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Experimental Stress Analysis

ANALYSIS OF CONTACT PRESSURE ON THE UNICONDYLAR KNEE REPLACEMENT

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Abstract: The paper deals with contact pressure analysis on two constructional types of modern type of knee prothesis - the unicondylar knee replacement. Contact pressure is analysed in two ways, the first is experimental using pressure sensitive Pressurex® films, and the second approach is numerical analysis made in FEM software package ANSYS Multiphysics 10. Results from both approaches are confronted and at the end there's judged what type of partial knee prothesis is more suitable for use.

1. Introduction

Nowadays we're able to increase quality of life for many people affected by failure of knee joint through the development of artificial implants. This surgical intervention belongs among today's standard orthopaedic operations. The most common reasons for knee replacement implementation are:

- degenerative knee joint disease (e.g. osteoarthritis),
- destruction of the joint in consequence of rheumatic disease,
- damage of knee joint caused by an injury,
- and others.

Recent knowledge in the field of orthopaedics and biomechanics lead in the last few years to the progression of so-called mini-invasive operations. In addition to total knee replacements there's now option to use partial (unicondylar) knee replacements in some cases. Rapid course of operation, short convalescence and lower price, these are the strongest reasons for the development of unicondylar knee replacements.

These replacements generally consist of three parts: femoral component, tibial plate and polyethylene (PE) insert (*Fig. 1*). We can found them in two design options differing by PE insert move ability (*Fig. 2*). In the first option PE housing is allowed to slide on tibial plate. In second case PE insert is completely fixed. These options have various consequences for the whole system functionality, when they are designed in a wrong way there's a need of immediate revision and following re-operation. This condition is of course undesirable and there's still the question which of the mentioned constructional solutions is more advantageous for this type of knee joint replacement.

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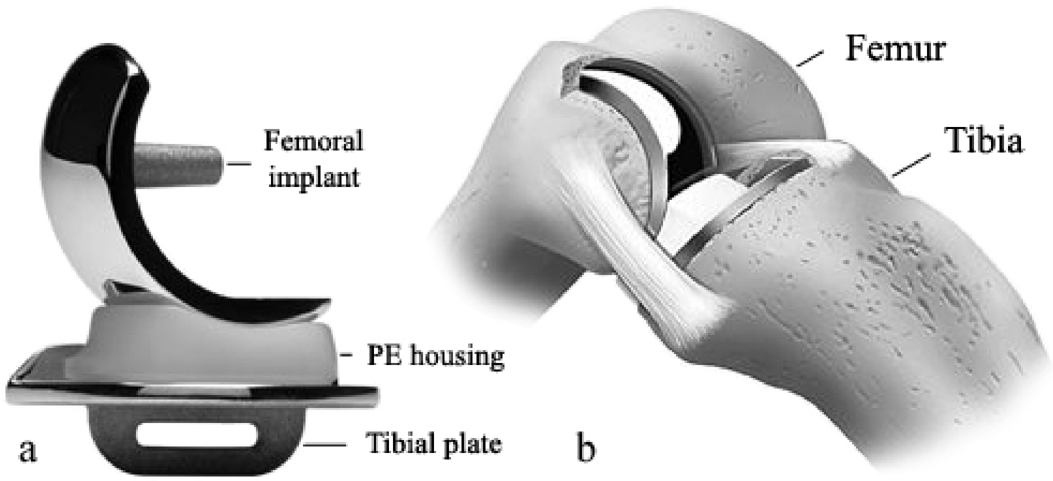


Figure 1: *Partial knee replacement; a) example b) scheme of implanted parts*

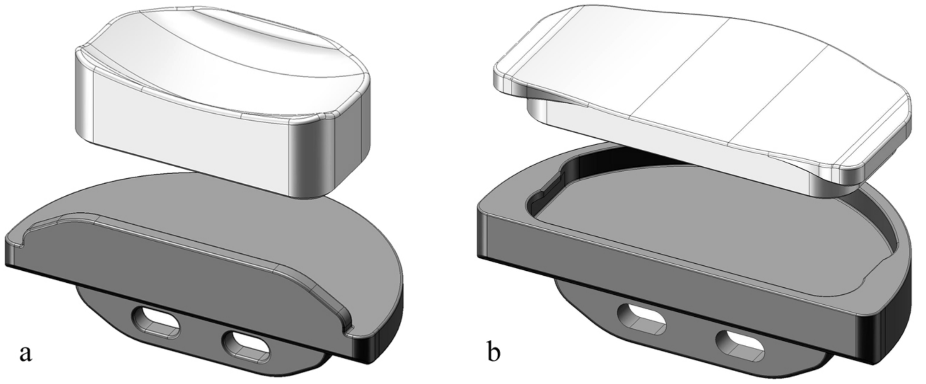


Figure 2: *Two constructional options of partial knee replacement a) free PE housing b) fixed PE housing*

Inasmuch as many works dealing with total knee implants testing indicates contact pressure as the main reason for replacement degradation, the goal of this work is to analyse this variable on the two unicondylar replacements options. Thereby would be objectively refuted or confirmed impact of constructional realizations on replacement's functionality according to contact pressures.

2. Used methods

2.1. Experimental tests

An apparatus allowing variable positioning of the femoral component against tibial plate and PE insert like it does, when implanted, during knee flexion/extension was built (Fig. 3). The Pressurex® indicating film, cut into necessary size, was inserted between PE housing and femoral component and then pushed against each other to contact under the load of approximately 1 300 N. The load was applied for over ten seconds so the topographical image of contact surface developed on film. Upon unloading, the film was removed. This process was repeated for a combination of five angles of flexion (Fig. 4). Since colour differentiation of pressure zones was needed, all used films were sent back to producer for further analysis.

In case of partial knee replacement with free PE housing LOW type (350 - 1 400 PSI; 2,5 - 10 MPa) of Pressurex® film was used and because of the presumption of bigger contact pressures, MEDIUM type (1 400 - 7 100 PSI 10 - 50 MPa) was used for type with fixed PE insert.

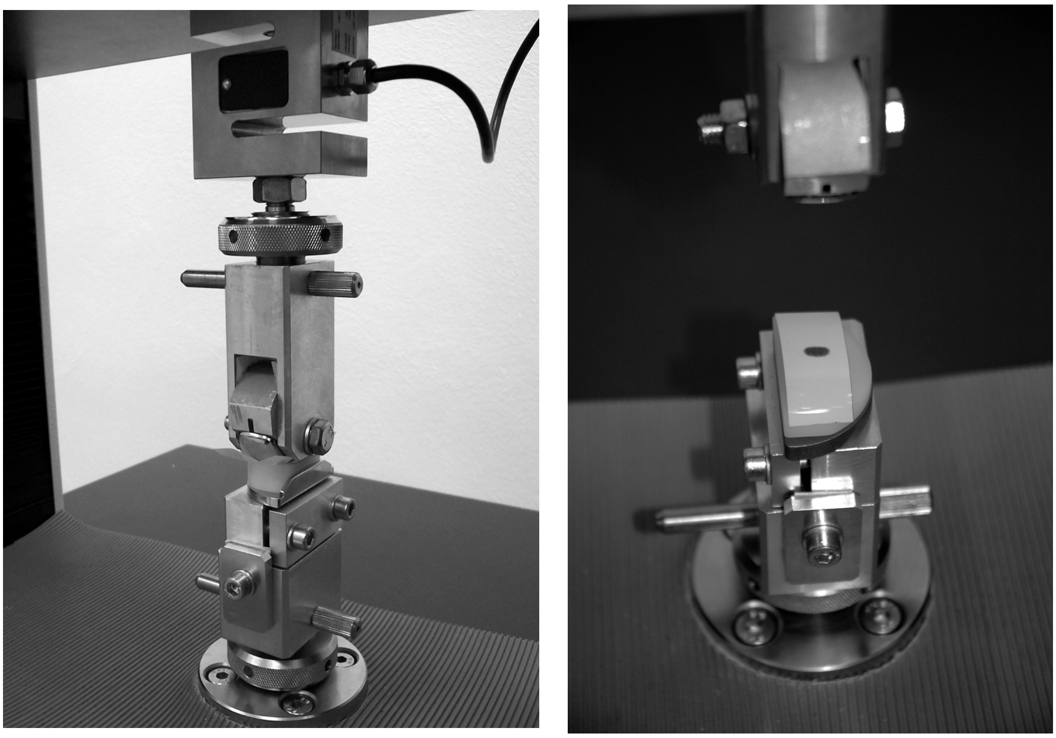
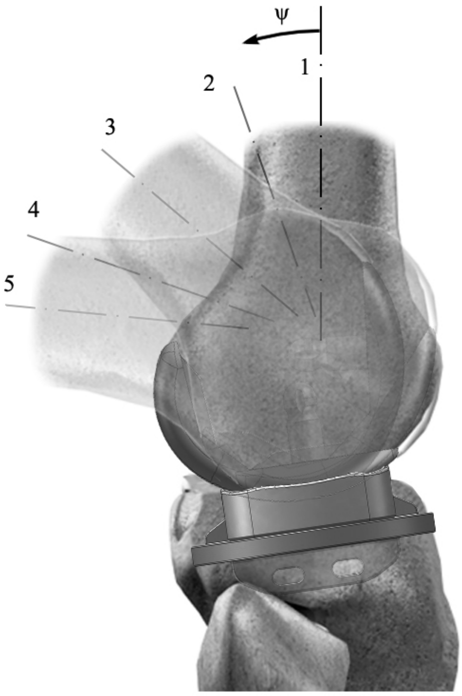


Figure 3: *Experimental tests of partial knee replacements*



Position number	Flexion angle ψ [deg]
1	0
2	20
3	50
4	70
5	85

Figure 4: *Five testing positions shown on knee joint*

2.2. Finite element method (FEM)

After experiments were done, FEM analysis of the same problem and five flexion angles was performed for comparison and confirmation of experimental results. 3D models of all replacement parts arranged as needed for specific angle of flexion were imported from Pro/Engineer into commercial FEM product package ANSYS Multiphysics 10.

In this study, 10-noded tetrahedral solid elements were used for the proposed models (Fig. 5). The mesh was locally refined due to better contact detection and more accurate results.

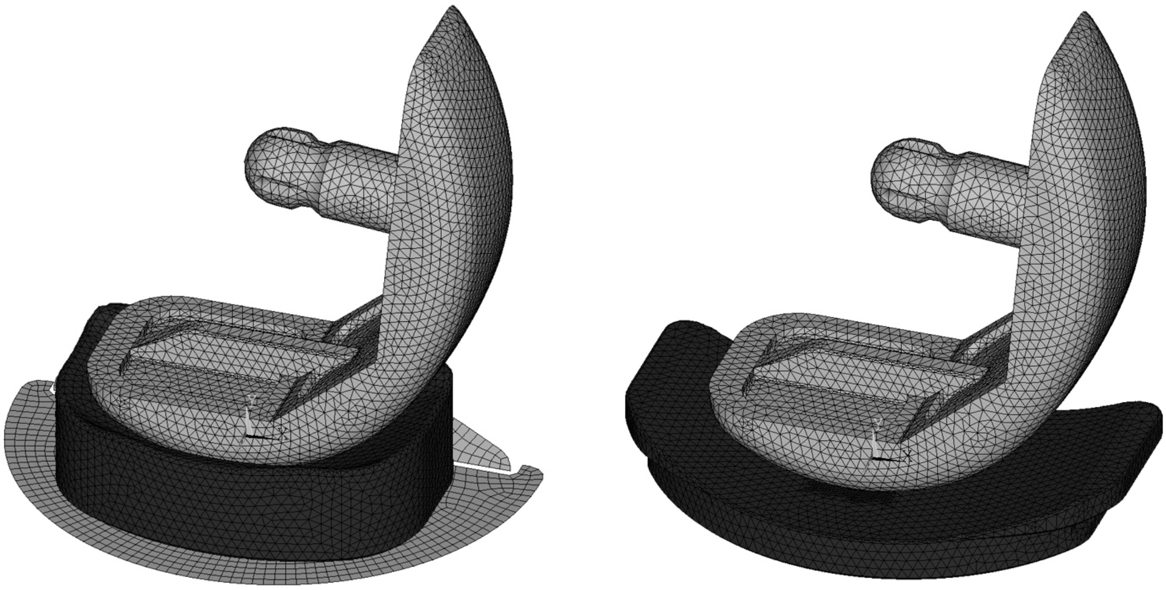


Figure 5: *Meshed models of both unicondylar knee replacements types*

All material models were considered as isotropic. Their properties are summarised in Table 1. The last step before performing computation was to apply boundary conditions and force load.

Table 1: *Material properties of tested components*

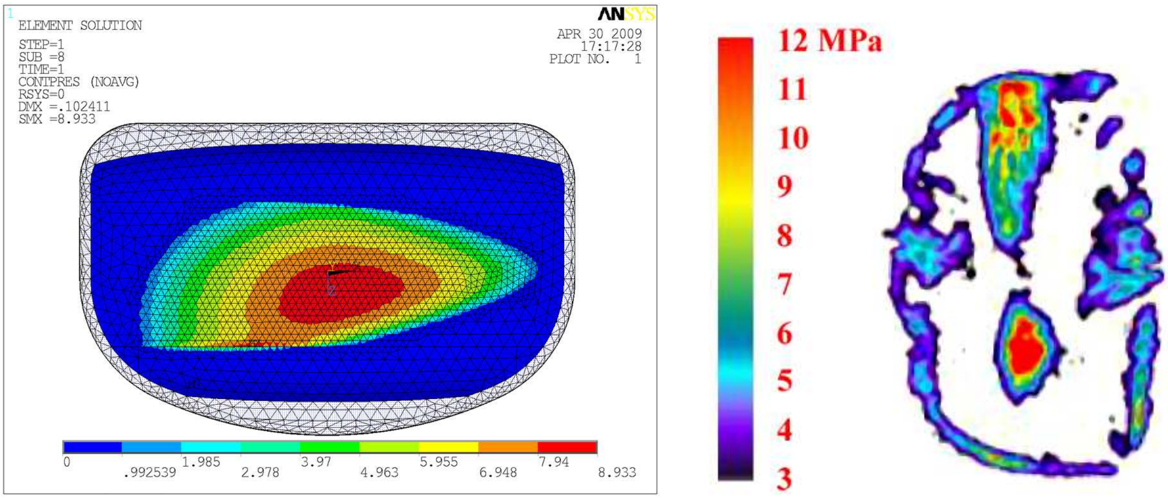
Tibial plate and Femoral component (Co-Cr-Mo alloy)	Young's modulus	E [MPa]	228 000
	Poisson's ratio	μ [-]	0,3
PE housing (ultra-high molecular weight polyethylene - UHMWPE)	Young's modulus	E [MPa]	500
	Poisson's ratio	μ [-]	0,3

In case of type with free PE insert there was defined contact between insert and femoral component and between insert and tibial plate. These contacts are including coefficient of friction with value of $f = 0.05$ for better simulation credibility. On the other hand contact between fixed PE housing and its tibial plate was replaced by zero displacement boundary conditions fixating insert in all three directions. This ensures less computational time with no major mistake in accuracy. In both cases, 1 300 N force load was transferred to pressure corresponding to femoral component's top areas size it is applied to. Zero displacement boundary conditions were also used on femoral component to make it move only in one direction - towards PE insert.

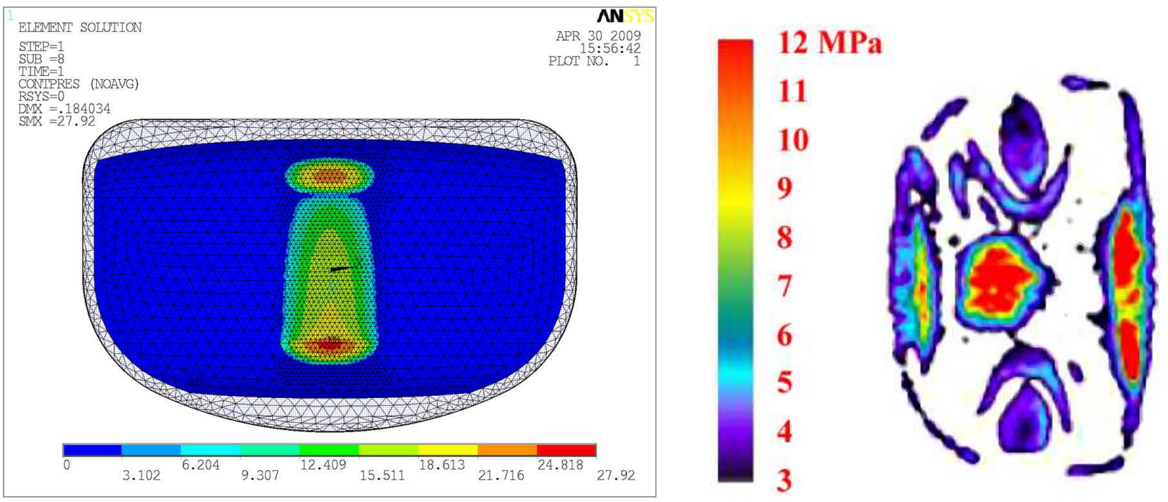
3. Results

The first set of results belongs to partial knee replacement with free PE insert. On left column can be seen result from FEM analysis, right column shows contact pressure distribution gained thanks to Pressurex films. Second set shows of course results for the type with fixed PE insert.

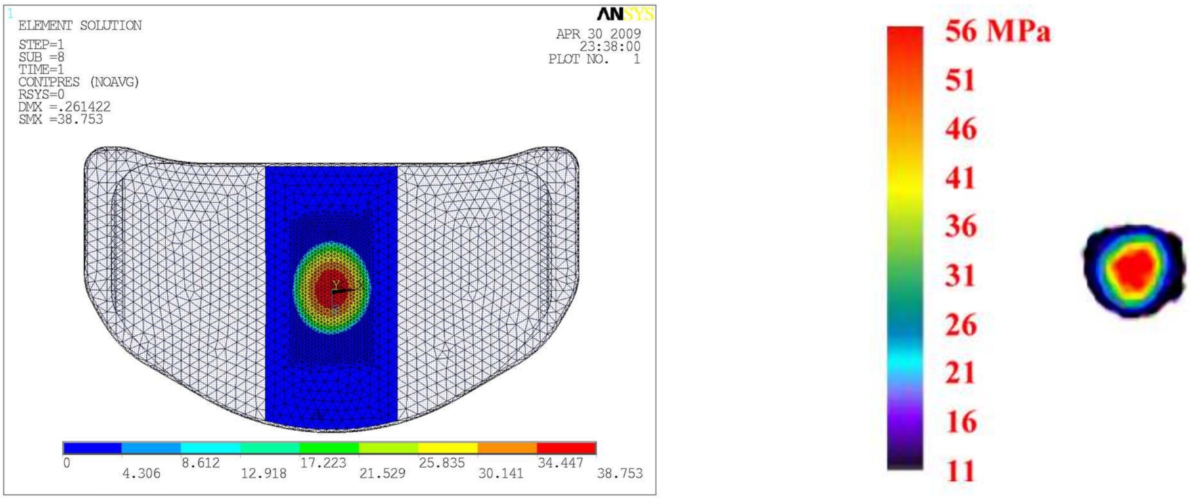
Free PE housing; Position 1



Free PE housing; Position 5



Fixed PE housing; Position 1



Fixed PE housing; Position 5

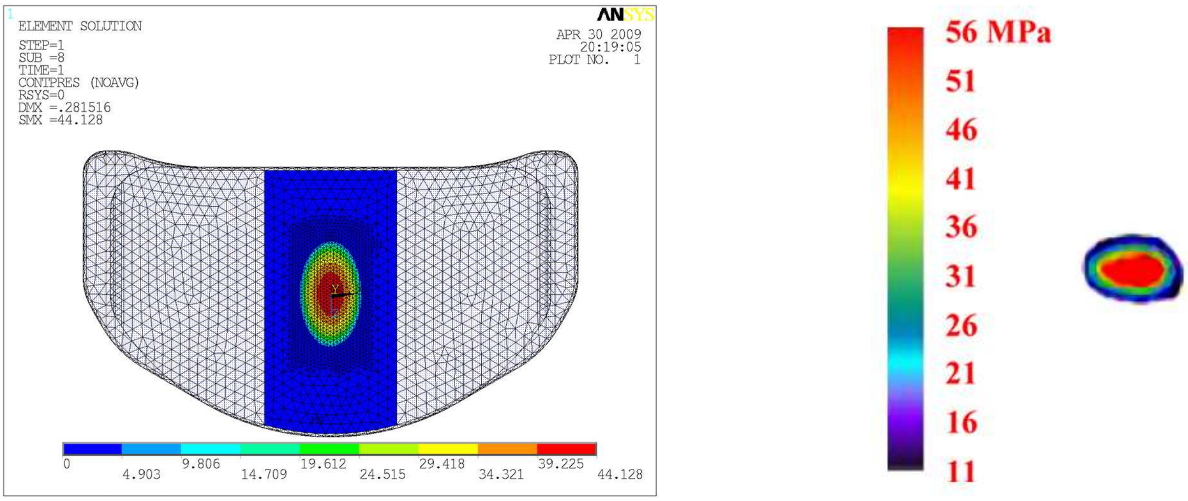


Figure 6: *Selected results form FEM analysis and experiments*

4. Conclusion

A unicondylar knee replacement replaces only half of the knee joint. It is performed if the damage is limited to one side of the joint only with the remaining part of the knee joint being relatively spared. It is now possible for the surgeon to replace only that area of the knee joint which is severely damaged. However, even with only half of the joint destroyed, many surgeons prefer doing a total knee replacement believing this is a better procedure than the half-knee (unicondylar) replacement. But equally, there are surgeons who believe it is more appropriate to perform a unicondylar knee in the right circumstance

For our selected types, the maximal values of contact pressure go to 12 MPa in the case of free housing and 56 MPa in the case of fix housing. In the case of free housing, we can see that results are not in good agreement. The difference is not only in the distribution of contact pressure, but also in values. In some cases the difference goes to100% in values.

In the case of fixed housing results are more acceptable. FEM analysis and experiments are in good agreement. The maximal difference goes to 10% in values.

This article is aimed only to the first step in optimisation of unicondylar knee housing. The second step will be to find an optimal design of housing according to the distribution and values of contact pressure. We wanted also to show, in this article, the reliability of FEM analysis, when contact analysis is performed.

5. References

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