The Effect of Stem Length on Strain and Micromotion in the Proximal Femur following Total Hip Arthroplasty

Scott R. Small, MS1, Sarah E. Hensley2, Paige L. Cook, BS2, Rebecca A. Stevens, BS2, Renee D. Rogge, PhD2, Michael E. Berend, MD1.

1JRSI Foundation, Inc., Mooresville, IN, USA, 2Rose-Hulman Institute of Technology, Terre Haute, IN, USA.

Disclosures: S.R. Small: 1; Orthalign. 5; Biomet, Stryker, DePuy. S.E. Hensley: None. P.L. Cook: None. R.A. Stevens: None. R.D. Rogge: 5; Biomet, Stryker, DePuy. M.E. Berend: 1; Biomet. 3B; Biomet, Orthalign. 5; Biomet, DePuy.

Introduction: Stress shielding leading to adaptive bone remodeling is a documented phenomenon in some total hip arthroplasty (THA) systems [1]. This remodeling can lead to complications including aseptic loosening of the femoral stem due to reduced quality of bone stock, often resulting in revision surgery. A primary goal in short stemmed THA stem designs is to restore joint function while preserving more native bone than traditional stem lengths. As a result of reduced component length, short stems must maximize primary stability to allow for adequate bone ingrowth for long term clinical success. The purpose of this study was to quantify the altered mechanical load distribution in the femur as a result of reduced stem length, while additionally capturing the effect of stem length on the three dimensional micromotion between the implanted stem and the surrounding bone.

Methods: Axial Strain Response:
Short, medium, and long stemmed variations (79, 102, and 135 mm respectively) of a currently marketed cementless stem design were implanted into fourth generation composite femur models (Sawbones, Vashon, WA) using incremental broaching and manual impaction by a board-certified orthopaedic surgeon. Six femurs were implanted in each of the three stem length experimental cohorts in addition to a group of six intact whole femur models for baseline comparison. Femurs were distally potted in a polyurethane resin within a cylindrical aluminum mold at a 12 degree varus angle. A speckle pattern was applied to proximal cortex in preparation for digital image correlation (DIC) strain analysis. Static axial loading replicating single-legged stance was performed on all specimens. A custom loading jig mounted onto an electrodynamic materials test frame (ElectroPuls E10000 A/T, Instron, Norwood, MA) was utilized to generate a 2000 N compressive joint reaction force applied at the femoral head coupled with a 1400 N abductor force distributed across the greater trochanter. Following a preconditioning cycle, load was applied at a rate of 60 N/s and held for 30 seconds. Still images were captured at 1Hz using paired high-resolution cameras (ARAMIS 5M, GOM, Inc., Braunschweig, Germany). Because DIC is a line-of-sight measurement, axial tests were repeated in anterior, posterior, medial and lateral views. Four trials per view, per specimen were performed. Strain responses were compared in full-field von Mises strain maps and via point strain analysis, where measurement points were delineated at 10 mm increments progressing distally down the anterior, posterior, medial, and lateral aspects of the femur.

Implant Stability:
In addition to the three stem lengths, two additional stem designs were tested for implant stability: a 89 mm variation of the previous stem with a reduced lateral shoulder (RLS), and a commercially available 107.5 mm wedge-shaped design (Taperloc Microplasty, Biomet, Inc). Following strain testing, three 8
mm viewing windows were drilled into the anterior cortex to allow for DIC deformation measurement of the implanted stem at the following locations: (P1) Proximal border of the ingrowth surface, (P2) Distal border of the ingrowth surface, (P3) Polished distal tip of the stem. Additional DIC speckling was applied to the surface of the stem exposed through the viewing windows.

Both axial and torsional micromotion testing were independently performed. Implant stability was quantified by the amount of three-dimensional relative motion between the exposed stem at each of the three measurement points and the surrounding cortical bone. In torsional testing, the trunnion was inserted into a custom loading jig allowing for medial-lateral bending, but constraining rotation. Under a constant axial load of 1675 N, cyclic loading (1 Hz) was applied in a range of +5 to -20 Nm of torque. In axial testing, a 1 Hz cyclic compressive load of 100 N to 1675 N was applied at the femoral head. DIC micromotion measurements were taken in the proximal two measurement regions (P1-P2) at cycles 100, 250, 375, and 500. Measurements were also taken at P3 at the end of the cyclic loading.

**Results:** Strain analysis:

In all specimens the medial and lateral aspects of the femur displayed the greatest strain response to single-legged stance axial loading (Fig 1). Cortical strain patterns in the short stems most closely matched the strain patterns of the unimplanted femur. Laterally, strain in the short-stemmed cohort ranged within -5% (p=0.119) to +7% (p=0.032) of the unimplanted femur response, while the medium stem ranged from -21% (p<0.001) to +4% (p=0.220) and the long stem ranged from -27% (p<0.001) to +8% (p=0.007) of the unimplanted cohort. Medially, strain in the short-stemmed cohort ranged within -43% (p<0.001) to +6% (p=0.064) of the unimplanted femur response, while the medium stem ranged from -52% (p<0.001) to +13% (p<0.001) and the long stem ranged from -62% (p<0.001) to +6% (p=0.043) of the unimplanted strain. Trends of peak strain response relative other stems were observed in the measurement regions near the distal tip of each successive stem length. This result illustrates the load shunting properties of implanted stems, corresponding to an increase in distal strain dependent on stem length and a corresponding decrease in proximal femur strain.

**Micromotion Analysis:**

Three-dimensional axial micromotion ranged from 0.047 to 0.091 mm at measurement point P1, and 0.052 to 0.075 mm at measurement point P2. When comparing stem length exclusively, no significant difference between the short, medium, and long stemmed versions of otherwise identical implants was observed at either border of the proximal ingrowth surface (p>0.063) as a result of axial loading (Fig. 2). Torsional loading resulted in greater micromotion response across all stems versus axial loading (p<0.081) (Fig. 3). The short stemmed implant exhibited the smallest micromotion response at the distal stem tip, however location of this measurement region varied between implant designs.

**Discussion:** Stem length in THA femoral components significantly alters the load and resulting strain distribution in the femur. Long stemmed components shunt load distally, while short stemmed components more closely mimicked the unimplanted natural femur model in this study. In both axial and torsional micromotion tests, isolated change in component stem length generated no statistically significant effect on primary implant stability. In cases where adequate bone stock is present in the proximal femur, a short stemmed component design may preserve bone stock while minimally impacting the natural strain distribution across the femur. Additionally, in this biomechanical model, shortened stem length did not negatively impact primary stability of the component.
Significance: Focus on bone preservation in primary THA has driven a renewed interest in short stemmed femoral components. This study suggests that, in the patient with high quality proximal bone, short stems may provide more physiological loading without sacrificing primary implant stability.

**Figure 2:** Femoral component micromotion as a result of cyclic axial loading
Figure 3: Femoral component micromotion as a result of cyclic torsional loading
Figure 1: Representative DIC full-field von Mises strain maps for each femoral component stem length

ORS 2015 Annual Meeting
Paper No: 0124