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STRESS ANALYSIS OF THE TOTAL REPLACEMENT OF THE TRAPEZIOMETACARPAL JOINT

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Abstract: *The article devotes to finite element analysis of the total replacement of the trapeziometacarpal (TMC) joint. Various types of analyzes were carried out dealing with influence of different geometry of the replacement. Apart from detailed models, more complex one including bones and ligaments was created to achieve more realistic conditions and thus, more trustworthy results. The goal of this study is to bring awareness about stress states depending on geometry of the replacement as well as provide an image of contact pressure distribution when loading the replacement.*

Keywords: Stress analysis, Finite element method, Trapeziometacarpal joint, Total replacement.

1. Introduction

Biomechanics is a scientific-medical branch that has been developing for decades, however, still offering many challenges regarding new inventions and innovations (Fuis et al., 2001, 2004, 2009, 2010, 2011 and 2011a) which help people avoid pain, make their physical activities easier and their lives satisfied. As a follow-up to (Svojanovský et al., 2014 and 2015), this article aims mainly at advanced comparison of contact pressure distribution between parts of the TMC replacement. Such a replacement serves as a surgical solution of a joint disease called rhizarthrosis which reduces mobility of a thumb or totally prevents from any motion.

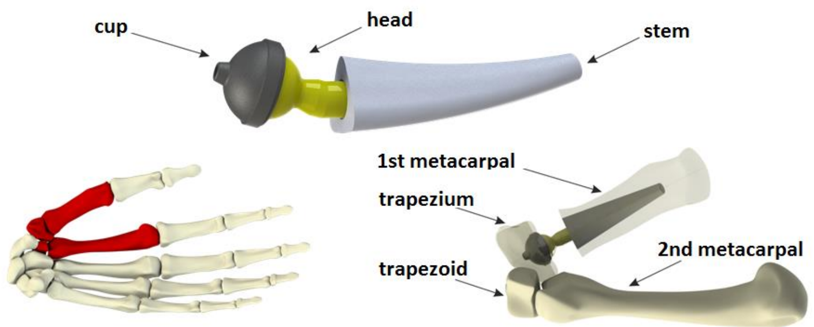

Fig. 1: Trapeziometacarpal replacement, its placement in thumb bones.

One of several types of TMC replacements, which are currently available, was chosen for this analysis. The replacement consists of three parts – a head interconnecting a cup and stem. These parts of the TMC replacement are inserted surgically to thumb bones – trapezial on one side and metacarpal on the other side (Fig. 1). Complex geometrical model of the TMC replacement inserted in thumb bones was performed on the basis of X-ray images of a real surgical intervention (Trtík, 2011).

2. Overview of analyzed models

Various models of the TMC replacement are to be analyzed using finite element method. As introduced

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below, there are three model sets (A, B, C), each of them dealing with specific conditions (Fig. 2). Material properties of the models A, B, C of the cup and head correspond with CoCrMo alloy.

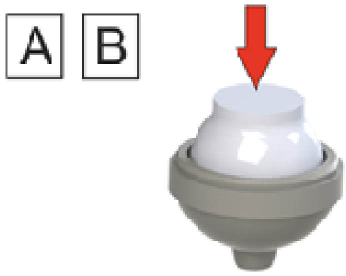

Fig. 2: Loading of models A and B.

MODEL A **-** detailed model of the cup and stem determined for investigation of influence of the cup type

Four various types of the cup geometry were created for comparison of stress states in contact between the stem and cup. Shape and size of the head is preserved (Fig. 3).

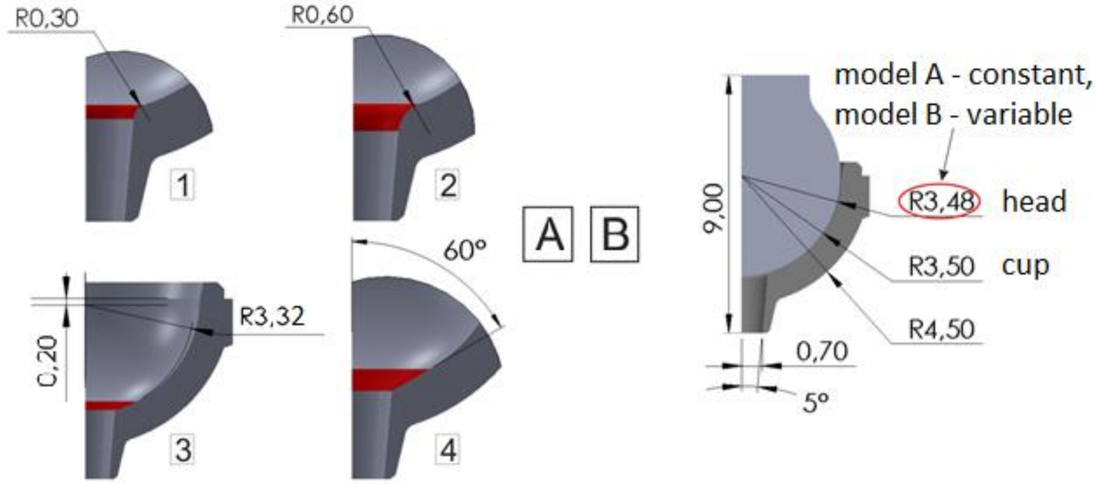

Fig. 3: Description of models A and B.

Model A-1 is typical for rounded transition (highlighted in red) of the spherical area with radius of 0.3 mm. The transition of model A-2 is rounded as well, however, with radius of 0.6 mm. Model A-3 is characteristic for spherical area nested in the reference spherical area whereas model A-4 is typical for conical transition of the spherical area of the cup. Transitions of the variants 1, 2 and 4 are connected smoothly to the reference spherical surface.

All the four variants of the model A are loaded by maximum force of 1000 N which is approximately the highest force achievable in normal life. In addition, the loading is carried out symmetrically with regards to the axis of rotation symmetry.

MODEL B – detailed model of the cup and head determined for investigation of the head size influence

To analyze influence of the head size, nine variants were created while preserving shape and size of the cup (Tab. 1). Material properties and loading conditions are the same as for the model A.

Tab. 1: Variants of the head sizes (spherical radius of the head).

Variant number	1	2	3	4	5	6	7	8	9
Spherical radius of the head [mm]	3.42	3.43	3.44	3.45	3.46	3.47	3.48	3.49	3.50

MODEL C – complex model of the cup, head and stem including relevant bones and ligaments (Fig. 4).

In an effort to perform finite element analysis of the TMC joint replacement as close to conditions in a human body as possible, surrounding bones and ligaments were included into this complex model. Moreover, bone tissue was divided into cortical (bone surface) and spongy (bone core) one.

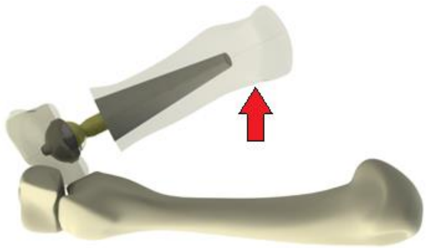

Fig. 4: Loading of the model C.

3. Results

In terms of results of the model A, variant number 4 (conical transition) evinces lowest equivalent stress as well as contact pressure (Tab. 2).

Tab. 2: Results for four variants of the model A.

Variant number	Description	Maximum equivalent stress [MPa]	Maximum contact pressure [MPa]
1	Rounded transition 0.3 mm	618	845
2	Rounded transition 0.6 mm	589	839
3	Nested spherical surface	518	834
4	Conical transition	376	584

Comparing profiles of contact pressure distribution along a path on the cup surface, Fig. 5 shows dependence of contact pressure distribution on the head size (spherical radius). Number 0 on the horizontal axis of the graph means connection line connecting conical and spherical surface.

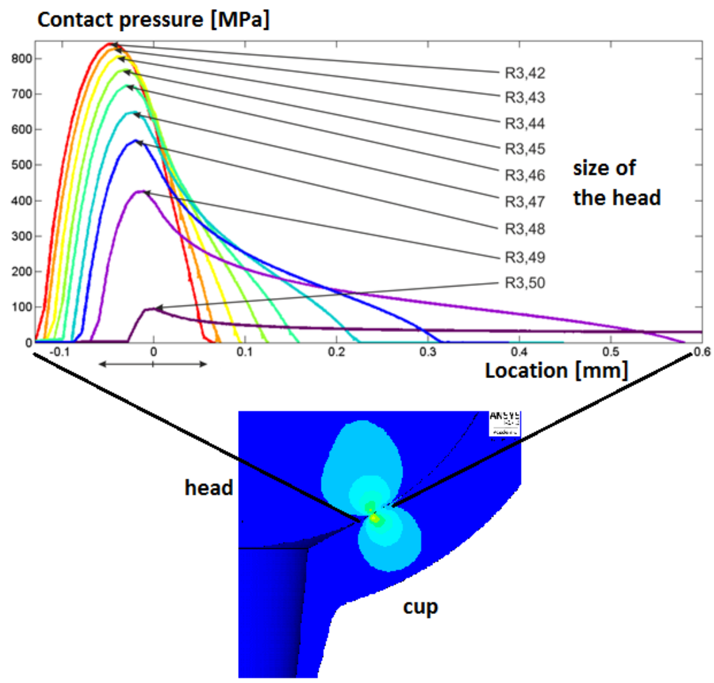

Fig. 5: Contact pressure distribution depending on the head size (spherical radius).

As emerged from the analysis of the complex model C including bones and ligaments, maximum contact pressure may achieve approximately 380 MPa when loading the thumb by force of 100 N as depicted in Fig. 6.

4. Conclusions

Finite element method was used to analyze stress states in contact between parts of the TMC replacement. Two detailed models and a complex one were created to investigate desired conditions.

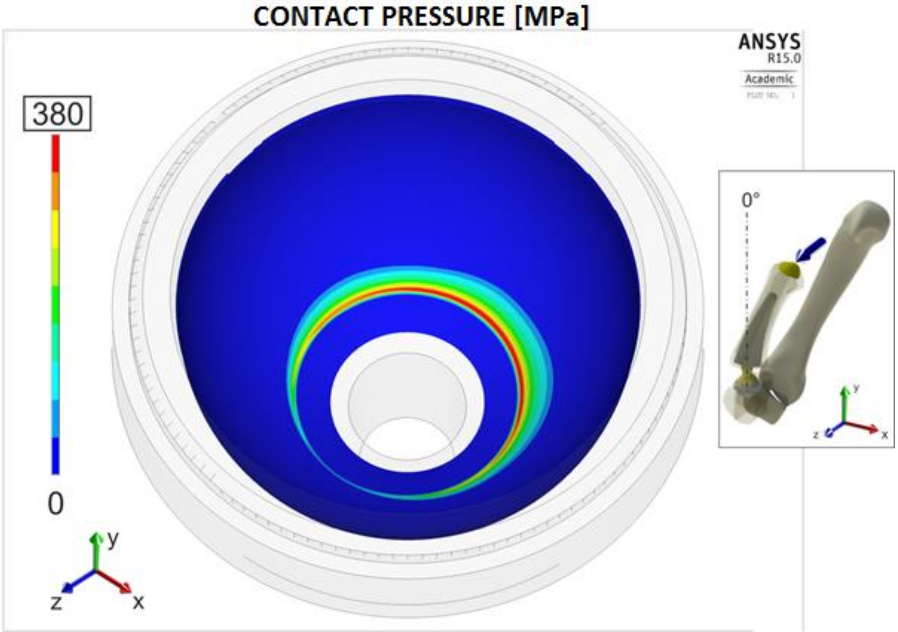

Fig. 6: Contact pressure distribution on the cup surface of the model C.

The detailed model A dealing with different types of a cup proved that the cup with conical-spherical shape evinces lowest maximum contact pressure as well as lowest maximum equivalent stress. The detailed model B compares stress states depending on size of the spherical part of the head. It came out that lowest contact pressure occurs when sizes of the head and cup are the same, alternatively head size is slightly smaller than cup size. There is a distinctively higher maximum contact pressure when the head reaches smaller sizes. However, going further to smaller head sizes, maximum contact pressure changes only slightly. Analysis of the model C proves that contact is mostly occurred in a narrow zone following spherical-conical surface transition. This is chiefly caused by ligaments which ensure static equilibrium among individual parts.

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