INTRODUCTION: Conventional standard length stem fixation during total hip arthroplasty (THA) may result in significant proximal bone resorption through stress shielding. Bone conserving designs are an alternative treatment option to conventional total hip arthroplasty (THA) in young, active patients. In particular, bone conserving designs, such as shorter stemmed femoral components, have potential advantages such as proximal bone preservation, greater ease of insertion, and more physiological bone remodeling. However, the ability of short stem femoral designs to provide sufficient short-term stability and stable physiological bone remodeling is unclear. The objective of this study was to examine the biomechanical effects of geometric modifications to an uncemented femoral stem on short-term fixation. Specifically, the influence of changes in stem length and medial-lateral geometry of the Omnifit (Stryker Orthopaedics) was examined using computational methods.

METHODS: Subject-specific finite element (FE) models of the intact and implanted proximal femur were developed from a computed tomography (CT) scan of a 45-year-old female donor (ScienceCare Anatomical, Phoenix, AZ) (Drexel University IRB, Philadelphia, PA). The scan was taken at an in-plane resolution of 0.781 mm with contiguous 1 mm thick slices to obtain the anatomic geometry and bone densities. Bone was modeled by linear tetrahedral elements that were assigned non-homogeneous, isotropic, linear elastic material properties based on the QCT data and reported density-modulus relationships [1,2]. A baseline implanted femur model was generated with the standard length titanium alloy Omnifit femoral prosthesis.

To examine the effects of stem length, five additional implanted femur models with shortened versions of the Omnifit (65%, 55%, 45%, 35%, and 25% of original length) were also developed (Figure 1). Based on these results, additional modifications were made to the medial-lateral geometry for the shortened 35% and 45% Omnifit designs, which included increased lateral fill (LF) and straightening of the medial geometry (MS). Four FE models with modified medial-lateral geometry were included in our analysis (Figure 1). Frictional sliding (μ=0.3) at the bone-implant interface was assumed for all the implanted models to represent the short-term conditions. Hip and muscle forces were applied to simulate loads during heel strike and 45% of gait, and stair climbing [3]. The short-term stability of the various stem designs was evaluated by computing the relative motion at the bone-implant interface. The periprosthetic bone strains (von Mises - effective) were also compared to assess the bone loading patterns. For illustrative purposes, only results for the 45% gait loading are shown here.

RESULTS: In general, as stem length decreased to 25% of the original Omnifit length, the relative motion at the bone-implant interface increased (Figure 2). The peak motion values for L06 to L02 stems increased from 157 to 277 μm, while the proportion of implant surface that exceeded 150 μm [4] increased from 0% to 15%. Under 45% gait load, the L03-LF design (91%) had a smaller proportion of implant surface that did not exceed 150 μm compared to the L03 design (94%), but the actual surface area that was conducive for bone ingrowth was approximately 14% greater for the L03-LF stem. On the other hand, the L03 stems with the straight medial geometry resulted in greater peak relative motions and greater proportion of implant surface that exceeded 150 μm.

The effective bone strain in the proximal femur increased as stem length decreased (Figure 3). The addition of the lateral fill reduced the loading through the stem tip for the L03 and L04 designs, while the straightening of the medial geometry (L03-LF/MS and L03-MS) increased strain shielding around the medial calcar.

DISCUSSION: Our study shows that alterations to the length and medial-lateral geometry of a femoral stem can influence interface relative motion and proximal bone remodeling. As stem length decreased, the stability of the implant was not substantially affected until it reached approximately 35% of the original Omnifit length. The shorter implants were less likely to experience beam bending and the proximal femur was more likely to experience more physiologic bone loading. Increasing lateral fill improved implant stability by providing more surface area over which bone ingrowth could occur, and also improved bone loading by minimizing loading through the distal stem tip. On the other hand, a straight medial geometry to the L03 stem reduced the conformity with the medial calcar, and negatively impacted bone loading and bone-implant relative motion. The change in medial geometry also dominated the behavior over the change in lateral fill (L03-LF/MS). The effects of stem length and medial-lateral geometry, as suggested by the FE results, will likely translate to differences in short-term stability and fixation of the short stem designs. Further, these data suggest that a short stem may be feasible from a biomechanical perspective. Further research will be needed to confirm these findings.


Figure 1. Shortened versions of the Omnifit and modified medial-lateral geometry for the L03 and L04 versions of the Omnifit (modifications shown by the red edges; LF-lateral fill; MS-straight medial geometry).

Figure 2. Bone-implant interface relative motion under 45% gait load (anterior face - left, posterior face - right).

Figure 3. Proximal femoral bone strain (effective) under 45% gait load.