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Advances in Ankle Replacement: A Review

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Abstract

Advanced ankle arthritis is a disabling chronic condition associated with severe pain, deformity, disruption of physical function and quality of life. Ankle arthrodesis has long been used as a successful treatment for advanced ankle arthritis. Total ankle replacement is a fast growing alternative to arthrodesis as it preserves joint mobility and function with good pain relief. Longer term outcome studies showing better survival rates with improved implant and instrumentation designs further fuel this revival of interest in total ankle replacement. This article reviews the evolution of total ankle replacement implants and instrumentation in addressing the various challenges in ankle replacement.

Keywords: Ankle arthritis; Total ankle replacement; Ankle arthrodesis; Arthritis

Introduction

Ankle arthritis is a debilitating degenerative condition that can result in significant deterioration of function, severe pain, deformity and reduced quality of life. A recent study has shown that patients with advanced ankle arthritis have reduced health related quality of life with Short Form 36 (SF-36) scores that are 2 standard deviations (SD) below a normal population. This study also reported that the disruption of health related quality of life and physical function are as severe as that in patients with advanced hip arthritis [1]. Management of advanced ankle arthritis that is recalcitrant to non-surgical methods has traditionally been fusion surgery. Ankle arthrodesis has been used successfully in the treatment of advanced ankle arthritis [2-5]. It has long been considered the gold standard treatment as it provides predictable results and pain relief with good fusion rates ranging from 60% to 100% in several studies [2-5]. However, ankle arthrodesis does have its limitations such as adjacent joint arthritis and gait abnormalities [6-9].

In the recent years, total ankle replacement (TAR) has gained increased popularity despite an initial drop in favour due to high failure rates requiring revision or fusion surgery. Newer implant designs with better outcomes and more long term outcome studies reporting good survival rates has continued to fuel this resurgence of TAR to address the problems of advanced ankle arthritis in order to preserve joint mobility. There are multiple challenges in the evolution of TAR such as poor accessibility of the ankle joint, bone preservation, stability of fixation and articulation of the polyethylene (PE). In this review article, we aim to describe and report on the various TAR models available, differences in concept devised to address these challenges, the evolution of implant and instrumentation designs and a brief report on clinical outcomes.

Total ankle replacement models

TAR was first introduced in the 1970s and initial results were discouraging due to high failure rates necessitating revision or arthrodesis [10-12]. Initial designs were highly constrained, required extensive bony resection for implant fixation with cement and had an all PE tibial component [10,11]. There were high failure rates associated with the first generation implants due to loosening, subsidence and osteolysis at the bone-implant interface as a result of large amount of shear, compression and rotatory stress [10,11,13-17]. Subsequent analysis of failures resulted in second generation implants that involved lesser bony resection and avoided cemented components with stem or peg fixation for stability. They were also designed to be less constrained to reduce the shear forces and torsion at bone-implant interface to reduce loosening and osteolysis experienced by the first generation implants. However, these second generation implants led to increased PE wear, symptomatic impingement and subluxation or dislocation of the components [10,13,15,17].

Following continued studies on biomechanics of implant failure and incorporating some important design features from the mobile bearing concept in knee arthroplasty, newer TAR implants were developed [10,11,15-17]. The new generation implants consist of three components which can be classified as fixed or mobile bearing. These components are divided to the tibial component which is the tibial metallic baseplate, the talar component which is the metallic domed component and the interposed bearing which is made of ultra-high molecular weight PE. Fixed bearing designs attach the PE onto the tibial baseplate whereas the mobile bearing designs allow independent motion of the interposed PE without attachment. Both designs are semi-constrained but they function quite differently in terms of rotational forces at the joint [10,11,15-17]. Mobile bearing implants has the advantage of reduced shear and torsional forces at the bone-implant interface. Due to the preservation of articulation between the bearing and the other 2 components, some authors suggest that this will help decrease the PE wear rate while others argued that the additional interface between the tibial metallic component and the bearing surface causes increased "backside" wear [10,11,16,18].

There are various types of TAR models available for use broadly classified in the fixed or mobile bearing group. They are all different in terms of the types of fixation, shape of the bearing and talar component, syndesmosis fusion, modular stem system and surgical approaches.

Agility Total Ankle Replacement (DePuy, Warsaw, IN, USA)

The Agility TAR is a fixed bearing system [19]. It was designed to address the issue of small surface area for fixation and articulation by providing a large tibial component with medial and lateral phalanges to allow excellent fixation and prevent talar component impingement against the arthritic medial and lateral malloelar articular surfaces. The additional syndesmosis fusion which is unique to this system further stabilizes the tibial component from rotation and shear forces during ambulation. The talar component allows medial and lateral shift beneath the tibial component and also is wider anteriorly than posteriorly simulating the anatomy of the talus making it more stable in dorsiflexion. The Agility system is implanted with bone cement under distraction using external fixators to assist in reducing bone removal and ensuring good ligamentous tension.

INBONE Total Ankle System (Wright Medical Technology, Arlington, TN)

It is a fixed bearing implant designed with the PE insert attached to the tibial baseplate and a talar component [20]. This system is unique in comparison to other TAR devices because it uses an intramedullary guidance apparatus that employs guide rods to adjust to the precise center of the talus and tibia. Following that, intramedullary reaming of the tibia can be performed from the same plantar heel incision through the subtalar joint into the tibia canal. This total ankle prosthesis attempts to address the issue of poor tibial component fixation by utilising a modular stem system which consists of small interconnecting stem pieces that can be built into a custom length stem for a more stable vertical fixation. It allows preservation of both the malleoli and decreases shear forces at the tibial bone-implant interface. The talar component is designed to cover maximum talar cut surface using cortical wall support to prevent component subsidence. Anatomical saddle shaped design of the talar component provides stability and limits axial rotation of the ankle joint during ambulation. It has a single talar stem to provide fixation stability. On top of that, this system is also distinctive such that if the subtalar joint is arthritic, a concurrent subtalar joint fusion can be performed using compression screws or fusion rods.

Salto Talaris Total Ankle Replacement (Tornier)

The Salto Talaris system is a fixed bearing prosthesis that is designed to deal with the concerns of small surface area and poor tibial fixation [21]. It possesses a tibial baseplate with large surface area and a central keel to provide strong tibial fixation. The tibial baseplate keel has a hollow bar to promote bony ingrowth. The PE insert can be easily attached to the tibial baseplate with a slide-lock mechanism. It also has a medial metallic rim on the tibial baseplate to prevent medial impingement and an optional polyethylene implant on the fibula side to articulate with the talar component. Articular geometry of the talar implant is carefully matched to allow for minimal bone resection and excellent fixation via a central keel as well. There is a sulcus on the articular surface of the talar component to increase stability of the polyethylene insert and prevent dislocation.

The Scandinavian Total Ankle Replacement (STAR) (Waldmar Link, Hamburg, Germany)

The STAR prosthesis is a three component mobile bearing system which utilises cementless fixation [22]. It has a trapezoidal shaped tibial baseplate to maximize cortical coverage and 2 large cylindrical barrels at the bone-implant interface covered with titanium plasma spray coating to enhance bony ingrowth. The talar component is designed to cover the talar dome both anterior and posteriorly together with medial and lateral facets. During implantation of the talar component, it also allows resurfacing of the gutters. It has a small raised ridge running from anterior to posterior surface of the talar dome which is congruent to the talar articulating surface of the polyethylene insert. This provides stable PE motion and constrains the medial and lateral motion of the mobile bearing. In addition, it does not allow inversion and eversion motion at the joint. At the bone-implant interface, it has a central keel which is also coated with titanium plasma spray to allow stable fixation.

Mobility Total Ankle Replacement (DePuy, Johnson & JohnsonCo, Leeds, UK)

The Mobility TAR system is a mobile bearing prosthesis that is designed to provide minimal bone resection and preserve bone stock [23]. The tibial component has a thick tibial baseplate and a short conical tibial stem that helps to prevent rotational instability. The talar component was designed to have a deep sulcus on the articulating surface to prevent PE insert dislocation. It has a triplane underside to keep minimal bone resection and 2 short fins to provide stability without risks of penetrating subtalar joint. It utilizes cementless fixation with non-bearing surfaces that are porous coated to enhance bony in-growth potential.

Hintegra Total Ankle Replacement (Newdeal SA, Lyon, France)

The Hintegra TAR is a mobile bearing system that is both bone preserving and designed to address the issue of fixation stability by creating anterior flange amenable to screw fixation for both tibial and talar components [24]. It has a tibial component that is a flat loading plate with pyramidal peaks against the tibia and an anterior shield that allows fixation with 2 screws. The talar component has a small radius medially to simulate normal anatomy of the talus. It also provides additional fixation with 2 screws into the anterior shield. This talar component is unique that it is designed with a 2.5mm high rim on both medial and lateral side to ensure stable motion and guides anteroposterior translation of the PE insert. However, it does not allow inversion and eversion at the ankle joint. Both the tibial and talar component are porous coated on the non-articulating surfaces for cementless fixation.

Zimmer Trabecular Metal Total Ankle Replacement

This new system is a mobile bearing total ankle prosthesis that is recently introduced as an alternative TAR system [25]. It is unique to other systems in that it uses an external fixator assisted alignment system to guide bony resections and implantation. The surgical approach is also different from other systems in using a lateral transfibular approach rather than the anterior approach to facilitate in reduction of wound complications. In light of this approach, a distal fibula osteotomy and temporary division of the ATFL would be required during the surgery followed by reconstruction after the TAR is completed. This implant provided an alternative option to ankle joint accessibility during resection and implantation but risks having complications of distal fibula osteotomy. On the other hand, the tibial component is concave with the base coated with Trabecular Metal surface for bony incorporation. It has 2 fixation rails on the base running medial to laterally to facilitate fixation stability. The talar component is a convex bicondylar shape with a smaller radius medially than laterally to simulate natural articular geometry of the talus. The bone-implant surface is also coated with Trabecular Metal and consists of 2 fixation rails similar to the tibial component to enhance fixation stability. This system requires bone cement injection into the rails during implantation.

Discussion

Total ankle replacements have come a long way from highly constrained designs to minimally constrained implants [10,11,15-17]. Analysis of implant failures from the past have revealed multiple lessons such as highly constrained designs leading to loosening, subsidence and osteolysis at the bone-implant interface, extensive bony resection for cement fixation resulting in unstable fixation and incongruous articulating surfaces leading to unequal distribution of load and increased polyethylene wear. With these findings, newer implants have been tailored and designed to counter these flaws. Minimally constrained designs, cementless fixation and articulating surface congruity are now part and parcel of all TAR implants [10,11].

Poor accessibility to the ankle joint has always been a challenge to TAR. The ankle joint cannot be dislocated for resection and implantation. Hence, newer surgical techniques and instrumentation have tried to address this concern. The Agility system uses an external fixator as distraction device during implantation [19]. The INBONE system uses an intramedullary guidance apparatus that employs guide rods to align the hindfoot and accesses the ankle joint from the subtalar joint [20]. This technique allows precise control of alignment and bony resection but in the expense of sacrificing the subtalar joint and also involves a large amount of radiation from fluoroscopy. Recently, the Zimmer Trabecular Metal TAR system introduced an external fixator assisted alignment apparatus coupled with a lateral transfibular approach to aid in reducing wound complications [25]. However, risks of complication from distal fibula osteotomy are present.

Bone preservation is the cornerstone of a successful TAR. Previous total ankle prostheses that employed extensive bony resection for fixation has resulted in poor fixation and high failure rates. Kofoed et al [26,27] shown that only the distal 1 to 1.5cm of the tibia is solid subchondral bone and several other studies have reported that the deeper the resection below the tibia plafond, the bony surface becomes weaker to compressive forces [28]. These encourage minimal bone resection during implantation to ensure a firm and secure bone-implant interface. The Mobility system was designed for minimal bone resection [23]. It has a long tibial baseplate to gain support from anterior and posterior tibia cortices while using a conical stem to attain stability. However, in order to insert the tibial component with conical stem, a bone window has to be created which potentially can cause nonunion and loosening. On the other hand, the Hintegra prosthesis's approach towards bone preservation is to create an additional anterior flange for both the tibial and talar component to allow screw fixation for stability [24].

In terms of fixation stability, the TAR systems have evolved from cemented fixation to uncemented fixation with or without additional surface material for bony ingrowth on the non-bearing surfaces of the tibial and talar components [10,11,15-17]. Uncemented fixation is the current "gold standard" adopted by most surgeons for all TAR systems [10,11]. Other modifications such as stems, bars, fins, pegs have been designed in both tibial and talar components to improve fixation. The Salto Talaris system has a tibial component with a central keel that has a hollow bar to promote bony ingrowth [21]. Alternatively, the STAR system employs 2 large cylindrical barrels on the non-bearing surface that are coated with bioactive materials to promote bony ingrowth for better fixation [22]. Using vertical fixation as a form of improving tibial fixation, the INBONE TAR prosthesis utilizes a unique modular tibial stem that can be constructed using small interconnecting pieces to a custom length [20]. As for the talar component, the Mobility system [23] deployed 2 short fins to help build a stable fixation while the INBONE [20] talar component has a single stem fixation. The Hintegra system is designed with anterior flange on both components to allow screw fixation for stability and bone preservation [24].

The PE articulation has also evolved since the advent of TAR. Initial designs were fixed bearing with all polyethylene tibial component using incongruous surfaces. The tibial component had a part of a cylinder while the talar component had a part of a sphere with smaller radius. This difference in surface congruency resulted in high polyethylene wear. Subsequent TAR designs utilize ultrahigh molecular weight polyethylene (UHMWPE) as part of a 3 component, mobile bearing prosthesis. These mobile bearing devices are designed to allow surface congruity of the articulating components to distribute load equally and reduce PE wear rate [29]. Newer designs have since been introduced to further improve on previous flaws such additional sulcus or ridges on the talar component to increase PE stability and prevent dislocation [10,11]. Besides, implants such as the STAR and Hintegra prostheses does not allow inversion-eversion at the ankle joint and is thought to prevent excessive edge loading of the PE bearing and decreased wear rate although there is lack of studies on this issue now.

Complications previously reported such as gutter impingement have also been reviewed and some implants are designed to resurface the medial and lateral gutter while others do not. While there are insufficient data in the literature to support routine resurfacing of the gutters, some studies do recommend prophylactic resurfacing of the gutters during implantation of TAR system to reduce incidence of postoperative impingement pain [30]. The STAR system designed the talar component to cover both medial and lateral surfaces and resurfacing is done during implantation [22].

Conclusion

New designs with improvements to previous TAR systems are changing the outcomes of TAR in advanced ankle arthritis. There are multiple models of TAR available that attempt to address different challenges in ankle arthroplasty. Better survival rates with long term outcome studies using these new implants are pushing the boundaries of treatment options for advanced ankle arthritis. TAR has a definite role in the treatment of advanced ankle arthritis to preserve joint mobility and we foresee an increasing trend of ankle replacement compared to arthrodesis.

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