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Partial Stem-Bone Contact Area Significantly Reduces Stem Stability

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PARTIAL STEM-BONE CONTACT AREA SIGNIFICANTLY REDUCES STEM STABILITY

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INTRODUCTION:
Cementless femoral implants rely on the limitation of relative motion between the cortical bone and the implant surface, often called micromotion, for implant stability [1,2]. Micromotion may be limited by providing stem-bone interference, or press-fit, at the time of implantation of a femoral stem. Such a design should, in theory, increase frictional resistance to micromotion due to stem roughness and increased contact pressure. Previous studies that investigated stem push-out stability have assumed circular intramedullary canal, i.e. 100% contact area, and elastic bone properties. However, the intramedullary canal is often irregularly shaped, especially in younger individuals (3), resulting in reduced stem-bone contact area. Additionally, bone viscoelastic behavior was shown to significantly reduce pushout load (4). Therefore, the objective of this study was to evaluate the effect of an irregular shaped intramedullary canal on initial diaphyseal fixation (i.e. push-out load). It was hypothesized that decreased stem-bone contact area would result in a significantly reduced stem push-out load and that the pushout load would be further reduced due to bone viscoelastic behavior. Stem fixation was analyzed using a three-dimensional finite element model and was evaluated by stem pushout load 24 hours after stem implantation.

METHODS:
The cross-section of the femoral bone intramedullary canal was assumed to be elliptical (Figure 1). 3D solid 8 node linear brick elements with reduced integration were used for both the bone and the stem for the finite element analysis using ABAQUS (Pawtucket, RI). The stem was modeled as a cobalt-chromium alloy with isotropic and homogeneous properties, where the modulus of elasticity was 210 GPa and Poisson's ratio was 0.3. The cortical bone was assumed to be transversely isotropic (5) and viscoelastic (6). A distributed load was applied to the top of the stem as a uniform pressure. The bottom cross-section of nodes was prevented from moving axially and radially. The friction for the press-fit was based upon the classic Coulomb dry friction model [7]. Three different values of friction coefficient, μ, were used in this study: μ =0.15 was selected to represent well-lubricated friction between the cortical bone and the implant; μ =0.40 was selected to reflect poor lubrication at the stem-bone interface [8,9]; μ =1.0 was selected to represent the friction between bead porous-coated titanium plates and human cancellous bone [10]. The analysis was split into three steps: resolution of the interference, and application of the load with elastic response and application of the load with viscoelastic response. The Elliptical Bone Model made if possible to run the input file for different nominal interference values, which were translated into contact area between the stem and canal wall. Percentage of contact area were then calculated by dividing by the value if the canal cross-section had been circular

RESULTS:
Stem pushout load had a nonlinear relationship with percent contact area (Figure 2); pushout load increased with contact area asymptotically and increased with coefficient of friction. The pushout load is also shown plotted against stem-bone interference and is shown compared with results of a circular intramedullary canal (Fig. 3) (4). The data shows that there is a significant reduction in pushout load when the canal is elliptical and contact area is reduced for all values of coefficient of friction. As shown previously, coefficient of friction significantly affects the pushout load; pushout load decreases as the canal is more lubricated.

DISCUSSION:
Based upon the results of this study, reduced stem-bone contact area has a diminishing effect upon the pushout load for distally press-fit femoral implants. The pushout load of a stem in a circular canal is nearly six times greater than the pushout load of a stem in the elliptical canal geometry of the current study. The pushout load will most likely vary significantly as the elliptical canal geometry changes. Additional reaming yields a more circular canal and additional contact area which should increase pushout load as demonstrated here. However, it does so at the expense of cortical bone thickness. The increase in pushout load with contact area can be attributed to an increase in contact pressure at the stem-bone interface. Contact pressure in combination with friction is responsible for restricting initial micromotion and aiding in the development of long term stability. Results also showed that cortical bone viscoelastic behavior reduces pushout load below that obtained from elastic response alone and that the pushout load is enhanced by increasing the static coefficient of friction between the implant and the bone. Clinically, the results of this study suggest that reaming to increase contact area, at the expense of cortical bone thickness, should be considered for long term stability.

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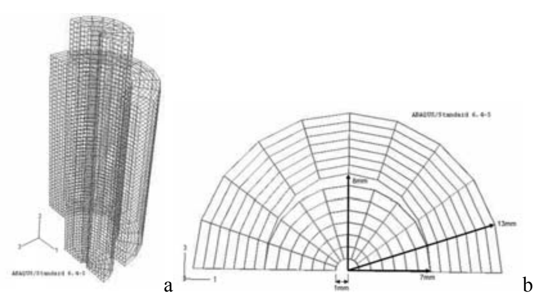

Fig. 1. a) Longitudinal and b) transverse cross-sections (half model shown).

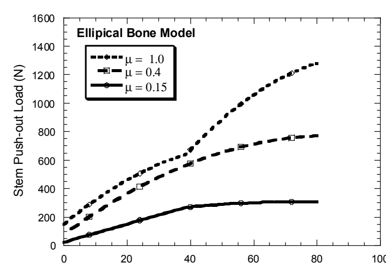

Fig. 2. Stem push-out load vs. contact area for elliptical bone canal.

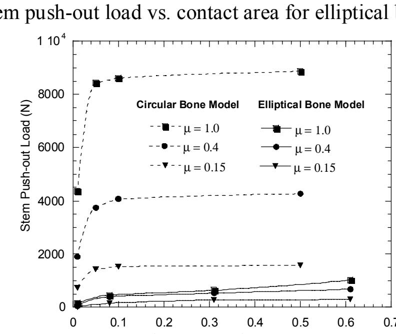

Fig. 3. Stem push-out load vs. stem-bone interference.