Sensitivity of Cementless Tibial Fixation to Varus and Slope Malalignment: A Biomechanical Micromotion Study

Eric M. Cohen, BS[2], Gabriel Makar, MD[3], Paul Ulrich, DO[3], Miguel A. Diaz, MS[1], Peter Simon, PhD[1,2], Steven T. Lyons, MD[3].
[1]Foundation for Orthopaedic Research and Education, Tampa, FL; [2]USF Health Morsani College of Medicine, Tampa, FL; [3]Florida Orthopaedic Institute, Tampa, FL.

INTRODUCTION: Cementless total knees now make up nearly 20% of primary total knee arthroplasty (TKA) and have been shown to have decreased cumulative revision rates, particularly in males under 65 years old. Cemented implants are often referred to as the gold standard, but concerns exist regarding failure of the cement-bone interface. With younger, more active patients receiving TKA, these concerns are even more paramount and may be solved by using cementless implants. Studies have identified that well-fixed tibial trays had bony ingrowth covering, on average, 27% of the tibial tray surface area, and hypothesized that angular resection errors may lead to excess micromotion inhibiting enough ingrowth to stabilize the tray (micromotion greater than 150 microns). Thus, the aim of this study is to evaluate implant micromotion as a measure of stability in newly designed cementless tibial trays after they are implanted in sawbones with neutral mechanical alignment and 0° of slope, 2° of varus with 3° of slope, and 5° of varus with 3°of slope. To our knowledge, this study is the first to examine the micromotion of new generation cementless tibial components implanted using mechanical and restricted kinematic alignment. Our hypothesis is that cementless tibial fixation placed in 5° of varus will have no difference in micromotion compared to that of components placed in 2° and neutral mechanical alignment.

METHODS: A total of 18 sawbone tibial bone models (Sawbones, Model# 1522-912) were divided into three testing groups. These tibial bone models have been utilized in several biomechanical studies. They are composed of two foam densities, where the inner core is 12.5 pounds per cubic foot (PCF) to replicate cancellous bone, and the outer wall is 40 PCF solid rigid foam to replicate the cortex. Each of the three tibial cut groups consisted of 6 samples: Group A (Control, n=6) were flat neutral alignment sawbones with 0° of varus and 0° of slope. Group B (Exp.1, n=6) were cut with 2° of varus and 3° of slope. Group C (Exp.2, n=6) were cut with 5° of varus and 3° slope. After the tibial cuts were performed, we then implanted the tibial components. Each sample underwent cyclic loading for up to 10,000 cycles at 2 Hz from 1xBW (687N) to 3xBW (2.1kN) (Figure 1). Digital Imaging Correlation (Aramis-3D DIC; GOM) was used to monitor the micromotion of the tibial component. This was performed by tracking high-contrast marker points across the test construct with high-resolution cameras (Figure 2). The average amount of micromotion and standard deviation for each measurement location are reported for preconditioning, baseline (first 50 cycles), and final (10k cycles). A one-way ANOVA with post hoc Tukey and Games–Howell tests was performed to compare tendon characteristics. Statistical significance was set at $\alpha = 0.05$.

RESULTS SECTION: The overall micromotion for each group increased over the duration of the testing but remained below the 150-micron threshold at preconditioning, baseline, and at the completion of 10k cycle testing. Group A remained the most stable, with micromotion remaining below 0.040 mm at every location and timepoint. In contrast, Group C showed higher micromotion, ranging from 0.0614 ± 0.0405 mm at D1 preconditioning, 0.1190 ± 0.0780 mm at D1 baseline, and 0.1315 ± 0.0783 mm at D1 at 10k cycles. Group B followed the same pattern, with D1 values rising to 0.0928 ± 0.0848 mm at baseline and 0.1009 ± 0.0912 mm at 10k cycles, both exceeding Group A (Figure 3).

DISCUSSION: Micromotion did differ significantly between tibial cuts of 2° of varus with 3° slope and neutral cuts with no slope cut, as well as a significant increase in micromotion when comparing neutral cuts to 5° of varus with 3° slope. The average micromotion for each of the three groups remained under the 150-micron level; however, a few samples in Group B and Group C did exceed this threshold. This study suggests that cementless TKAs may continue to show durability and longevity even in instances where the tibia is placed in varus alignment and increased slope, as all groups remain below the micromotion threshold. However, caution should be taken as a significant increase in micromotion was observed at varying degrees of varus, and larger angles may quickly exceed this value, inhibiting biologic fixation.

SIGNIFICANCE/CLINICAL RELEVANCE: Within the range tested, modern cementless tibial trays generally maintained micromotion below the osseointegration threshold; however, varus and posterior slope malalignment decreased the fixation margin of safety. These findings support precise alignment during cementless TKA to optimize early stability and promote biologic ingrowth.
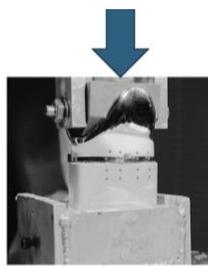

Figure 1. Each sample underwent cyclic loading for up to 10,000 cycles at 2 Hz from 1xBW (687N) to 3xBW (2.1kN). The average amount of micromotion and standard deviation for each measurement location are reported for preconditioning, baseline (first 50 cycles) and final (10k cycles).
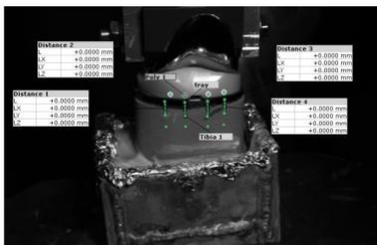

Figure 2. Digital Imaging Correlation (Aramis-3D DIC; GOM) was used to monitor the micromotion of the tibial component. This was performed by tracking high-contrast marker points across the test construct with high resolution cameras.
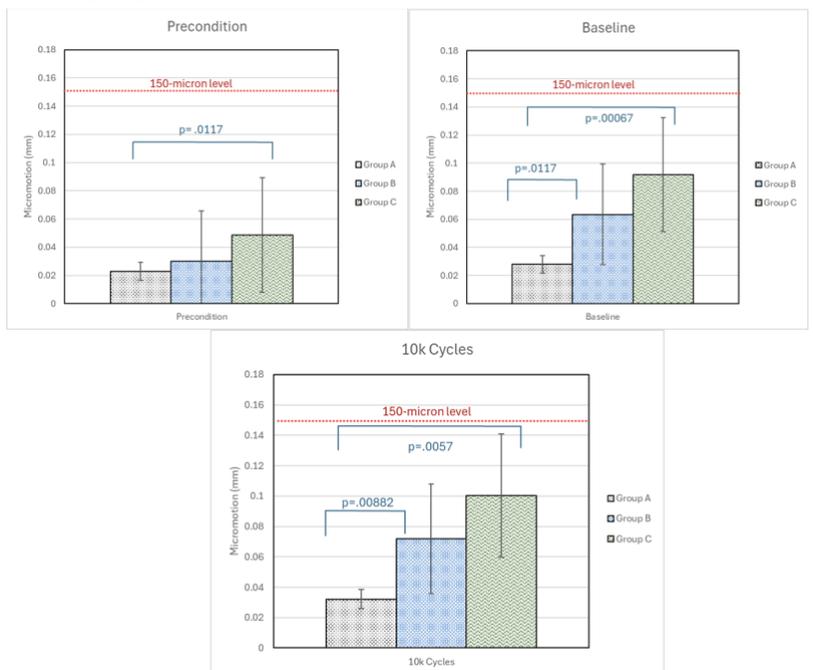

Figure 3. Micromotion plots comparing each group during preconditioning, baseline (first 50 cycles), and at final (10k