
Kinematic Evaluation of the Zimmer® Trabecular Metal™ Ankle Using Robotic Technology

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ABSTRACT

Purpose: The goal of this study was to quantify the kinematics of the ankle complex following surgical implantation of the Zimmer *Trabecular Metal* Ankle compared to the natural, healthy ankle before surgical intervention.

Methods: Kinematic evaluations, including functional simulations and laxity testing, were performed on five cadaveric specimens using robotic technology. These evaluations were first performed on the natural, non-symptomatic ankle. Following that evaluation the Zimmer *Trabecular Metal* Ankle was surgically implanted in these specimens by a fellowship trained, board certified foot and ankle orthopaedic surgeon. The evaluations were repeated on the implanted specimen.

Results: The laxity of the ankle complex before and after implantation was not statistically different in anterior / posterior translation or internal / external rotation. The implanted ankle demonstrated similar kinematics during the functional simulation compared to the natural ankle, except in pronation / supination from 30 to 19 degrees of plantar flexion.

Conclusions: The kinematic performance of the ankle complex following implantation with the Zimmer *Trabecular Metal* Ankle was shown to be similar to the kinematic performance of the natural, healthy ankle.

INTRODUCTION

Ankle arthritis can cause pain and inflammation in the joint which could lead to decreased functionality. Ankle arthrodesis is the most common surgical procedure performed for this condition.¹ This procedure is successful at relieving pain, but there are questions about the long-term success of this procedure in terms of lower limb function, including changes in gait following arthrodesis.² Total ankle arthroplasty (TAA) has the potential of relieving the pain and preserving the normal function of the ankle. But early ankle replacements had many issues including lack of improvement in joint function.

One key aspect in restoring natural kinematics following total joint arthroplasty is restoring the natural shape of the articulating surfaces of the joint. A previous study has shown that joint laxity increases following total ankle arthroplasty with an implant design that does not replicate the natural geometry of the articulating surface.³ The Zimmer *Trabecular Metal* Ankle is designed to replicate the anatomy with its bicondylar design and sagittal curvature.

Kinematic performance of a joint involves two different aspects. One is the laxity of the joint, quantifying the end points of motion, and the other is the motion of the joint during a functional activity. There are very few methods that can evaluate both of these kinematics metrics. Robotic technology has been shown to accurately evaluate both of these kinematic metrics.⁴ The objective of this current study was to compare the kinematic performance of the intact, non-symptomatic, ankle joint and an ankle implanted with the Zimmer *Trabecular Metal* Ankle using robotic technology.

METHODS

Testing Overview

Five fresh frozen cadaveric ankle specimens were used, consisting of the entire tibia and fibula through the toes (age: 80.9±9.5 years, body-mass-index (BMI): 17.9±4.5) for this study. Each specimen was secured to testing fixtures to facilitate robotic manipulation and anatomic coordinate system tracking. The proximal tibia and fibula were fixed into aluminum cylinders using bone cement and the calcaneus was fixed to a rigid L-bracket with screws. Then a CT scan was performed on the specimens with fixtures attached. From the CT scan, 3D bone models were produced that facilitated the creation of anatomical coordinate systems in the tibia, which included the fibula and calcaneus. These anatomic coordinate systems were then registered to the fixtures. This registration allowed the forces and torques to be applied at the specimen specific anatomic joint center and allowed the position of these anatomic coordinate systems to be quantified during the testing.

The specimens were rigidly attached to a six-degree-of-freedom robotic arm (KR 500 KUKA Robotics, Augsburg, Germany) via the above mentioned fixtures for kinematic testing (Figure 1). This study quantified the motion of the tibia with respect to the calcaneus. The kinematic performance of the intact ankle complex was first quantified for all specimens. Following intact testing, the specimen was removed from the robot, and the specimen was implanted with the Zimmer *Trabecular Metal* Ankle by a fellowship trained, board certified foot and ankle orthopaedic surgeon. After implantation, the specimen was re-attached to the robot and the kinematic performance was quantified. The kinematic evaluation included the quantification of the ankle complex laxity and simulated functional activity.

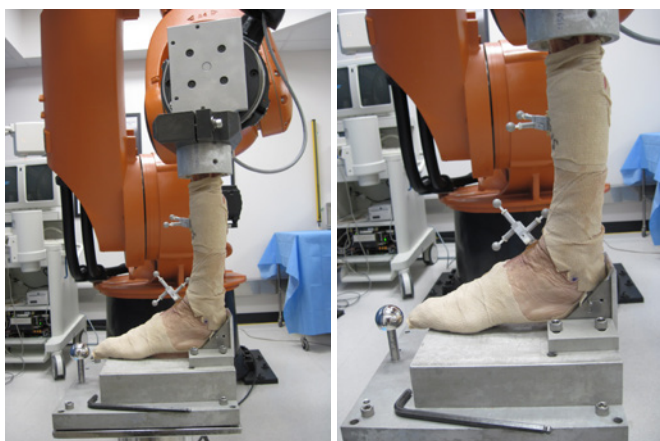


Figure 1: Robotic setup for kinematic testing (A: Overview, B: Close-up)

Laxity Testing

The kinematic evaluation began by determining the neutral path of motion of the ankle complex. The neutral path was determined using kinematic control for dorsiflexion / plantar flexion and force-torque control for the other degrees of freedom. The inputs for the force-torque control were zero in all directions except axial load, which applied 44 N. At a given flexion angle, the robot moved in force-torque control to obtain the desired values within given tolerances ($\pm 2.5\text{N}$ & $\pm 0.1\text{Nm}$). When these tolerances were met, the position of tibia with respect to the calcaneus was recorded and the ankle flexed to the next position. This evaluation began at 15 degrees of dorsiflexion and ended at 30 degrees of plantar flexion, through 1 degree increments. The position on the neutral path was used as the starting point for the laxity evaluations. Joint laxity was assessed at 15 degrees of dorsiflexion, neutral, 15 degrees of plantar flexion, and 30 degrees of plantar

flexion. At each angle, tibial internal-external laxity (IE) was evaluated by applying $\pm 3\text{ Nm}$, and anterior-posterior laxity (AP) was evaluated by applying $\pm 100\text{ N}$. All laxity evaluations were performed with a 44 N compressive load applied. Similar ankle positions and loads were used in previous evaluations of the intact and implanted tibiotalar joint.^{3,5} During the laxity evaluations the position of tibia with respect to the calcaneus was recorded. Laxity of the implanted ankle was compared to that of an intact ankle using a paired Student's T-test with a p-value less than 0.05 being considered significant.

Functional Simulation

The functional simulation was meant to simulate the weight bearing portion of the gait cycle from heel-strike to heel-off.⁶ This simulation was performed in a similar manner to the neutral path determination. This evaluation started at 30 degrees of plantar flexion and terminated at 15 degrees of dorsiflexion with 1 degree increments. At each flexion increment, the applied compressive load was 200 N, and the remaining forces and moments were unconstrained. The position of the tibia with respect to the calcaneus was recorded at every flexion angle. Kinematics of the implanted ankle were compared to that of an intact ankle using a paired Student's T-test with a p-value less than 0.05 being considered significant.

RESULTS

Laxity of the ankle complex

The laxity of the implanted ankle was not significantly different than the intact ankle in total AP laxity (Figure 2), anterior laxity, or posterior laxity at any flexion angle tested. The largest AP difference between the implanted and intact laxity was at 15 degrees of dorsiflexion. The intact ankle had a laxity of 6.36 ± 2.04 mm and the implanted ankle had a laxity of 4.96 ± 1.29 mm. The laxity of the implanted ankle was not significantly different than the intact ankle in total IE (Figure 3), external or internal laxity. The largest IE difference between the implanted and intact was in neutral in internal rotation where the intact ankle had a laxity of 9.41 ± 3.74 degrees and the implanted ankle had a laxity of 13.87 ± 5.05 degrees.

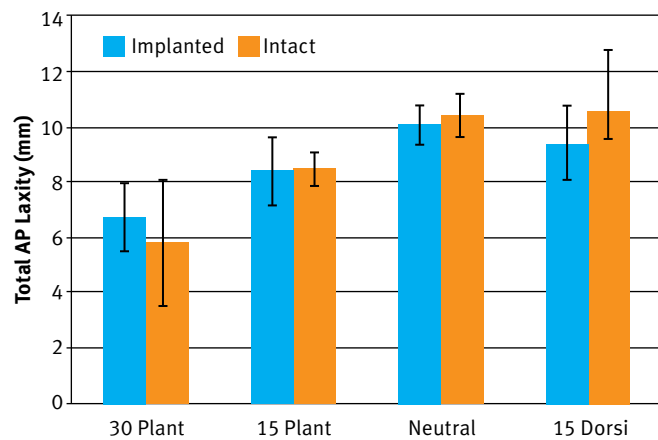


Figure 2: Total anterior-posterior laxity for the intact and implanted ankle complex

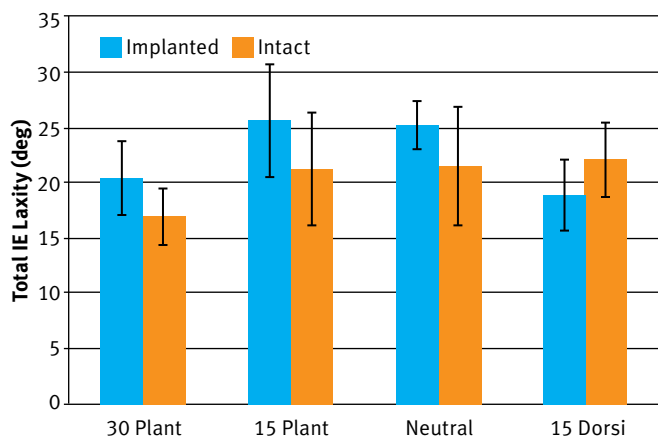


Figure 3: Total internal-external laxity for the intact and implant ankle complex

Functional Simulation

The functional simulation of heel-strike to heel-off demonstrated that the intact ankle complex has small translational movement during this activity. The largest translation was seen in the AP direction where the tibia translated on average 2.57 mm anteriorly throughout the entire activity. The TAA was not significantly different in any translational degree of freedom when compared to the intact. The intact ankle complex was internally rotated (Figure 4) and pronated during this simulation. The implanted ankle was not significantly different in internal rotation (Figure 4), and pronation-supination, except for pronation-supination from 30 degrees to 19 degrees of plantar flexion.

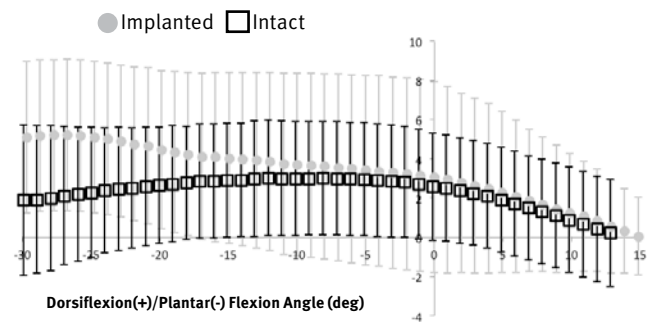


Figure 4: Internal (-) – external (+) rotation of the ankle complex during the functional simulation of heel-strike to heel-off for the intact and implanted ankle

DISCUSSION

This study has its strengths and weaknesses. The primary strength of the study is the use of robotic technology to accurately quantify the laxity and functional kinematics of the same cadaveric ankle before and after implantation. The primary weakness of this study is the number of samples, which was five. This study was accepted and presented at the American Orthopaedic Foot and Ankle Society meeting in 2014.⁷

CONCLUSION

In the specimens evaluated for this study, the Zimmer *Trabecular Metal* Ankle with its anatomic articulation was shown to have kinematics that are not different from the kinematics of the healthy ankle joint. This study has the limitation of a small sample size, but the findings suggest that the Zimmer *Trabecular Metal* Ankle has the potential to create kinematics similar to a healthy joint.

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