patients. TAR appears to regain more natural ankle joint function. R.M. Queen compared the kinetics of TAR with that of the INBONETM or Salto Talaris, as well as that of the normal contralateral ankle in bilateral patients; the results showed that walking speed, step time, step and stride length, and propulsion ground reaction forces improved following TAR. However, peak dorsiflexion did not change. At the same time, the dorsiflexion angle during heel strike was increased on the nonsurgical side [25].

A. Rosello Anon et al. reported that kinetic gait parameters were similar to those of a healthy ankle following TAR with HINTEGRA [26]. M.E. Hahn reported that both arthrodesis and TAR patients were similar in terms of demographics and anthropometrics. Neither group increased their average daily step count [27]. Gait patterns in both treatment groups were not completely normalized [24]; however, both treatment groups did not exhibit equivalent to

normal plantar flexion motion, ankle moments, and power when compared with the normal group. Further investigation is needed to determine why patients who have undergone TAR do not use the plantar flexion motion in the terminal-stance phase, as well as to explain the limited increase in power generation at toe-off after replacement [24].

In addition, walking speed, step, and stride length improves from the preoperative phase to each postoperative time point. Peak dorsiflexion did not changed over time or between sides; however, the dorsiflexion angle during heel strike was increased on the nonsurgical side. Peak plantar flexion moment, stance, step time, weight acceptance, and propulsion ground reaction forces improved from the preoperative period to 1 year postsurgery on the surgical side. These results indicated that fixed-bearing TAR was effective at improving gait mechanics in patients with painful end-stage ankle arthritis. In addition, TAR resulted in the maintenance of ankle dorsiflexion during the stance phase; however, a decrease in dorsiflexion angle was present during heel strike on the operative side when compared with the nonoperative side up to 2 years following TAR. Finally, following TAR, the asymmetry in temporal gait variables and peak plantar flexion moment were improved, although differences did remain between the operative and nonoperative limbs for stance, step, and swing time, as well as for the peak plantar flexion moment 2 years following TAR. This remaining gait asymmetry is of potential concern because of the possibility that the patient might overload the contralateral limb and engage compensatory walking mechanics that could lead to secondary injuries following TAR [25].

4. Indication and contraindication

If adequate conservative measures for the treatment of end-stage ankle osteoarthritis have failed, surgery may be taken into consideration. M.R. McGuire reported that TAR is indicated in rheumatoid patients with severe ankle involvement who have not responded to medical management. TAR is especially suitable for those patients who will place minimal stress on the ankle, those for whom no destruction of the hip or knee joint is found, and for those who are 65 years of age or older. The elderly may not tolerate the prolonged immobilization or repeated operations that arthrodesis may require. TAR should not be used in young patients with post-traumatic arthritis [28]. J.R. Ramaskandhan found that early outcomes following TAR for patients with post-traumatic OA are comparable with those for patients with OA and rheumatoid arthritis [29]. More importantly, patients whose lifestyle or employment requires them to walk down ramps may have an advantage with TAR when compared with an arthrodesis. In addition, I. Hetsroni reported that TAR has better quality-adjusted life years when compared to arthrodesis, albeit at a higher cost [10].

TAR improves clinical and functional outcomes independent of preoperative tibiotalar alignment when postoperative alignment is restored to neutral at the time of replacement. Therefore, one of the keys to success may be to achieve coronal plane balance by performing additional osseous and soft- tissue procedures in patients with coronal plane deformity [30]. Preoperative talar varus deformity increases the technical difficulty of TAR and is associated

with an increased failure rate. Deformity of >20° has been reported to be a contraindication to replacement. T. Trajkovski determined whether clinical outcomes of TAR in patients with ankle arthritis and a preoperative talar varus deformity of 10° were comparable with those of patients with a varus deformity of <10°. Satisfactory results can be achieved in patients with varus malalignment of 10°, which should not be considered a contraindication to TAR [31].

With the population ageing, the absolute number of patients affected by ankle OA is likely to increase, which means that there are more and more potential candidates for TAR. For this reason, there is a trend of increasing indications; as such, clinical guidelines regarding implant migration must be established to ensure successful outcomes [3]. On the other hand, some patients might be younger and have higher physical demands, placing the damaged joint under increased stress [32]. Based on this, young age and high physical demand are currently considered contraindications for TAR.

Taking into account numerous individual criteria, the most appropriate indication substantially influences the outcome of patients with end-stage ankle arthritis who are treated by ankle TAR.

5. Technique of TAR

We present a typical case who underwent TAR. She was a 59-years-old woman and had a severe pain on her left ankle. She failed to respond to a trial of conservative treatment for ≥6 months.

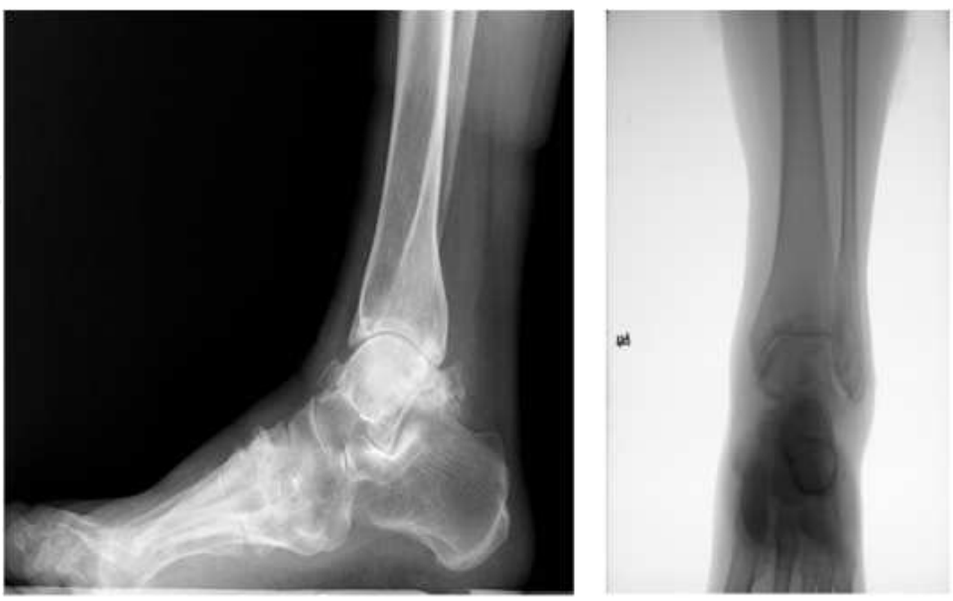

Figure 1. The preoperative X ray images showed a severe osteoarthritis in the left ankle.

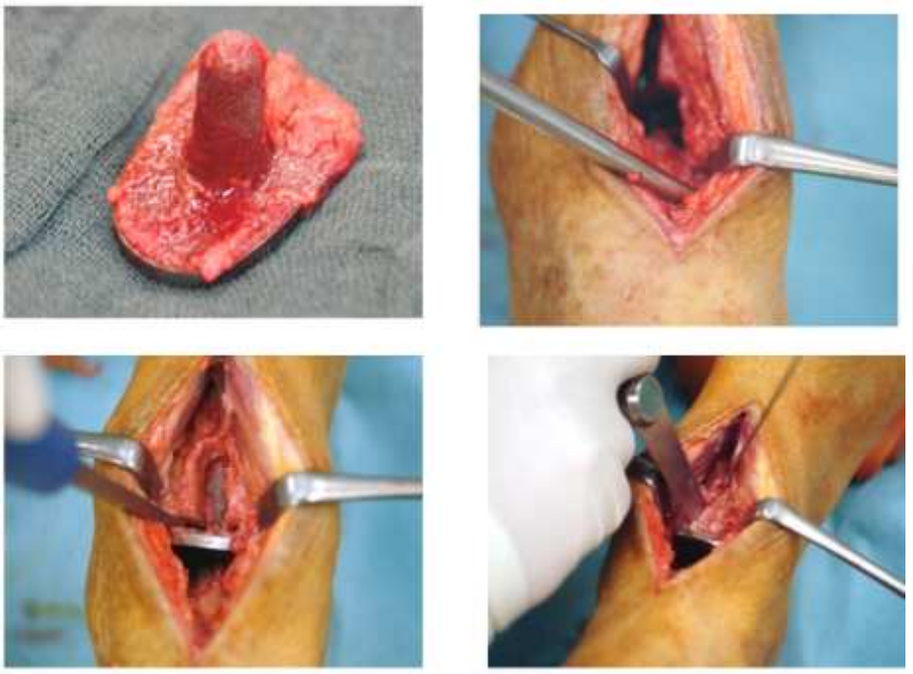

Figure 2. The picture showed incision and the osteotomy.

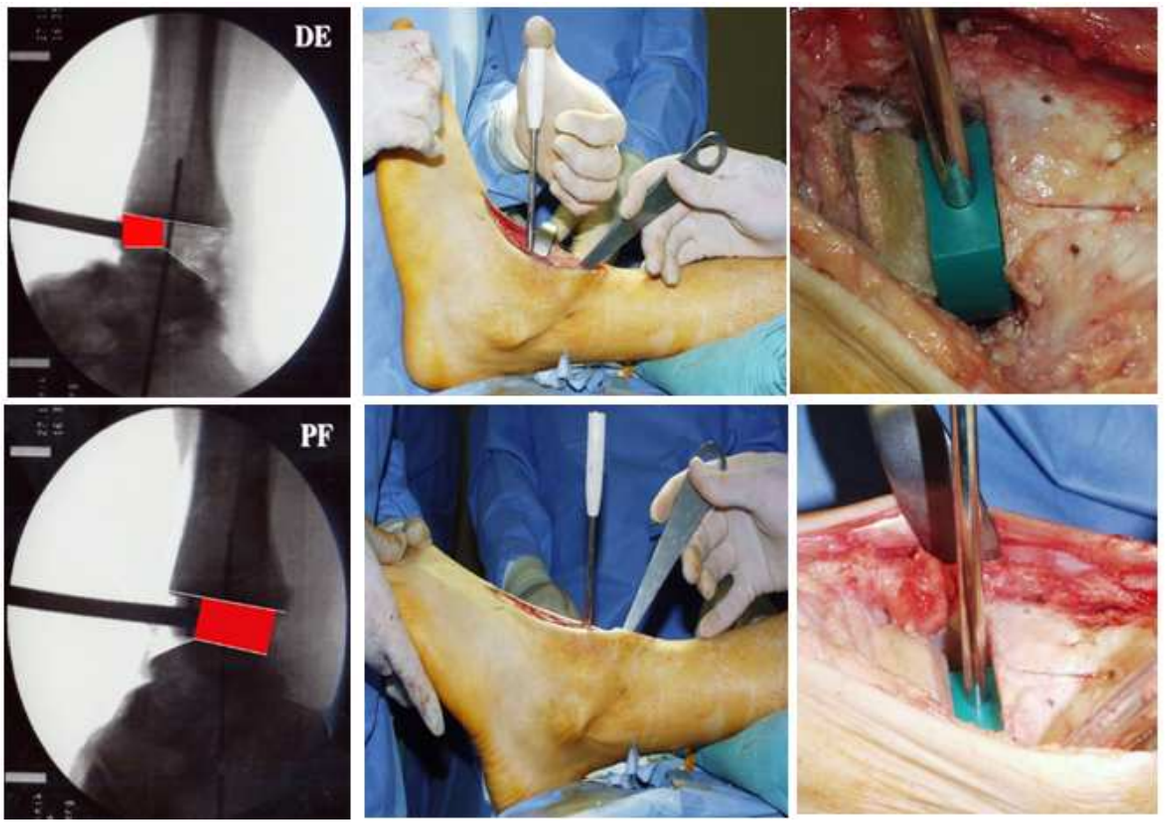

Figure 3. The pictures showed that the ankle joint is in a good alignment with the template.

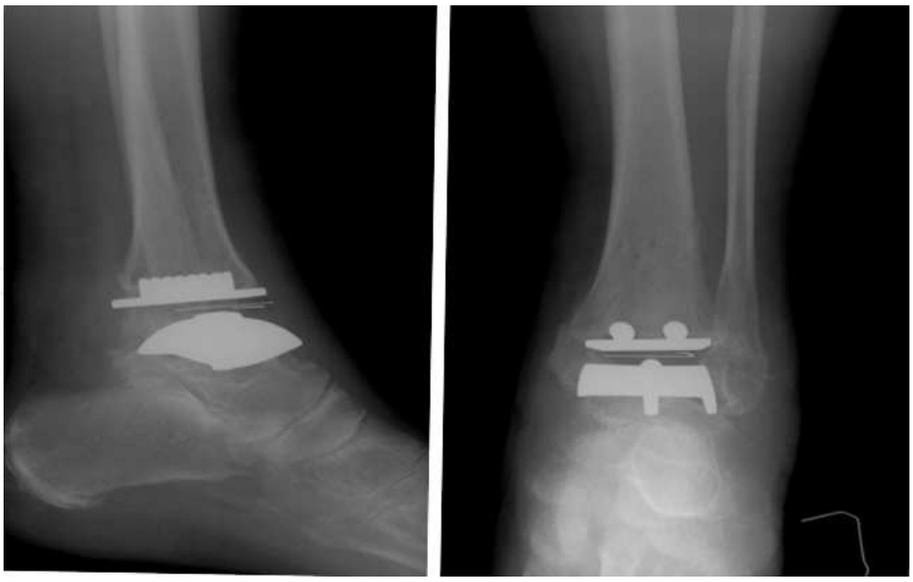

Figure 4. The pictures showed the X rays image of ankle joint after TAR 2 years postoperatively.

6. Outcomes of TAR

Modern TAR systems have either a fixed-bearing or a mobile-bearing design. In the United States, fixed-bearing, two-component designs are more commonly used. S. Noelle reported that STAR prostheses achieved a high satisfaction rate following TAR, and exhibited clear pain relief in patients between March 2005 and May 2010 [33]. J.R. Jastifer reported that the overall implant survival of STAR prosthesis was 94.4% at a minimum of 10 years of follow-up. A total of 39% of patients required additional surgical procedures, most of which were performed more than 9 years postoperatively, and one patient required a revision of the prosthesis. Preoperative VAS pain scale scores, Mean Buechel–Pappas Scale scores, and mean AOFAS Ankle–Hindfoot Scale scores improved from 8.1 to 2.1, from 32.8 to 82.1, and from 32.8 to 78.1 at the latest follow-up, respectively. All patients reported their outcomes as good or excellent. In the current cohort of STAR ankle patients, implant survival, patient satisfaction, pain relief, and function ratings were high. However, the rate of additional procedures was also high, which highlights the need for patient follow-up and additional long-term outcome studies on TAR [17].

Early clinical results indicate that the Salto Talaris fixed-bearing TAR system can provide significant improvements in terms of pain, quality of life, and standard functional measures in patients with end-stage ankle arthritis [34]. Implant survival at a mean follow-up time of 2.8 years was 96% when metallic component revision, removal, or impending failure was used as the endpoint. For the Salto Talaris total ankle implant, a high incidence of bony overgrowth occurs at the margins of the tibial tray. The frequency and amount of overgrowth were directly related to the amount of cortical coverage at the bone–implant interface [35]. Patients who underwent TAR with the INBONETM or Salto Talaris prosthesis demonstrated that they were

able to walk faster, and they also exhibited an improvement in gait symmetry. However, this improvement did not appear to return the patient to a symmetric walking pattern by 2 years post-TAR [25].

The Agility prosthesis typically exhibited greater relative motion than did the STAR, with significant differences observed for both the tibial component in inversion–eversion rotation and for the talar component in internal–external rotation. The magnitudes of the relative motions were affected by the loading direction and compression. The motion magnitudes were quite large, with values exceeding 1, 000 mm for the Agility talar component in plantar flexion–dorsiflexion and in inversion–eversion. Large motions at the bone–implant interface, resulting from weak initial fixation, may inhibit implant osseointegration early in the healing process, and it may also contribute to the overall likelihood of implant failure resulting from aseptic loosening [19].

The overall survival rates of the HINTEGRA implant were 94% and 84% after 5 and 10 years, respectively. The mid-term survivorship of the HINTEGRA implant was comparable with that of other third-generation TARs [36]. The mid-term to long-term survivorship of a TAR in which a HINTEGRA implant was used is promising, and it is in agreement with the survivorship findings for other third-generation total ankle implants. There were no polyethylene failures and amputations. The generation category of the prosthesis, the cause of ankle OA, and the age of the patient were identified as independent risk factors for prosthesis failure.

There is a concern that placing a TAP in the setting of a fused hindfoot will create abnormal stresses on the ankle joint and will thus lead to increased early wear or degeneration of the implant. Ipsilateral hindfoot arthrodesis in combination with TAR may diminish functional outcome and prosthesis survivorship when compared to isolated TAR. J.S. Lewis reported that TAR with the STAR performed with ipsilateral hindfoot arthrodesis resulted in significant improvements in pain and functional outcomes, which was in contrast to prior studies; however, overall outcomes were inferior to those observed for isolated TAR [37]. The authors of this study have speculated that the mobile-bearing design may play an important role in the transfer of rotational movement from the tibia into calcaneal inversion/eversion in patients with a fused hindfoot [37].

Future work could examine the effect of normalizing gait asymmetry on long-term outcomes following TAR. Additional work should focus on gait changes following TAR, as well as on gait symmetry results when comparing fixed and mobile-bearing implants to better assess the overall viability of modern TAR prostheses as a long-term solution for the treatment of severe, painful ankle OA.

7. Complications

The first- and second-generation ankle prostheses were cemented and constrained, which led to higher failure rates [11, 12]. With continuously improving design and fewer constraints, third-generation ankle implants are increasingly favored; however, the technical demands of

TAR are substantial. There are still some complications that the surgeon should treat carefully. The recorded complication rate of TAR was 23%, while intraoperative bone fracture and wound healing had a failure rate of at least 50% [38]. The short-term complications of TAR included intraoperative malleolar fractures and skin necrosis. The mid-term clinical outcomes showed a 41% complication rate including instability, infections, subtalar arthritis, malalignment, and one tibial bone cyst, which led to the need for subsequent surgery. Adequate patient selection and a thorough knowledge of associated complications are mandatory to reduce the number of complications and increase the rates of ankle replacement survivorship [39, 40].

M.A. Glazebrook classified the complications following TAR into three tiers: high-grade, medium-grade, and low-grade. High-grade complications result in a greater than 50% failure rate in TAR, including deep infection, aseptic loosening, and implant failure. Medium-grade complications are defined as technical error, subsidence, and postoperative bone fracture. Finally, low-grade complications are defined as intraoperative bone fractures and wound healing problems, which should be considered [41]. Recently, R.J. Gad thought that the three-grade classification system of complications did not reliably reflect practitioners' experiences, and they thus categorized complications as either high or low risk for the early failure of TAR [38].

7.1. Loosening of the prosthesis

Initial clinical results were poor, largely because of early loosening [42, 43]. Aseptic loosening is the predominant failure mechanism in TAR; in fact, A. Henricson reported that about 40% of revision cases are due to aseptic loosening [44]. Primary stability may be affected by the initial implant fixation; in addition, known uncemented talar designs rely on bone ingrowth for fixation, which requires minimal relative motion between the implant and the host bone.

The greater magnitudes of relative motion in the Agility prosthesis suggest that primary instability of the implant may contribute to its higher clinically observed aseptic loosening rate. However, large motions at the bone–implant interface, resulting from a weak initial fixation, may inhibit implant osseointegration early in the healing process and contribute to the overall likelihood of failure resulting from aseptic loosening [19]. Future TAR designs will require better fixation to improve outcomes.

Implant migration is a good clinical evaluation tool for the loosening of prosthesis following TAR. Implant migration was defined as a change in implant location from the immediate postoperative radiograph. J.W.-Y. Fong designed a radiostereometric analysis marker insertion protocol to evaluate the stability of the migration of a fixed-bearing design following TAR [45]. The results showed that the migration of a fixed-bearing design was within the normal range.

S.A. Brigido presented a measurement technique to assess implant migration, which was supported by the high level of inter-rater reliability and intraclass correlation. The results showed that the mean INBONETM implant migration was 0.7 mm at 1 year and 1.0 mm at 2 years. Time and sex were significant predictors of implant migration [3].

Although talar subsidence and migration are recognized complications, empirical observations of postoperative patients with a Salto Talaris ankle replacement have suggested a high rate of posterior bony overhang and resultant overgrowth. In addition, it has been noted that a relatively high percentage of these implants were inserted at an angle other than perpendicular to the anatomic axis of the tibia. Specifically, the implants were usually placed in varus and with a positive slope [35].

7.2. Periprosthetic fracture

Inlay fractures are relatively common, which indicates potential for the improvement of implants. The documentation of intraoperative surgical errors leading to revision surgery varies significantly among registers [46]. The results of the present study indicate a high incidence of hypertrophic bone proliferation when the dimensions of the tibial component do not match the anteroposterior depth of the tibia at the plane of resection. Despite the high occurrence rate, the clinical relevance of hypertrophic bone is obscure. After insertion, the position of the components is not expected to change. Disruption of the extraosseous talar blood supply at the time of ankle replacement may be a factor contributing to talar component subsidence—a common mechanism of early failure following ankle replacement [39].

The stable biological coating of prosthesis components and high initial structural stability is critical for successful TAR. Continuing observation of patients who have undergone TAR is warranted for the purpose of conducting long-term analysis of prosthesis failures in order to improve the outcomes associated with this surgical technique.

7.3. Infection

Deep infection rates following TAR have been reported to be as high as 4.6% [47]. M.S. Myerson retrospectively reported on the patient- and prosthesis-associated demographics of infected TAR and the outcomes following treatment. The results showed that the treatment of deep infections following TAR is dependent on an accurate and timely diagnosis. A more uniform diagnostic approach, including immediate ankle joint aspiration and the evaluation of inflammatory markers before starting antibiotics, may allow for early surgical intervention, as well as for improved monitoring of a patient's response to treatment. Only a limited number of patients who develop a deep infection following primary or revision TAR can expect to undergo successful joint-preserving revision arthroplasty. However, hindfoot arthrodesis with intramedullary fixation and structural allograft may be a reliable alternative [48].

Patients with a body mass index higher than 30 showed a higher rate of complications after TAR. Cardiovascular and peripheral vascular disease, smoking, osteoporosis, and overweight are risk factors for a worse survival rate. Preoperative MRI and long-leg X-rays to evaluate any angular deformities of other joints are recommended. Additionally, angiography and neurological examination is recommended for selected patients.

In conclusion, adequate patient selection and thorough knowledge of the surgical technique used are mandatory to reduce the number of complications and to increase ankle replacement survivorship.

8. Revision of TAR

Design improvements have increased the success of TAR; revision rates of TAR are higher than those for hip and knee replacement. The revision rates of TAR are approximately 10%–17% at 5 years [38, 40]. In the current cohort of STAR patients, implant survival at a minimum of 10 years of follow-up was high. However, 39% of patients required some sort of secondary procedure, most of which occurred after 9 years of follow-up [17]. A. Henricson et al. defined ankle replacement revision as the extraction of one or more bone-incorporated components or the exchange of a broken plastic component without any known trauma' [49, 50]. Based on the definition, the authors classified the revision of TAR as having either mechanical causes or nonmechanical causes.

8.1. Mechanical causes of revision

Malalignment and periprosthetic fracture are the major sources of mechanical failure in TAR [23]. S. Manegold et al. classified periprosthetic ankle fractures following TAR into three different types, which are based on three items: the cause of the fracture, the anatomic location of the fracture, and prosthesis stability.

The first parameter evaluates the fracture cause—Type 1: an intraoperative fracture; Type 2: a postoperative traumatic fracture; and Type 3: a postoperative stress fracture. The second parameter is the anatomic location of the periprosthetic fracture. The fracture is assigned a letter (A through D). Concomitant injuries involving bimalleolar fractures and diaphyseal lower-leg fractures are classified as AB and BC, respectively. The third parameter involved the stability of the implanted components. If there are no clinical or radiographic signs of implant loosening, or if the fracture does not reach the prosthesis, the implant can be considered stable. In the presence of periprosthetic osteolysis or fracture-related implant loosening, the prosthesis is classified as unstable. This classification is relatively clear and can be conducted on the basis of the treatment options used. However, the effectiveness of the classification system still needs to be confirmed by the treatment results [51].

Coronal plane malalignment at the level of the tibiotalar joint is not uncommon in end-stage ankle arthritis. Restoration of neutral coronal plane alignment is important in TAR. If an ankle joint prosthesis is not well balanced and edge loading occurs, increased contact stresses on the polyethylene insert can result in accelerated polyethylene wear and premature implant failure. Ancillary procedures performed before, during, or after TAR to correct deformities are thus important in preventing failure due to instability in the varus ankle [31].

There are limited choices currently available in the revision of ankle replacements due to the need to correct osteotomy for alignment. However, the "salvage" can be challenging because a lot of bone has been lost. Alternative approaches include direct arthrodesis with shortening, arthrodesis with interposition graft (autograft, allograft, or shape porous metals), or revision ankle replacement with a larger replacement.

8.2. Nonmechanical causes revision

The most prevalent cause of non-mechanical revision involves aseptic loosening. Ellington and Myerson provided a grading system that ranged from 1 to 3 to define the severity of talar component subsidence and to predict the outcomes following revision. In grade 1, the subsidence of the talar component is minimal. In grade 2, the talar component has subsided into the talar body, but it has not violated the subtalar joint. In grade 3, the talar component has migrated onto or through the subtalar joint [15, 52].

M.A. Prissel et al. described a technique for the management of extensive talar aseptic osteolysis for the revision of Agility systems with the use of geometric metal-reinforced polymethylmethacrylate cement augmentation. This technique preserves the subtalar joint, provides immediate component stability, and restores component alignment and height [15]. The authors used three or four titanium plasma-coated triangular metallic arthrodesis rods (3 mm or 7 mm) or large-diameter acetabular screws placed in a triangular or quadrangular orientation around the periphery of the remaining talus and the body of the calcaneus. The superior aspects of the rods or screws should create a parallel surface, allowing the talar component to reside at the proper level to restore the anatomic height of the hindfoot and mechanical function of the ankle joint [15].

Collectively, the classification of periprosthetic fractures and the grading system used for component subsidence can facilitate therapeutic decision making, as they allows for the differential analysis of the causes of these conditions; they can also serve as a guide when making the choice between operative and nonoperative treatment options. There were still obvious functional limitations following the revision of TAR, with fewer than half of the patients returning to previous activity levels. However, the revision of TAR is still a cost-effective alternative to other available options and it still allows for additional revision should late failure occur.

9. Decision-making process of using arthrodesis or TAR

Patients with ankle arthritis and deformity who experience severe pain and functional disability, and do not respond to nonoperative treatment modalities, are candidates for TAR [53]. Currently, there is no consensus regarding which treatment, arthrodesis or replacement, is better for end-stage ankle arthritis.

Ankle arthrodesis is still considered to be the gold standard for the treatment of end-stage ankle arthritis. Ankle arthrodesis yielded good radiographic and functional outcomes in primary arthrodesis [54, 55], bilateral ankle arthrodesis [56], or combined ankle and hindfoot arthrodesis, even in revision cases following TAR [57]. Arthroscopic ankle arthrodesis provides not only an alternative to traditional open techniques but also an obvious advantage including decreased complications, reduced postoperative pain, and shorter hospital stays [58, 59, 60, 61]. There exists fair evidence-based literature (grade B) to support a recommendation for the use of ankle arthroscopy for ankle arthrodesis [62].

Ankle arthrodesis has an approximately 10%–40% nonunion rate [23, 53]. Osteonecrosis of the talus and smoking are known risk factors for nonunion [53]. Risk factors associated with prolonged hospital stay were advanced age, female sex, diabetes mellitus, and more than one general or surgery-related complication [63]. The published literature on the long-term follow-up of modern TAR achieved significantly higher implant survival rates, patient satisfaction, pain relief, and range of motion (ROM) and American Orthopaedic Foot and Ankle Society (AOFAS) scores following the third ankle prosthesis [29, 64]. Complication and survivorship rates were comparable between both groups [65]. Compared to arthrodesis, the primary advantages of TAR include maintenance of motion of the ankle and reduced risk of developing adjacent joint arthritis. J.J. Jiang reported that TAR was independently associated with a lower risk of blood transfusion, non-home discharge, and overall complications when compared to ankle arthrodesis during the index hospitalization period. TAR was also independently associated with a higher hospitalization charge, but the length of stay was similar between the two groups [66]. S. Singer reported that improvement in patient-reported Ankle Osteoarthritis Scale and Short Form-36 scores were similar for both arthrodesis and TAR groups [24]. In addition, R. Rodrigues-Pinto reported that complication and survivorship rates were comparable between both TAR arthrodesis groups [65]. A multicenter study showed that the intermediate-term clinical outcomes of TAR with third-generation prostheses were comparable in a diverse cohort in which treatment was tailored to patient presentation; the rates of reoperation and major complications were higher following ankle replacement when compared with arthrodesis [67].

Although the AOFAS hindfoot scale is the most frequently used outcome instrument in TAR studies, its score has been under recent scrutiny with respect to its moderate level of correlation, its satisfactory degree of reliability, and its degree of responsiveness [68, 69, 70]. The SF-36 and Visual Analog Scale (VAS) pain scoring systems are generic, but validated, outcome measures. Therefore, it will be essential to standardize data collection, evaluation, publication, and the assessment of register data in TAR. TAR outcome measurement by means of registers has several specific requirements necessitating additional documentation beyond the basic dataset [46].

In conclusion, the current investigation demonstrated that neither arthrodesis nor TAR replicated normal ankle function, and there were no differences in ankle power, moments, or temporal gait parameters between the two patient groups. Both arthrodesis and TAR achieved good clinical outcomes. Compared with ankle arthrodesis, the rates of complication with TAR are comparable. Although complications following TAR are frequent, the results of TAR are improving and promising; TAR can reliably improve a person's quality of life. Nevertheless, patient selection and education are essential.

10. Conclusion

TAR is becoming the modality of choice for the treatment of end-stage degenerative joint disease of the ankle. To maintain the longest function of ankle replacements, the design of the

prosthesis should allow for smooth and continuous interaction and normal gait. TAR offers better mobility, improved gait, and reduces the development of subsequent subtalar joint arthritis when compared with ankle arthrodesis. The decision to treat with TAR or ankle arthrodesis depends on the surgeon's technique, as well as on the patient's condition. Improved operative techniques, the surgeon's experience, as well as appropriate patient selection can anticipate better outcomes. Deformities of the ankle and foot should be corrected before TAR is performed. The revision of a replacement is ultimately inevitable due to aseptic loosening and infection. Despite the functional limitations following the revision of TAR, the revision still offers a cost-effective alternative to ankle arthrodesis.

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