Introduction: Proximally HA-coated femoral components have shown excellent clinical outcomes with durable implant fixation and protection against endosteal migration of wear debris [1, 2]. Radiographic follow-up of these hips have demonstrated evidence of cancellous condensation and cortical thickening around the midstem region where the stem transitions from coated to uncoated [2], which provide secondary stabilization around the midstem [3]. To prevent midstem fixation and promote proximal load transmission, one theoretical solution would be to shorten the stem and polish the uncoated distal portion [3]. A short-term follow-up of patients with this proposed stem solution showed improved proximal fixation compared to patients with the historical stem (Omnifit, Stryker). However, the incidence of pain in these patients was also higher.

The objectives of the current study were to: 1) examine the biomechanical effects of stem length and distal finish on a proximal HA-coated stem using computational methods; and 2) compare the computational results with radiographic and clinical outcomes.

Materials and Methods: 3-D finite element (FE) models of the proximal femur from a 45-year-old female donor (ScienceCare Anatomical, Phoenix, AZ) was developed (IRB approved). Clinical CT was taken at an in-plane resolution of 0.781 mm with contiguous 1 mm thick slices to obtain the anatomic geometry. Bone was modeled by linear brick elements that were assigned non-homogeneous, isotropic, linear elastic material properties based on the QCT data and reported density-modulus relationships. Two finite element models of the titanium alloy Omnifit-HA femoral prosthesis (Stryker) were developed: a historical design ("long") and a short design ("short"). The short stem was approximately 2.5 cm shorter than the long stem with an approximately 30% reduction in HA-coated surface area. The distal portion of the short stem was also polished (μ=0) instead of matte (μ=0.3). The proximal HA-coated areas were assumed to be fully bonded to the bone. Corresponding natural femur models were also generated.

Hip and muscle forces were applied to simulate loads during heel strike of gait [4]. Stress and relative motion at the bone-implant interface was compared for the long and short stem femurs. Bone remodeling signal was determined by comparing the strain energy density in the periprosthetic bone for the implanted femur and natural femur [5].

Results: Bone remodeling, as predicted by the long stem model, was consistent with previous clinical and computational studies [2, 3, 4]. The short stem design resulted in less proximal bone resorption than the long stem (Fig. 1). While the peak interface stresses were greater for the long stem design, the short stem design experienced moderately high interface stresses over a larger surface area (Fig. 2). In addition, the maximum relative motion at the distal bone-implant interface was approximately doubled for the short stem compared to the long stem during peak gait loading (Fig. 2).

Discussion: Our study shows that femoral stem length and distal stem polishing can influence proximal bone remodeling and interface relative motion. Our findings are consistent with a previous clinical study of the short and long stem designs [3] where short stem patients achieved significantly higher BMD in the proximal femur (Gruen zone 7). Our study also predicts higher BMD in the proximal femur, however in Gruen zones 1 and 2.

Further, the clinical findings indicated that a greater proportion of the patients in the short stem group experienced pain compared to the long stem group (50% vs. 24%) at six months follow-up. It is notable that although the difference in pain incidence between the two groups decreased at 2 years, the short stem group still experienced 20% more pain. As suggested by the FE results, the difference in pain incidence was possibly due to decreased initial instability and larger interface relative motions produced by the short stem. Also, the short stem may not promote beam bending due to its reduced length, but instead may generate stem toggling. The difference in pain incidence may also be related to the relative location of the stem tip and the bone against which it rests. The stem tip for the short stem design rests against less stiff bone in the proximal region and provides less bony support than the stiffer cortex that is adjacent to the long stem tip. Longer-term follow-up of these patients may provide more insight into the clinical performance of the short stem design.

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References: