MODELING OF A NEW DESIGN OF THE ACETABULAR COMPONENT FOR TOTAL REPLACEMENT OF A HIP JOINT

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Abstract: The abstract describes a development of new design of the acetabular component of a hip joint. Development is divided into few parts. At first was verified if it is possible to use finite element method for the modelling of new design of the acetabular component. Afterwards was investigated if modification of a non-weight bearing area causes more uniform contact stress distribution. Next part of the development is focused on optimalization of new shapes of the acetabular components and determination of distribution contact pressures for these new cups.

Introduction

On already used total replacements of a hip joint take some negative events that influence endurance of total replacements. The aim of our effort is development of new design of the acetabular component of a total replacement of a hip joint which will minimize or even eliminate these negative events. Finite element method was used for verification of a new design of a hip cup. The contact stress distribution on the acetabular surface was investigated with finite element method. Computing models were evaluated in terms of results of the contact stress distribution on the acetabular surface. We tried to achieve the most uniform contact stress distribution and decrease maximal value of a stress.

Materials and Methods

The point of this technical solution of new hip cup is to design such a shape of the joint surface that will be symmetrical towards the hip joint stress [6]. This shape is designed as the basic mathematical models of the distribution of the contact stress.

Designs of new type of the acetabular component were proceeded from results of the model for calculation of the contact stress distribution in physiognomic hip joint. This model is used for the research non-weigh bearing area of the joint surface. The non-weigh bearing area entails in medial part of the joint surface the most uniform contact stress distribution and movement a maximal stress point inside acetabulum. From many results of mathematical models and experimental measurements, the hip joint resultant force is oriented eccentrically in regard of acetabular hemisphere. This force effects on lateral margin of the acetabulum. The medially located the non-weigh bearing area contributes to the symmetry of the bearing area with regard to the hip joint resultant force. The effect of the uniform contact stress distribution in symmetry of the joint surface with regard hip joint resultant force was used for the design of new acetabular component.

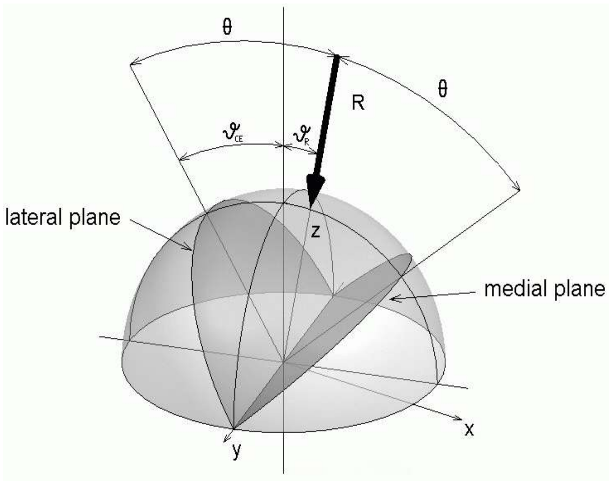

Figure 1: Model with uniform contact stress distribution

Mathematical models of a contact stress distribution [1, 2, 3, 4] was used for a determination of a contact stress distribution with an indirect measuring. Three basic mathematical models were used [5]: The model with uniform contact stress distribution in Figure 1, model with linear descent pressure in plane perpinducular to the hip joint resultant force in Figure 2 and model with the cosine contact stress distribution on the acetabular surface in Figure 3. Mathematical equation describing contact stress distribution on the joint surface was derived for each mathematical model. In terms of these equations were determined contact stress distribution of each model. We compared and analysed these distributions. The model with cosinus contact stress distribution was chosen as suitable for our next work.

Numerical model contact stress distribution in Figure 4 was created in ABAQUS 6.3 software. Model was entered by its geometry, material properties, loading and replacement. Inputs were used type element and boundary conditions. Output was resulatant contact stress distribution. Model is created from ceramic head of the replacement and polyethylen hip cup.

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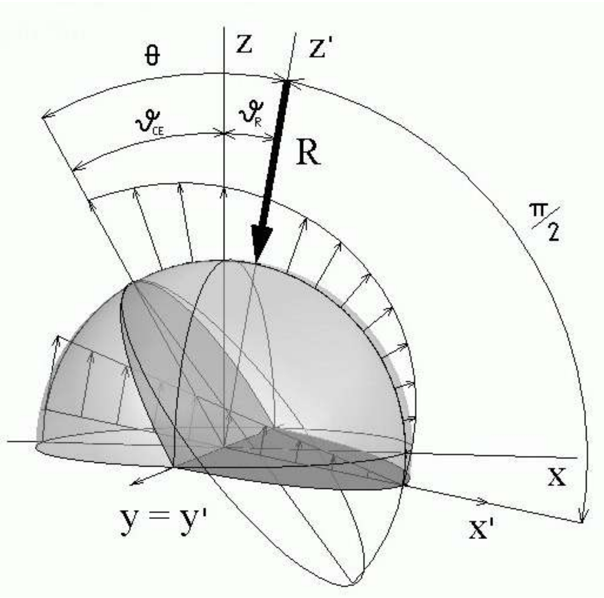


Figure 2: model with linear descent pressure in plane perpinducular to the hip joint resultant force

Contact job was computed between these parts. We compared the results of the contact stress distribution acquired from this mathematical model with the results of the numerical model from the finite element analysis of the contact stress distribution. Resulting distributions are in Figure 5.

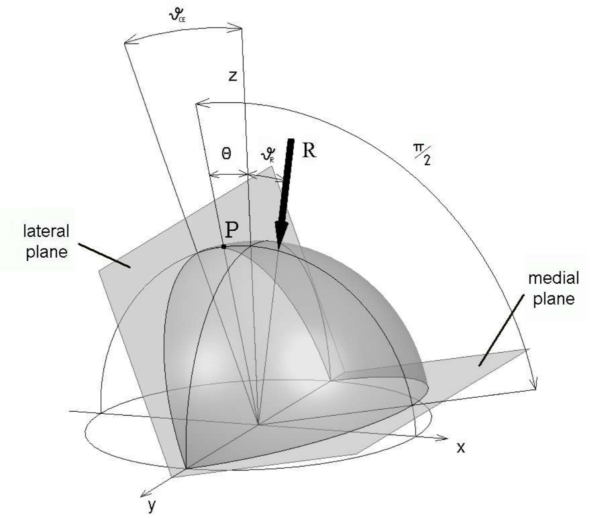


Figure 3: Model with cosine contact stress distribution

From the comparison, we found out that both of them are very similar. In terms of the comparison results were indicated, that it is possible to use the finite element method for the modeling of the non-weigh bearing part of the total replacement of the hip joint [5].

The new design of the cup was created in terms of above mentioned presumptions. The point of this technical solution of the new hip cup is to design such a shape of the joint surface that will be symmetrical towards the hip joint stress [6]. Three basic forms of this shape was designed. A cup with a hollow, a tapered cup and a cup with a medial asymmetrical joint surface. The cup with the hollow in Figure 6 was chosen as the most suitable from these three designs.

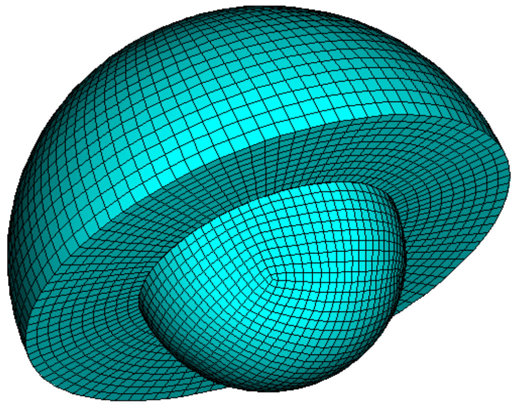
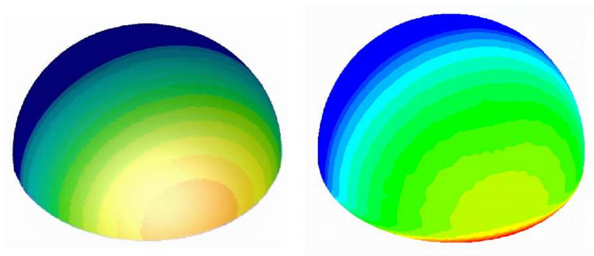


Figure 4: Numerical model

The finite element model of the cup with the hollow was created based on known dimension. The model was created same method as the model of classic cup. The hollow was placed to the non-weigh bearing area agreeable with presumption of the symmetrical toward loading of the hip joint. A dimension of the hollow was optimized with calculations of few models. The same optimalization was made for location the hollow on the non-weigh bearing area of joint surface.



(a) (b)

Figure 5: Resultant contact distribution – (a) mathematical model with cosine contact stress distribution, (b) numerical model

Results

The finite element models of the cup were computed as a contact job between an acetabular component and a femoral head. A resultant contact stress distribution of the classic cup is shown in Figure 7.

The contact stress distribution of the cup with the hollow in Figure 8 is more uniform then the contact stress distribution of the basic hip cup. From comparison of the results of the contact stress distribution in the Figure 7 and Figure 8 is obvious that the contact stress distribution of the cup with hollow is more uniform. Decrease of the contact stress gradient by way of modification of the non-weigh bearing area was succeeded.

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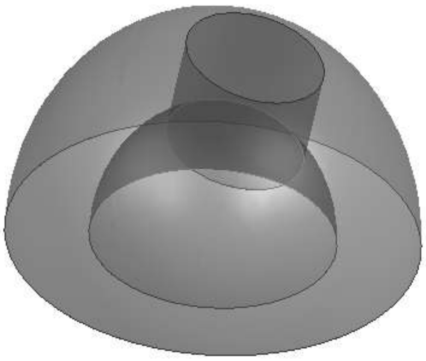

Figure 6: Model cup with hollow

The maximal value of the contact stress was increased by the hollow in the non-weigh bearing area. This maximum was on the edge of the hollow. We substituted this concentrator and a cup margin by filleted edge. We attempted to decrease maximal value of the contact stress by this modification. The new model of the cup with hollow and fillet edge is shown in Figure 9.

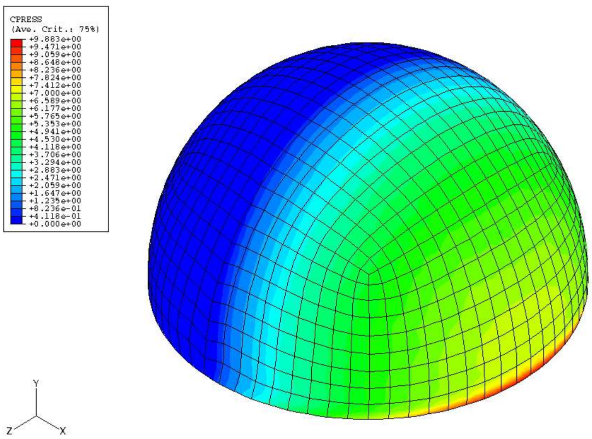

Figure 7: Resultant contact stress distribution of the classic cup

The resultant contact stress distribution of this cup is in Figure 10. From the results is clear that maximal stress was decreased of one third. The resultant contact stress distribution was not influenced by this modification. We made model of the classic cup with fillet edge to verified influenced contact stress distribution by this filleted edge. The resultant contact stress distribution is in Figure 11.

Discussion

We compared the mathematical model with cosine contact stress distribution on the acetabular surface with the numerical model from the finite element analysis and indicated that it is possible to use the finite element method for the modeling the non-weigh bearing part of the total replacement of the hip joint.

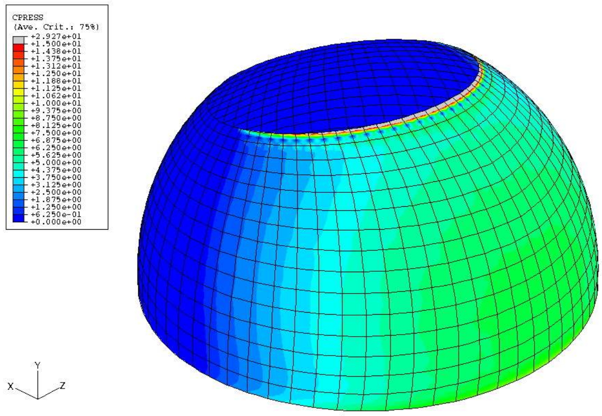

Figure 8: Resultant contact stress distribution of the cup with hollow

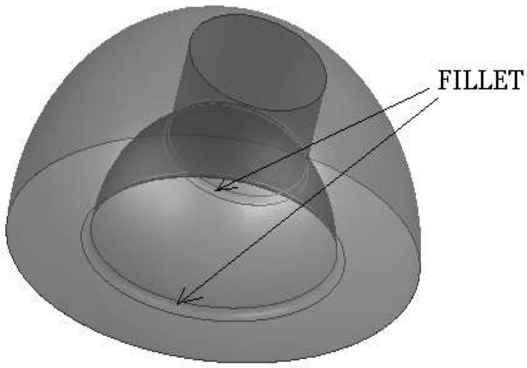

Figure 9: Model cup with hollow and filleted edge

We chose the most suitable design of the hip cup. It is the cup with hollow. We created the finite element model of the cup with the hollow and we computed the contact stress distribution for different dimensions of the hollow. The results from these models were compared with the model of the basic cup and we determined if the contact stress distribution is more uniform.

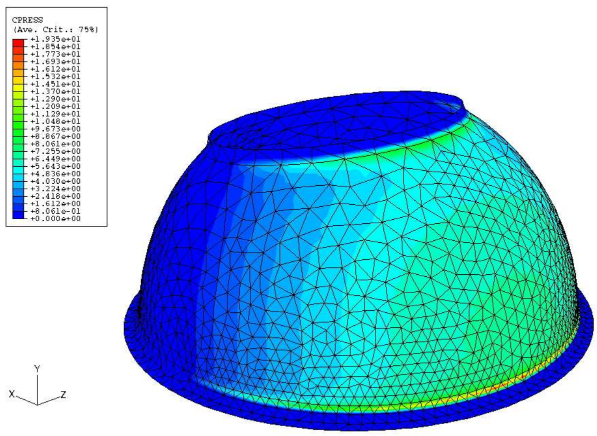

Figure 10: Resultant contact stress distribution of the cup with hollow and filleted edge

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We achieved more uniform contact stress distribution from design of the non-weigh bearing area of the hip joint.

In case of cup with hollow the maximal value of contact stress was increased and was placed on the hollow edge. We decreased this stress extreme by the filleted edge of the hollow and the inside edge of the cup.

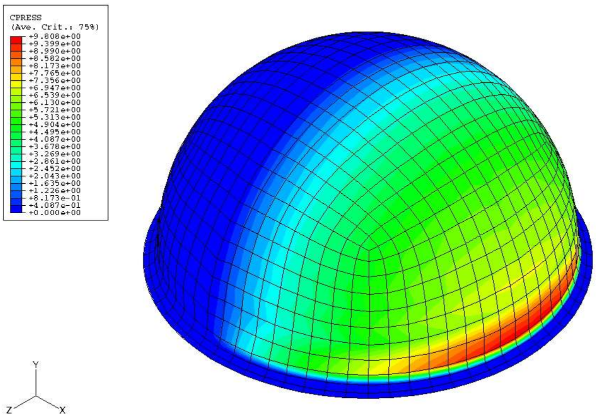

Figure 11: Resultant contact stress distribution of the classic cup with filleted inside edge of the cup

We found out from comparison of results of the distribution of the classic cup in Figure 7 and the classic cup with filleted edge in Figure 11 that filleted edge did not influence resultant contact stress distribution.

In next phase of development we will focuse on determination of the contact stress distribution by experiment.

Conclusions

The aim of our work was development of new design of the acetabular component of the hip joint, which will reach our requirements.

We achieved more uniform contact stress distribution form design of the non-weigh bearing area of the hip joint. Our calculation confirms these presumptions. The result will have to be verified by experiments with real cups. If the results from finite element analysis are according to experiment results, than we will be able to continue in next phase of the development.

Acknowledgements.

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