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Original article

The effects of total ankle replacement on ankle joint mechanics during walking

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Abstract

Background: End-stage ankle arthritis impairs joint function and patients' mobility. Total ankle replacement is a surgical procedure to treat severe ankle arthritis. Salto Talaris Anatomic Ankle™ (STAA) was designed to mimic the normal ankle anatomy and flexion/extension of the ankle movement. The purpose of this study was to examine the effect of an STAA ankle replacement on ankle joint function and mechanics during gait.
Methods: Five patients with end-stage unilateral ankle arthritis were recruited. Patients performed level walking in a laboratory setting on 2 occasions, prior to and 3 months after the STAA ankle surgeries. American Orthopedic Foot and Ankle Society (AOFAS) hindfoot score was obtained. A 12-camera motion capture system was used to perform walking analysis. Gait temporo-spatial parameters and ankle joint mechanics were evaluated. Paired Student's *t* tests and non-parametric Wilcoxon matched tests were performed to examine the differences in biomechanical variables between the pre- and post-surgery walking conditions.
Results: Compared to the pre-surgical condition, at 3 months of post-STAA surgery, patients experienced greater improvement in AOFAS hindfoot score ($p = 0.0001$); the STAA ankle demonstrated a 31% increase in ankle joint excursion ($p = 0.045$), a 22% increase in ankle plantarflexor moment ($p = 0.075$), a 60% increase in ankle power absorption ($p = 0.023$), and a 68% increase in ankle power production ($p = 0.039$). Patients also demonstrated a 26% increase in walking speed ($p = 0.005$), a 20% increase in stride length ($p = 0.013$), a 15% decrease in double support time ($p = 0.043$), and a 5% decrease in total stance time ($p = 0.055$).
Conclusion: Three months after surgeries, the STAA patients experienced improvements in ankle function and gait parameters. The STAA ankle demonstrated improved ankle mechanics during daily activities such as walking.

Keywords: Ankle mechanics; AOFAS score; Arthritis; Gait analysis; Total ankle replacement; Walking

1. Introduction

Ankle joint arthritis is a progressive cartilage degenerative disease, which is signified by pain, limited range of motion, and stiffness. Over 70% of ankle joint arthritis is a result of joint traumas such as ankle fractures and ligament ruptures.[1] Rheumatoid arthritis and osteoarthritis account for the rest of the percentages of ankle joint arthritis.[1] Currently, over 1% of the adult population suffers ankle joint arthritis worldwide.[2]

End-stage ankle arthritis impairs ankle joint function and results in physical disabilities. Due to the effectiveness of reducing joint pain and improving patients' mobility, ankle arthrodesis (ankle joint fusion) has been an important treatment method for patients with end-stage ankle arthritis.[3] It was reported that ankle arthrodesis results in satisfactory outcomes and acceptable gait function.[4–7] However, there were limitations associated with ankle arthrodesis. Firstly, the tibio–talar joint is fused and loses its motion, which causes compensatory motion and increased mechanical stress at other associated parts of the foot and leg. In the long term, the risk of developing subtalar and midtarsal degenerative joint disease is thus increased.[8,9] Secondly, patients with arthrodesis develop compensatory walking patterns and demonstrate asymmetrical gait.[5] In the past 40 years, total ankle replacement (TAR) has become an alternative of arthrodesis for the treatment of severe ankle arthritis. TAR can eliminate ankle joint pain and return ankle joint to function.[8,10] Although there is still a debate whether one procedure is better than the other,[4,7,10,11] TAR does have

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some advantages over ankle arthrodesis. Compared to a fused ankle joint, a TAR could restore normal ankle range of motion resulting in a less compromised gait.[12] Also, adverse effects on the other joints of the same limb are less likely to occur.

Early TAR designs were two-component designs that included a tibial component and a talar component. Both components were constrained to allow 1° of freedom of motion. The outcomes of constrained two-component TARs were not satisfactory due to component loosening and failures.[13,14] In the 1990s, the development of an unconstrained, meniscal bearing type of TAR had led to improved clinical outcomes.[15–17] The mobile-bearing three-component TAR design is characterized with metal tibial and talar components articulating with an unattached polyethylene meniscus. Mobile bearing TARs represented by the Salto mobile-bearing TAR (Tornier Inc., Montbonnot Saint Martin, France) have achieved a 93% survivorship at 6.4 years follow-up and an 85% survivorship at 8.9 years follow-up.[18,19] In recent years, based on the success of the Salto mobile-bearing TAR, the Salto Talaris Anatomic Ankle™ (STAA) (Tornier Inc.) was introduced to customers in the US. The STAA is characterized with unconstrained tibial and talar components and a polyethylene insert secured to the metal tibial component. This two-component STAA is a new generation TAR that mimics the anatomy and flexion/extension movement of the normal ankle joint (http://www.tornier-us.com/lower/ankle/ankrec004/). Specifically, the talar implant mimics the anatomy of the talar dome and the flexion/extension axis is the axis of a cone to allow normal external rotation of the foot during dorsiflexion.

To date, there are no studies that report on the kinematic or kinetic changes that occur with the STAA system. It is not known how quickly a patient could gain ankle function and strength after receiving the STAA. It is not clear whether the STAA could improve patients' ability to perform daily activities (e.g., level walking). Therefore, the purpose of this study was to examine the ankle joint function and mechanics during level walking in patients with unilateral ankle arthritis on the following 2 occasions: pre- and 3 months post-surgery with the STAA. It was hypothesized that the TAR joint would demonstrate improved clinical and functional outcomes, gait parameters, and ankle joint mechanics when compared to the same limb before surgery during level walking.

2. Methods

Five patients (3 males and 2 females; 67 ± 6 years, 91 ± 17 kg, 173 ± 7 cm, mean ± SD) who developed unilateral ankle osteoarthritis due to severe ankle joint injuries (e.g., ankle fractures and sprains) volunteered in the study. All patients were diagnosed with advanced, end-stage ankle arthritis (Grades 2–3 based on Canadian Orthopaedic Foot and Ankle Society classification[20]) before TAR surgeries. Standard surgical procedure for installing fixed bearing TARs was performed. Patients had gone through a standard rehabilitation protocol after the surgeries. Specifically, for the first 6 weeks of postoperation, patients wore walker boots; from the 2nd to the 10th week, patients performed active range of motion exercise at the ankle and strength exercises of the core, hip, and knee joints; from the 6th to the 10th week, scar massage was conducted; stationary biking exercise was introduced; patients also practiced weight-bearing activities including standing, weight shifting, and short distance walking; from the 10th to the 16th week, patients continued their gait training and strength training of core, hip, knee, and ankle; patients also started unilateral stance exercises, bilateral heel raises, and balance exercises. This study was approved by Institutional Review Board at Ball State University. All subjects were informed of the study procedures and signed informed consent forms prior to participation in the study.

Patients' clinical and functional outcomes were assessed by an experienced physical therapist via the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score system.[21] During the assessment, ankle joint pain, function, hindfoot motion, and joint alignment were evaluated with a maximum score of 100.

Three-dimensional (3D) trajectories of reflective markers placed on the body were captured during testing trials using a 12-camera (MX 40) motion capture system (100 Hz) (VICON Inc., Denver, CO, USA). Ground reaction forces were also collected (1000 Hz) during testing trials using 2 embedded AMTI force platforms (Model OR6-7-2000; Advanced Mechanical Technologies Inc., Watertown, MA, USA). VICON Workstation (Version 5.2.4; VICON Inc.) was used to reconstruct and process the raw 3D trajectory data and ground reaction force data.

Subjects came to the Ball State University Biomechanics Laboratory on 2 separate occasions for the study: pre- and 3 months post-TAR surgery (all performed by the same surgeon) using the STAA in the affected ankle. During both visits, subjects followed identical testing protocols. Subject anthropometrics were gathered and then spherical retro-reflective markers (14 mm) were fitted bilaterally on specific lower extremity anatomical landmarks following the Plug-in-Gait model protocol. Subjects then performed a general 5 min warm-up on a stationary bike before testing trials. Next, subjects were instructed to perform level walking gait trials at a self-selected pace within the gait analysis walkway (approximately 10 m in length). Walking movement was performed in a barefoot condition. Trials were deemed acceptable if the foot of interest landed completely on the force platform and the subject maintained a consistent gait pattern. A minimum of 5 trials were required to come from the affected ankle.

VICON Workstation (Version 5.2.4) was used to generate gait temporo-spatial parameters such as walking speed, stride length, stance time, and double support. In addition, ankle joint mechanics including maximal dorsiflexion, maximal plantarflexion, and joint excursion (joint range of motion from peak dorsiflexion to peak plantarflexion during stance of gait), peak ankle joint moment, and peak ankle joint power were analyzed for both pre- and post-TAR surgeries. Standard inverse dynamic calculations were performed to obtain joint moments and powers.[22] Stance time and double support time were normalized to a full gait cycle (identified as heel strike of the affected ankle to the next heel strike of the same ankle). Ankle joint moments and powers were normalized to body mass.

Statistical analysis was performed using SPSS software for Windows (Version 19.0; IBM Corp., Armonk, NY, USA).