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The Effect of Press Fit on Osseointegration of Acetabular Cup

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***Abstract*—** The primary cause of Total Hip Replacement (THR) failure for younger patients is aseptic loosening. This complication is twice more likely to happen in acetabular cup than in femoral stem. Excessive micromotion between bone and implant will cause loosening and it depends in patient activities, age and bone. In this project, the effects of different metal back design of press fit on osseointegration of the acetabular cup are carried out. Commercial acetabular cup designs, namely Spiked, Superfix and Quadrafix are modelled and analyzed using commercial finite element software. The diameter of acetabular cup is based on the diameter of acetabular rim to make sure the component fit to the acetabular cavity. A new design of acetabular cup are proposed and analyzed to get better osseointegration between the bones and implant interface. Results shows that the proposed acetabular cup designs are more stable compared to other designs with respect to stress and displacement aspects.

***Keywords*—**Finite element analysis, total hip replacement, acetabular cup, loosening.

I. Introduction

TOTAL Hip Replacement (THR) is an effective procedure in improving the quality of life for millions of patients worldwide especially who experienced osteoarthritis. Ironically, it has become the victim of its own success. Originally intended for old people with age 50 years old and above, THR is increasingly used on younger person, nowadays. The younger and active person requires a prosthesis that can last longer and endure an active lifestyle without the need of revision. According to Wroblewski (2002), design goal have advanced from simply lighting pain and uncomforted for the elderly patients, to returning young active patients to more physically demanding lifestyle as well as sport activities [1]. The primary cause of THR failure for younger patients is aseptic loosening especially at the acetabular cup. The cause of aseptic loosening is still clearly debated, but the final explanation might be sought in the combination of multiple etiologic factors including, prosthesis stiffness, particulate reaction and stress shielding.

In this study, four different model of acetabular cup are used to analyze the micromotion and stress of press fit hip replacement surgery on acetabular cavity. The models namely, quadrafix, spiked, superfix and proposed model are analyzed using a commercial finite element simulation together with an in-house experimentally validated micromotion algorithm. The purpose of this study is to investigate the effect of different metal back design of press fit on osseointegration of the acetabular cup.

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II. Finite Element Model

Finite Element model of the pelvis bone was reconstructed from a normal healthy bone data set. The geometry of pelvis bone is based on computed tomography (CT) scan data. A good visualization of the details on the CT scan data could only be achieved by defining the appropriate threshold for the cortical bone and cancellous bone. Finite element model of human pelvis which consist of three part namely, ilium, ischium and pubic, is illustrated in Fig. 1 while different type of acetabular cup in Fig. 2. The diameter of acetabular cup is depending on diameter of patient acetabulum cavity. Due to the reason, selection of suitable acetabular cup design and diameter must be selected before a surgery can be proceed. The prosthesis, comprising a titanium hemispherical metal shell inserted with 450 inclinations and 250 anteversion.

Size of triangular mesh element of bone must be almost the same as the implant as well to make sure nodes between two models were connected each others. The surface mesh of both the implant and the bone were used for creating bone-implant contact.

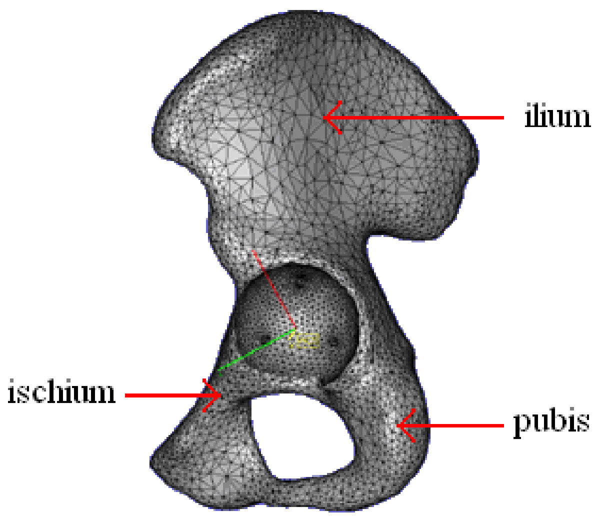

Fig. 1 3-D model of human pelvis bone

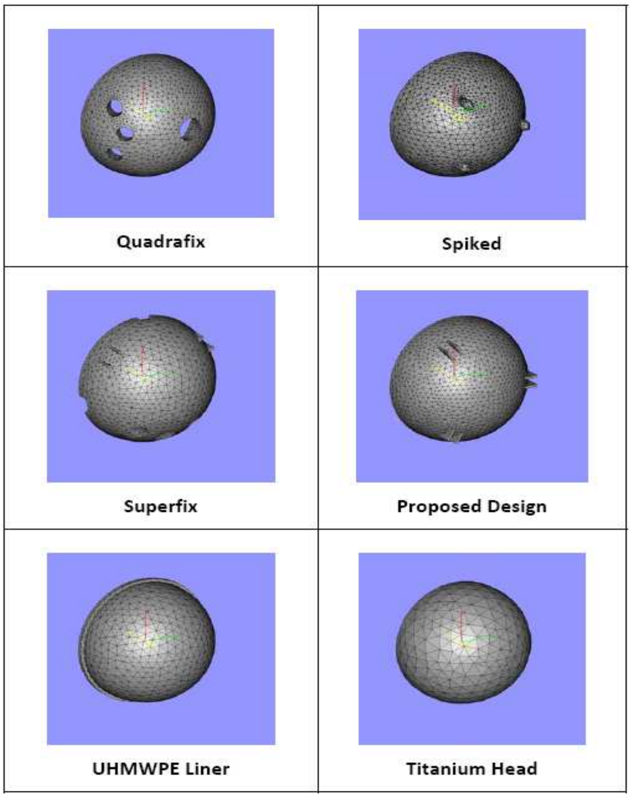

Fig. 2 Different designs of acetabular component

A. Material Properties

The bone, cup, liner and head were merged together in solid geometry to perform the analysis. Location for each component was identified in Fig. 2. The material properties of all models were assumed to be linear elastic, homogeneous and isotropic, as shown in TABLE I.

TABLE I
MATERIAL PROPERTIES FOR FINITE ELEMENT ANALYSIS MODELS

Component	Modulus of Elasticity (MPa)	Poisson's Ratio	Mass Density (kg/m^3)
Pelvis Bone	16,200	0.36	1
Titanium Cup	110,000	0.30	4,500
UHMWPE Liner	800	0.45	941
Titanium Head	110,000	0.30	4,500

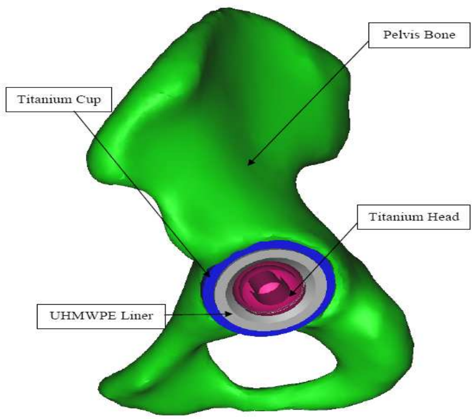

Fig. 3 Merging or position of finite element models after assigning their material properties

B. Interface Connection

Each surface area had a different element shape in the system. An assumption was made that a perfect fit applied between the outer surface of the implant and the inner bone. The perfect match at the interface was done using the surface mesh of the aligned acetabular cup implant as a 'cut-out' for the respected hip model [2]. A friction coefficient value of interface connection for each component was also considered, as shown in TABLE II.

TABLE II
FRICTION COEFFICIENT VALUE OF EACH CONTACT BODY

Component	Friction Coefficient
Pelvis Bone	0.61
Titanium Cup	0.40
UHMWPE Liner	0.15
Titanium Head	0.40

C. Loading and Boundary Conditions

Loads were applied on the acetabular system that simulating a standing still condition. The resultant force acts normal downwards onto the titanium head. The load on the head is approximately four times of average weight (68kg) and distributed evenly through both hips. The reason for this larger load was to simulate a worst case scenario. The corresponding loads for all models were 1112N and applied to the titanium head surface.

The constraint applied on the model at the sacro-illiac joint and pubic symphysis selected area of the pelvis bone. Fixed displacement with zero degree of freedom was considered in x, y and z axis as well as no movement in each constraint nodes. The constraint conditions were illustrated in Fig. 4.

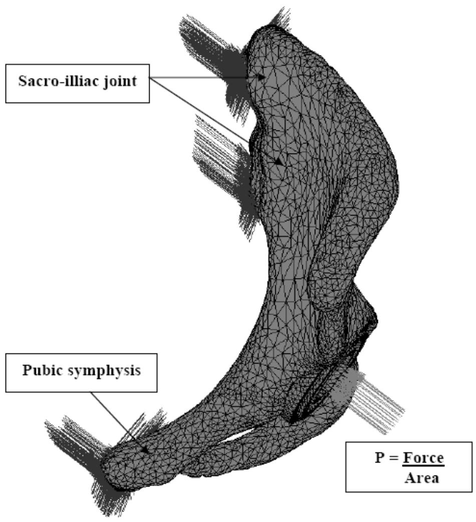

Fig. 4 The finite element model showing the nodes with fixed displacement and face load acting on acetabular system

III. RESULT AND DISCUSSION

Generic finite element models of a pelvis bone and acetabular system were developed in order to test various aspects of resurfacing components and hip replacement. In this project, one such test was carried out to show the effect of thin acetabular cups (such as those used for surgery procedure) once they have been press fit into the pelvis bone. The deformation of the cup and the stresses within the bone are analysed to characterize the stability of acetabular metal back features.

Paired nodes across the interface are identified and relative micromotion throughout the cycle load phase (0 – 50%) calculated. Values from a series of nodal pairs covering the whole interface are interpolated as a function of two variables that is linear and homogeneous in both independently. Beside that, results for nodal pairs are presented as if viewed from medial-lateral (M-L), superior-inferior (S-I), anterior-posterior (A-P), and giving the cavity a circular appearance.

A. Micromotion of Bone-Cup Interface

Fig. 5 shows the total micromotions during the simulated load cycle reach the highest values at 1.64 µm for quadrafix acetabular cup design. Micromotions are highest at the pole and the lowest at the periphery. The value of micromotion in proposed design models is 1.10 µm, considered less in comparison to 3 other different models (quadrafix, superfix, spiked). In comparison to the metal back design cases, magnitudes of micromotions in spiked, superfix and proposed design are generally lower that is less than 1.5 µm. Based on Soballe (1993) studies, osseointegration was observed in the presence of micro-movements averaging 30 µm, while micro-movements larger than 150 µm were reported to compromise or inhibit the biological integration of the prosthesis [3].

The spiked model, where the spiked located at the cavity of pelvis bone, shown greater achievement in stability, where this model was successfully reduce the relative micromotion about 0.2 µm compared to quadrafix (hole metal back) design. The superfix and propose design models also show the improvement on stability where the both models almost model reduce the maximum micromotion exceeds 1.13 µm. From this result, quadrafix design is important in acetabular cup to achieve stability by adding something like a holder (spiked and screw), to reduce movement of acetabular cup after implant.

Besides, it was found that increases in gait speed not only cause an increase in the general levels of micromotion but also cause the maximum values to occur earlier in the cycle. For example, in Spears (2000) studies, for the slowest mode of gait, the greatest micromotion over 100 µm occurs at toe-off whereas for faster mode gait, micromotion at heel-strike [4]. From this perspective, it was notified that patients' activity will influences the pattern of relative micromotion.

B. Micromotion of Cup-Liner Interface

Fig. 6 shows the relative micromotion at the cup-liner interface for 3 acetabular cups (spiked, quadrafix and proposed design). The superfix model doesn't have liner because the author want to study about different between attached liner and direct contact between cup and head which is metal to metal contact.

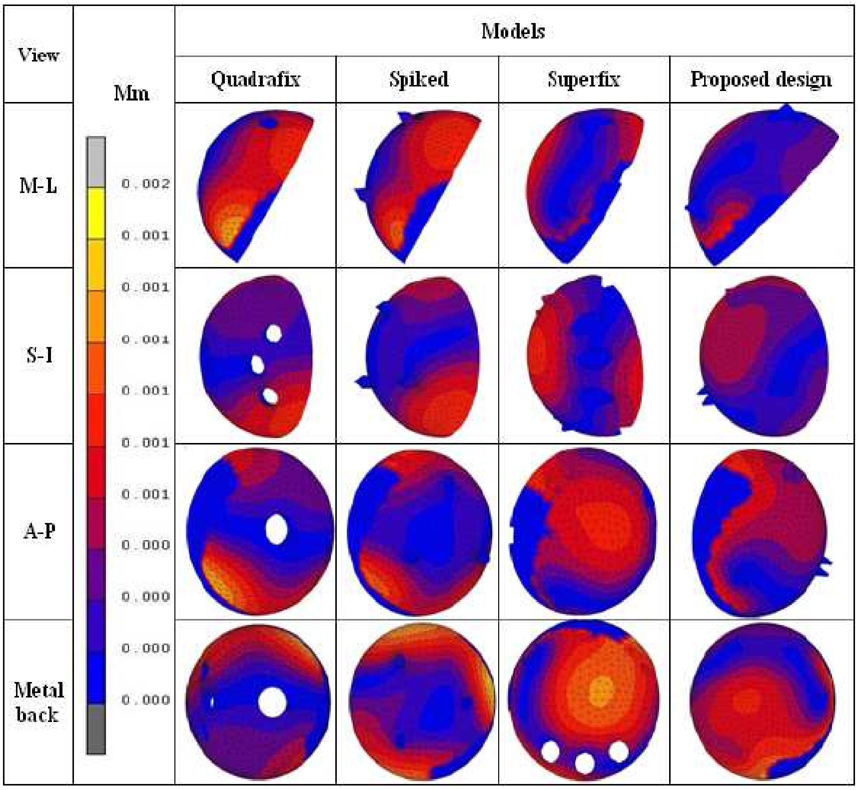

Fig. 5 Micromotion at the bone-cup interface of each model at different views

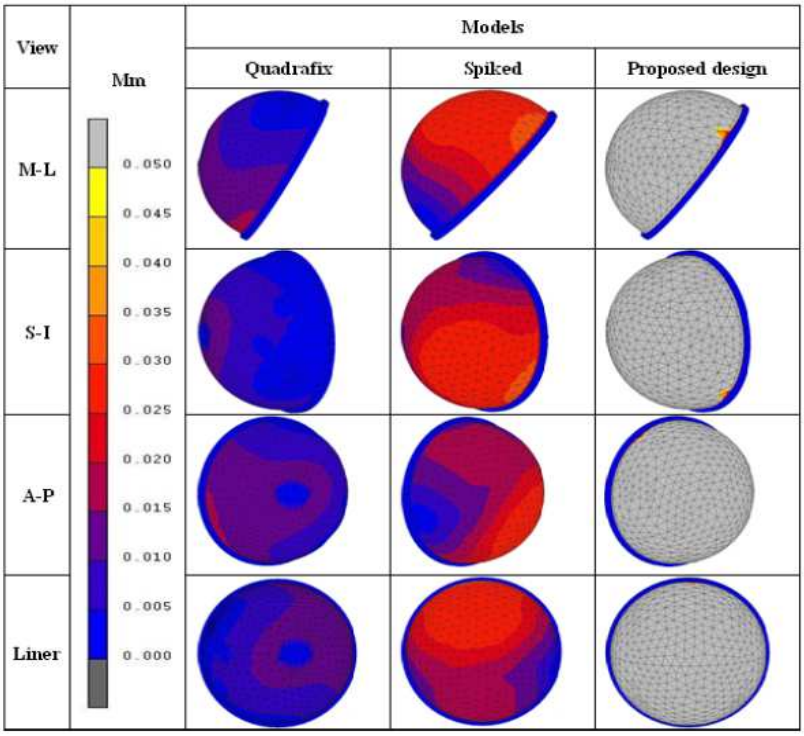

Fig. 6 Micromotion of the cup-liner interface of each model at different views

Liner in quadrafix acetabular system having less relative micromotion which is 16.18 μm compared other two designs (spiked and proposed design). The result shows that the hole metal back design has improve the stability at liner-cup interface as well. It's due to interlocking mechanism such as hole that makes the liner less move. Liner relative micromotion has relation with wear after repeated loading occur at one particular position which define as fatigue loading.

Multiple rotation and motion occur in the hip during gait, such as internal-external rotation, flexion-extension and abduction-adduction motions will lead through wear on liner surface. Previous studies, using different gait data showed that most relative micromotions liner accruing in the superior-posterior quadrant [5]. The result obtains, in term of magnitude and distribution of micromotion are very similar to this project. This emphasizes the specificity of individual gait cycles and how important these differences are to characterize the tribology of the artificial hip. The important of a 3D analysis of relative micromotion in the resulting analyzed wear between two contact surfaces. Varying amounts of relative liner micromotion for different patients are an important factor in assessing the wear and heat generation in the artificial hip joint [6].

C. *Micromotion of Liner-Head Interface*

Fig. 7 shows the relative micromotion at the liner-head interface for all four models. Based on the result, Quadrafix and Superfix models less movement which is only 35 μm. Other two design, perform a very large movement at the pole of contact surface area. From the diagram, Superfix model show highest stability of titanium head because this models have large diameter compare other three design and it's do not have liner in acetabular system (metal to metal contact).

Material selection and liner design are found to be an important factor to reduce micromotion between contact surfaces. Furthermore, by increasing the constraint at the back surface of the liner, due to secure locking mechanism can be expected to decrease backside abrasive wear.

IV. Conclusion

The micromotion is intrinsically dependent and as such, the used of complex computational models can contribute significantly to development of better metal back features design for artificial hip joint. This computational model has been developed with the objective of obtaining the effect of press fit on osseointegration of acetabular cup which would easily evaluate new material combination, geometries and individual load cases associated with specific activities.

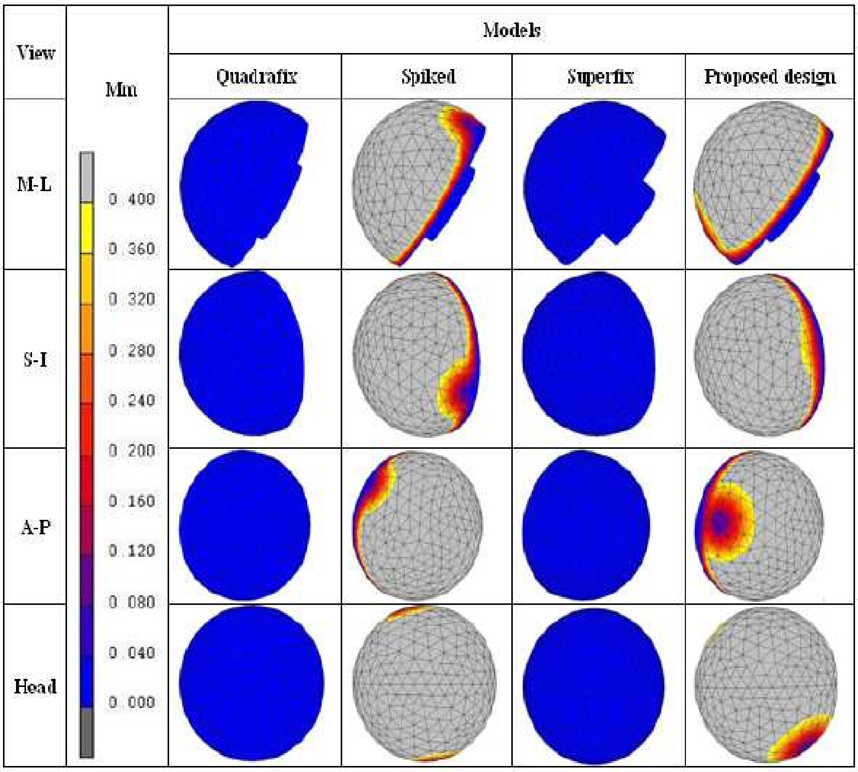

Fig. 7 Micromotion of the liner-head interface of each model at different views

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