In Vitro Assessment of Allowable Bone Loss for Implantation of a Zweymuller Stem for Total Hip Arthroplasty Revision Surgery

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Introduction

Total hip arthroplasty patients typically experience some degree of stress shielding and subsequent bone remodeling during the life of the primary femoral stem. If a patient experiences pain, subsidence of the stem, or stem loosening, a revision surgery is necessary. The purpose of this experiment is to determine, by finite-element modeling and in-vitro testing, what amount of bone loss in the proximal femur is permissible for a Zweymuller stem to be achieve stability.

Methods

The Zweymuller stem will be implanted into a cadaveric femur and tested under cyclic loading and the micromotion will be recorded. The micromotion measurements help to predict the life of the implant. The femur would first be tested with full bone stock, and then the bone would be removed in approximately 1 cm horizontal layers and retested to simulate proximal bone loss, as shown in Figure 1. A simplified 2D model of the femoral stem was created to get a rough estimate of the amount that the stresses would increase following bone loss. It is shown in Figure 2.

The calculations of maximum normal stresses are shown in Figure 3. The shear is assumed to be uniformly distributed along the stem.

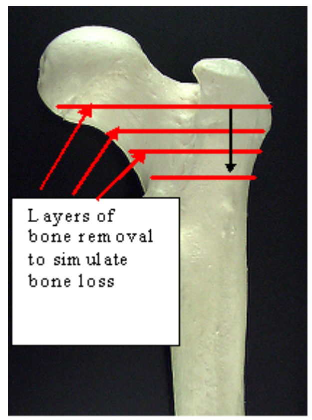


Figure 1: Simulation of Bone Loss

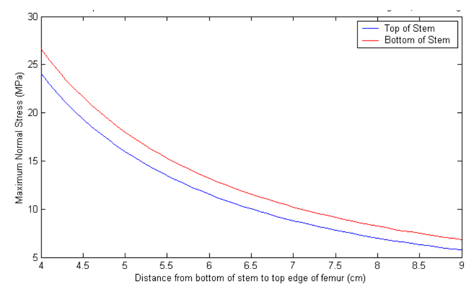
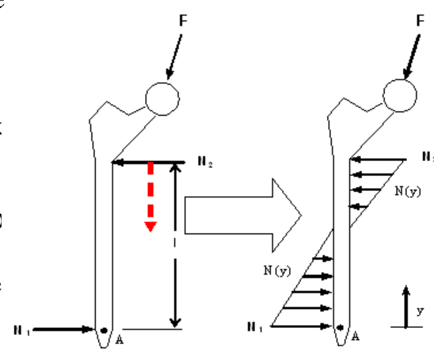


Figure 3: Maximum Normal Compressive Stresses on Femoral Stem Interface with Joint Force at 10 degrees, Stem Length of 12cm.



$$F_{x,\text{point}} = F_{x,\text{distribued}}$$

$$N_1 - N_2 = \int_0^{\ell} N(y)\,dy$$

$$M_{A,\text{point}} = M_{A,\text{distribued}}$$

$$N_2 \ell = -\int_0^{\ell} y N(y)\,dy$$

Solving for N_{1D} and N_{2D} :

$$N_{1D} = \frac{2}{\ell}\left(2N_1 + N_2\right)$$

$$N_{2D} = 6\ell\left(N_1 + N_2\right) - \frac{2}{\ell}\left(2N_1 + N_2\right)$$

$$V_D = \frac{F\cos(\theta)}{2\ell}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^{\ 2}}$$

Figure 2: Simplified 2D Model of Femoral Stem

Results

Using these calculations, the relationship between bone loss and maximum normal stresses can be seen in Figure 3.

The dramatic increases in stress with only a few centimeters of bone loss with an angle of 10 degrees suggest that a well-designed FE analysis as well as an in-vitro experiment could be very beneficial in determining the feasibility of using an uncemented Zweymuller stem in revision surgery.

Discussion

Crowninshield et. al conducted a finite element analysis of a cemented stem and reported maximum compressive stresses of 10Mpa at the proximal end on the medial side using a joint load of 3000N at an angle of 20 degrees [1].

There are drawbacks to this analysis, like the assumption of distributed shear, the straightness of the stem, and the fact that the model is 2-dimensional. Despite these drawbacks, the model is a reasonable first approximation, and suggests that this experiment will grant surgeons more guidance when performing revision surgeries on total hip replacements in order to better serve their patients.

References

[1] Crowninshield, R.D., Brand, R.A, Johnston, R.C., and Milroy, J.C.: The Effect of Femoral Stem Cross-Sectional Geometry on Cement Stresses in Total Hip Reconstruction: *Clin Orthop Relat Res*. 1980 Jan-Feb; (146):71-7.