Micromotion Patterns at the Bone-Implant Interface of a Mobile-Bearing and a Semi-Constrained Total Ankle Replacement: an *in vitro* Biomechanical Study

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May 15, 2012
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My disclosure is in the Final AOFAS Program Book. I have no potential conflicts with this presentation.
Introduction

Total ankle replacement (TAR) is an effective treatment for end-stage arthritis in the tibiotalar joint. However, this procedure has a high failure rate, more than 2.5 times that of hip and knee replacements[1]. Of these failures, nearly half are attributable to aseptic loosening. The underlying cause of aseptic loosening is believed to be excessive motion at the bone-implant interface[2,3]; therefore, studying the micromotion patterns in TARs is essential in reducing the incidence of these failures.

Objectives:

• Design a loading apparatus capable of applying relevant loads to the foot/ankle that stress the bone-implant interface while enabling measurement of bones and implant components

• Determine the initial post-operative micromotion magnitudes between the bone and implant in modern total ankle replacements

• Compare the initial fixation of two TAR designs with different aseptic loosening rates

**TAR Design Comparison**

<table>
<thead>
<tr>
<th>Agility</th>
<th>STAR</th>
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<tbody>
<tr>
<td>• Two-component semi-constrained</td>
<td>• Three-component unconstrained</td>
</tr>
<tr>
<td>• Ti tibial component</td>
<td>• CoCrMo tibial component</td>
</tr>
<tr>
<td>• CoCr talar component</td>
<td>• CoCrMo talar component</td>
</tr>
<tr>
<td>• UHMWPE bearing fixed to tibial comp.</td>
<td>• UHMWPE mobile bearing</td>
</tr>
<tr>
<td>• Porocoat® sintered Ti bead ingrowth surface</td>
<td>• Ti plasma spray ingrowth surface</td>
</tr>
<tr>
<td>• Aseptic loosening rate: 7.1% [4-7]</td>
<td>• Aseptic loosening rate: 5.7% [6,8-15]</td>
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</tbody>
</table>
Six pairs of human cadaver lower limbs were tested with the Agility in one ankle and the STAR in the other.

Each limb was subjected to six test configurations:
- Compressed – Uncompressed
- 3 Rotations: Plantarflexion-Dorsiflexion (PF-DF), Inversion-Eversion (INV-EV), and Internal-External Rotation (IR-ER)

Relative bone-implant micromotions were calculated using 3-D displacement measurements of the tibia, talus, and implant components taken with the Optotrak Certus.

2-Way Repeated Measures ANOVA:
- Primary outcome measure: peak micromotion magnitude during 3rd cycle
- Effects of implant type and Compression
- 1 ANOVA for each loading direction and implant component (6 total)
Loading Apparatus

Application of isolated moments to the unconstrained foot via foot-plate
- Applied using a custom assembly consisting of a servomotor, u-joint, ball spline, u-joint, and fixture block connected in series
- Applied individually about each axis (PF-DF, INV-EV, and IR-ER)
- Cycled 3 times through range of motion at a constant angular velocity (2 deg/s) to a torque limit of 3 Nm (or predetermined angular displacement limits in PF-DF)

Application of compressive loads:
- Applied via linear hydraulic actuator (A591-4, Instron) through steel cable looped around foot-plate
- Directed through the ankle’s center of rotation with cable guides
- Preloads of 15 N for uncompressed scenarios, and 75 N (INV-EV) or 300 N (PF-DF and IR-ER) for compressed scenarios

Counter-balances to eliminate the effect of external loads other than applied moments and compression:
- Cable counterweights to counter the weight of the apparatus
- Disc counterweight to balance the moment caused by the moment applicator arm
This figure shows a representative example (specimen H1351) of the micromotion magnitude patterns for the talar component during 3 cycles of PF-DF with and without compression. Ankles start in the neutral position and are plantarflexed initially, reaching their maximum PF angle just prior to 50% corresponding to their peak micromotion magnitudes. In the STAR, another micromotion peak occurs at approximately 80% of the cycle, which corresponds to the maximum DF angle.
Results

Tibial Micromotion

Talar Micromotion

Peak micromotion magnitudes for the tibial component for all loading scenarios. Micromotion values are plotted as mean with error bars as one standard deviation. # p=0.040

Peak micromotion magnitudes for the talar component for all loading scenarios. Values given as mean with error bars as one standard deviation. * p<0.001; # p=0.006; @ p=0.001; % p<0.001

- Greater micromotion in the Agility in INV-EV (p = 0.037)
- Decreased micromotion due to compression in IR-ER (p = 0.019)
- Greater micromotion in the Agility in PF-DF (p = 0.002) and IR-ER (p = 0.038)
- Decreased micromotion due to compression in PF-DF (p = 0.037) and IR-ER (p = 0.0001)
- Significant interaction between compression and implant type in PF-DF (p = 0.027) and IR-ER (p = 0.003)
Conclusions

• Greater micromotion magnitudes are correlated with higher aseptic loosening rates

• TAR designs must stabilize the implant in the bone at the time implantation in order to reduce aseptic loosening rates

• Biomechanical cadaveric testing provides an effective means by which implant’s initial fixation may be evaluated