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BIOMECHANICAL OPTIMIZATION OF THE ANGLE AND POSITION FOR SURGICAL IMPLANTATION OF THE DEPUY SILENT HIP IMPLANT

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INTRODUCTION

Total hip replacements (THR) are becoming increasingly popular in the younger, more active population. However, survivorship at 10 years of hip implants in young patients has been shown to be low, primarily due to implant loosening, which requires that the patient undergo revision surgery [1]. Conservative implants have consequently been developed to preserve more healthy bone stock for future revision procedures, and improve the physiological loading of the hip joint [2-4].

Stemless uncemented implants are becoming increasingly popular, as they require a less invasive surgical approach and are said to provide nearly physiologic loading [5-7]. The Silent Hip (DePuy International Ltd., Leeds, UK) is a new conservative implant with a straight short stem for metaphyseal fixation. This implant was designed specifically for the younger population, and features a high neck cut for maximal bone preservation [8]. However, there is no prior biomechanical research on this implant. In particular, there is no research to support one surgical implant orientation over another. The purpose of this study is therefore to determine the orientation of the Silent Hip implant within the proximal femur that will confer the greatest degree of biomechanical stability.

METHODS

General Method

Biomechanical experiments were performed on an implanted Silent Hip under subclinical level loads in order to validate a corresponding Finite Element Model (FEM). This model was then subjected to subclinical level loads and the resultant stress distributions were compared to those of an intact femur with the purpose of minimizing the percent difference between the models. Those orientations which produced the lowest percent differences were defined as the optimal orientations, as they exhibited stress distributions most similar to an intact femur. This validation approach has been successfully used previously by the authors for orthopaedic biomechanics applications [9, 10].

Hip Implant Specifications

The Silent Hip (DePuy International Ltd., Leeds, UK) is a straight short stem hip implant with a tapered profile for implantation in the femoral neck (Figure 1). It is composed of a Ti 6Al-4V alloy, and utilizes the DuoFix™ fixation system, which consists of a layer of hydroxyapatite coated beads to promote bony ingrowth. A 12/14 cone enables the Silent Hip to be combined with either a ceramic or metal head, for optimal choice of friction couple. The implant selected for use in this study had a stem diameter of 22mm, with a stem length of 50mm. It was fitted to a 36mm diameter ceramic femoral head.

Figure 1: DePuy Silent Hip with ceramic femoral head and acetabulum

Biomechanical Testing

The Silent Hip was implanted into 21 large, left, fourth-generation composite femurs (Model #3406, Pacific Research Laboratories, Vashon, WA, USA) in one of three maximum angles, three maximum positions, or neutral, with a sample size of three for each. Specifically, the maximum orientations were defined from a neutral orientation as 10° varus, 10° valgus, 10° anteversion, 5mm inferior, 3mm anterior, and 3mm posterior. These angles and positions were selected based on the respective implant and femur sizes, and discussions with an experienced orthopaedic surgeon. The stem was implanted using the Brainlab Software-Guided Hip Navigation System (Brainlab, Feldkirchen, Germany) to ensure accurate placement.

The distal condyles of the femurs were augmented using a bandsaw, and their distal ends were potted in cement-filled steel cubes under 7° of adduction. The femurs were then instrumented with two 350Ω linear pattern strain gages (Model CEA-06-125UW-350, Vishay Measurements Group, Raleigh, NC, USA) along their medial and lateral surfaces, and two proximally located 350Ω general-purpose rosette gages (Model CEA-125UY-350, Vishay Measurements Group, Raleigh, NC, USA).

The prepared femurs were located in an Instron 8874 tester (Instron, Norwood, MA, USA) at 0° initially, to simulate the single-leg stance phase of walking. They were then axially loaded with a subclinical load of 1000N, and the strains were recorded. The femurs were then moved to 20° of sagittal plane hip flexion to simulate the heel strike condition, followed by 15° of hip extension for the toe-off phase. Each femur was loaded three times per gait cycle condition. Three intact femurs were also instrumented and tested to provide a baseline strain distribution.

Hip Implant CAD Models and Assemblies

SolidWorks 2014 (Dassault Systèmes SolidWorks Corporation, Waltham, MA, USA) computer-aided design (CAD) software was utilized to generate solid models of the Silent Hip and ceramic femoral head. A previously created CAD model of the artificial femur was used as the femur model [11].

The Silent Hip, femoral head and synthetic femur were assembled using SolidWorks 2014. The head of the intact femur was initially resected at a predetermined location, following which a separate assembly was generated for each of the 7 predefined stem orientations within the femur (Figure 2). These assemblies were then exported into ANSYS Workbench 15.0 (ANSYS, Inc., Canonsburg, PA, USA) for finite element analysis (FEA).

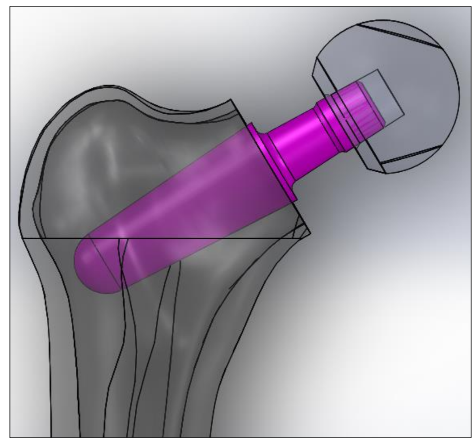

Figure 2: Example of the neutral orientation assembly of the Silent Hip within the femur model, assembled using SolidWorks 2014

Finite Element Method

Material properties, contact definitions, and analysis settings were defined in ANSYS Workbench 15.0. Manufacturer supplied physical properties were used for the titanium alloy stem (E=113.8GPa, v=0.342), ceramic head (E=358GPa, v=0.24), and cortical (E=16GPa, v=0.26) and cancellous (E=155MPa, v=0.3) regions of the femur. For each orientation assembly, a Boolean operation was used to subtract the stem volume from the cancellous bone. Interactions between the stem and head construct, and the stem and cancellous bone, were set to bonded contact to simulate press-fits with assumed full bony integration of the stem. A force of 1000N was applied to the superior surface of the head at a 7° adduction angle. The distal condyles of the femur model were set as a fixed support to simulate the potted condition of the femurs experimentally.

A preliminary mesh was developed for use in each orientation assembly (Figure 3). It consisted of 386603 meshed tetrahedral elements, which have been previously shown to be optimal when modelling femur geometry [12]. Regions of interest, such as the proximal femur and stem-femur interface, were refined using spheres of influence and refinements. Stress maps of the femur were generated for each orientation, and maximum stresses were compared to an intact femur.

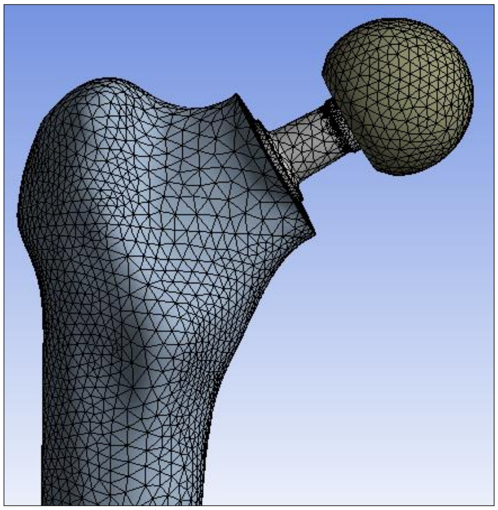

Figure 3: Preliminary mesh of the neutral orientation

RESULTS

Preliminary results of the single-leg stance loading situation indicate that an intact femur loads primarily around the femoral neck region and along the proximal medial shaft, where stress distributions were found to be highest (Figure 4). The implanted femurs were found to share a similar loading pattern, with three areas of maximum stress: the posterior neck (1), anterior neck (2) and proximal medial shaft (3) (Figure 5). When compared to the intact femur, the stresses developed in the implanted femurs in each of these zones were found to be higher, and hence those orientations that reduce maximum stress would yield a stress distribution most similar to an intact femur. To determine these optimal orientations, the percent difference was calculated between the maximum stresses developed at each zone in the intact femur compared to those in each implant orientation (Table 1).

For Zone 1, the orientation that yielded the lowest percent difference was the anterior implant position, while the lowest percent difference in Zone 2 was seen in the posterior implant position, followed closely by the neutral orientation. A valgus angle generated the lowest percent difference from an intact femur in Zone 3, with the neutral and posterior orientations also yielding low results.

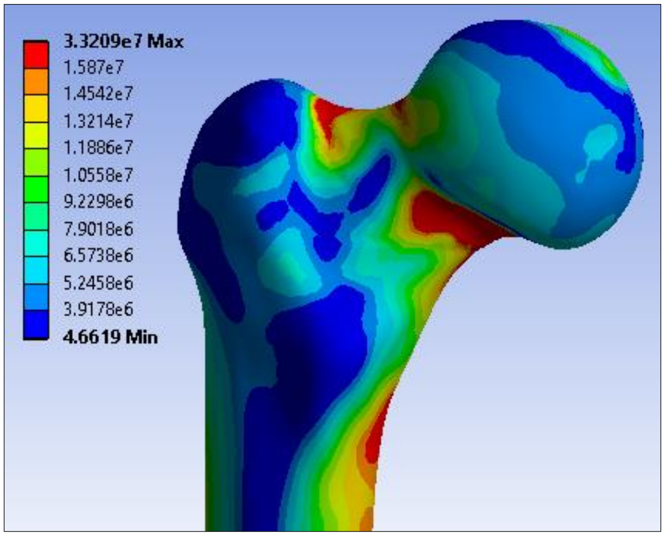

Figure 4: Coronal plane view of the Von Mises stress distribution (Pa) in an intact femur

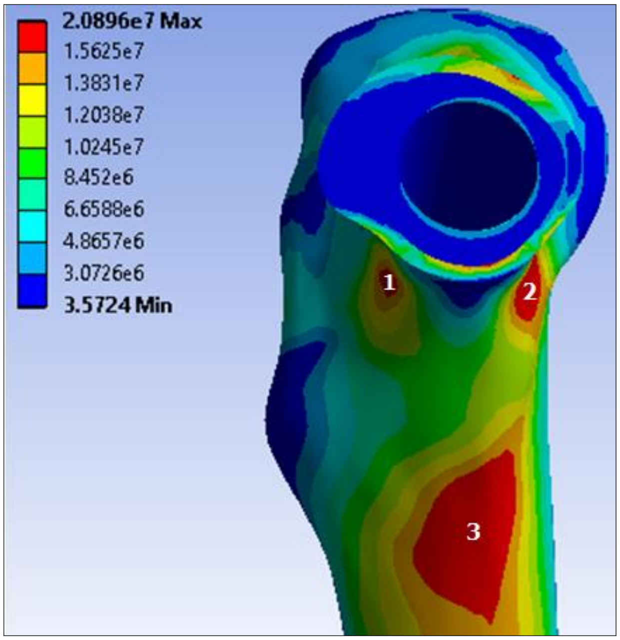

Figure 5: Sagittal plane view of the Von Mises stress distribution (Pa) of a neutrally implanted femur with the 3 zones of max stress indicated

Table 1: Percent difference between the maximum stresses developed in each zone of the intact femur compared to those of each implant orientation

Implant Orientation	***Zone 1 (%)***	***Zone 2 (%)***	***Zone 3 (%)***
Neutral	43.4	4.9	4.5
Varus	44.1	11.8	7.7
Valgus	34.3	16.4	2.3
Anteversion	34.5	30.7	9.8
Inferior	54.7	14.4	7.6
Anterior	29.6	25.0	7.1
Posterior	57.4	-4.5	4.1

DISCUSSION

This study endeavoured to determine the optimal implant orientation for the Silent Hip within the proximal femur. Preliminary results showed that a valgus orientation is best when aiming to minimize the stresses developed in the proximal medial femur. A posterior or neutral orientation was determined to be optimal when considering physiologic stresses developed in the anterior neck of the femur, while an anterior position generates the lowest stresses on the posterior neck. These results are comparable to previous studies on implant orientation within the femur, which also determined valgus to be a clinically desirable orientation [13, 14].

These results have implications for the surgical placement of the Silent Hip within the proximal femur. To yield a stress distribution most similar to an intact femur, the Silent Hip should be implanted in a posterior and valgus orientation. However, if lower posterior femoral neck stresses are desired given specific patient requirements, then an anterior position should be selected.

It should be noted that biomechanical testing must still be completed to verify the finite element models; however, the results are not expected to vary significantly, as this procedure has been previously verified [9, 10]. The current study is also limited in that it only examines the maximum implant orientations in a single-leg stance loading scenario. Future work will examine the range of potential implant orientations within the proximal femur, in addition to the loads expected in the heel-strike and toe-off phases of walking. This will enable determination of the optimal 3D orientation of the Silent Hip within the femur.

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