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Viscoelastic Effects of Unreamed Intramedullary Nailing

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Introduction

Surgical techniques involving non-reamed bone intramedullary (IM) nail installations present the opportunity for bone-nail interference or "press-fits." These installations may result in bone fractures due to large circumferential stresses/strains in the bone. In addition, other risk factors for iatrogenic fractures include unknown pre-existing fractures [1], increased stress due to the selection of entry hole location [2], and excessive force during insertion [3]. Therefore, the objective of this research was to examine the stresses/strains on bone implanted with an IM nail when bone-implant interference exists. The viscoelastic properties of bone in the circumferential directions [4,5] were added to account for the time-dependant behavior of bone under these loading conditions. It was hypothesized that small interference can result in stresses/strains that would result in bone failure, and that the viscoelastic effect of bone can elevate bone strains above that predicted by elastic analysis resulting in failure at lower interference fit amounts.

Methods

A 3D model of a femur was obtained from the VAKHUM project (http://www.ulb.ac.be/ project/vakhum). This femur was imported into SolidWorks (Concord, MA), and a Smith & Nephew Delta Femoral Nail was implanted into the bone by cutting the femur as specified by the manufacturer and inserting simplified screws. The nail was 12 mm in the shaft diameter, 13 mm in the head section diameter, and 440 mm long. The entry hole diameter was held constant at 13.5 mm, and the diameter of the intramedullary canal was varied.

This model (Figure 1) was imported into ABAQUS/CAE (Providence, RI) for finite element analysis. The nail and screws were specified as stainless steel (E=193.053 GPa, ν=0.33), and the femur was broken into different material properties. The femoral head (E=1.3 GPa, ν=0.3) and proximal bone (E=0.32 GPa, ν=0.3) were modeled to be more dense and less dense, respectively, linearly elastic and isotropic cancellous bone [6]. The femoral shaft was modeled as transversely isotropic (E1=11.5 GPa, E22=11.5 GPa, E33=17 GPa, ν12=0.51, ν13=0.31, ν23=0.31, G12=3.6 GPa, G13=3.3 GPa, G23=3.3 GPa). The fracture region material was specified to have 1% of the stiffness of the cortical bone to simulate an early healing response. The model was fixed at the distal end of the femur to prevent any translation and rotation. A creep power law [4] for transverse viscoelasticity was used to model the time dependant effects of the press-fit.

To simulate different press fits between the nail and the intramedullary canal, the intramedullary canal diameter was examined at 11, 11.25, 11.5, 11.75, and 12 mm which resulted in diametric press-fits (δ) of 1, 0.75, 0.5, 0.25, and 0 mm respectively.

Results

The results of this study showed that bone-nail interference greatly increased the strains in the cortical bone located in the femoral shaft. Figure 2 shows femoral cortical bone strain resulting when the intramedullary nail is 0.0, 0.125 and 0.25 mm larger than the diameter of the intramedullary canal. The circumferential strain increases nonlinearly with the amount of interference between the intramedullary nail and the intramedullary canal. Results also indicated that cortical bone strain increased after 24 hours. The increase was nonlinear with interference. For an interference of just δ=0.125 mm, the post-creep strain exceeded the bone fracture threshold within 24 hours. Though the strain in the bone increased due to creep, stress in the nail and femur decreased by means of stress relaxation as shown in Figure 3.

Discussion

Bone fracture results from high circumferential strain resulting from "press-fit" of hip prostheses [7]. Results presented here indicate that interference of an IM nail as low as 0.125 mm would cause fracturing of cortical bone. These results are similar but lower than experimental results [7], which found that cracking can occur in cortical bone under a 0.35 mm press fit. However, the strains in the current study are elevated to some extent beyond physiological levels due to the ideal (i.e. complete conforming surfaces between the bone and implant) press-fit conditions used in the model. The anatomical intramedullary canal is irregular and varies in size throughout the canal. Non-uniform intramedullary surfaces reduce the degree of press-fit compared to ideal conditions. In addition, press-fit is reduced during installation by "plowing" that occurs as the implant enters the canal. Both shape and plowing effects if included in this analysis would reduce strains to some extent and increase the amount of bone-nail interference prior to predicted failure.

The effect of creep on cortical bone strain was found to significantly increase the likelihood of iatrogenic fracture. This effect was intensified at higher press fit values because the amount of strain due to creep increased nonlinearly. The results of this research support the reaming of the intramedullary canal before the insertion of an intramedullary nail. By doing this the surgeon can either reduce or eliminate the amount of press fit which in turn will reduce the likelihood of iatrogenic fractures being introduced into the femoral shaft.

References

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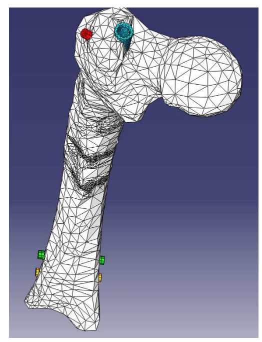

Figure 1. Finite element model of implanted intramedullary nail

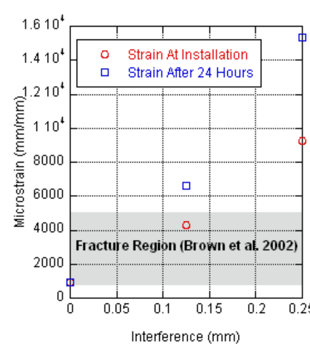

Figure 2. Cortical bone circumferential strain due to press-fit of nail

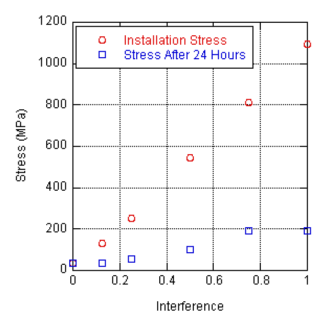

Figure 3. Stress relaxation of the intramedullary canal