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FEM Analysis in the Hip Joint Reconstructed with Classical and Modified Hip Resurfacing

Anna Maria RYNIEWICZ, Tomasz MADEJ

AGH University of Science and Technology
Faculty of Mechanical Engineering and Robotics
Al. Mickiewicza 30, 30-059 Kraków, Poland
e-mail: anna@ryniewicz.pl

The aim of the work is personalized strength analysis using finite element method (FEM), carried out in the virtual hip joint supported by the hip resurfacing. The material for the procedure was the clinical case of patient, recommended to the resurfacing operation. The preoperative strength analysis was carried out on a numerical model of the patient's hip belt, reconstructed on the basis of computed tomography. The research material were implanted prostheses: Birmingham Hip Resurfacing (BHR) and Birmingham Mid Head Resection (BMHR) systems. The strength analysis was carried out using Femap NE/Nastran v.8.3. Huber-Mises-Hencky (HMH) hypothesis was assumed to determine and evaluation of stress and displacements in the structure of the prosthesis and periarticular tissues. The distributions of the stresses in the prosthesis and the surrounding tissues after resurfacing operation have not too large values. In the case under consideration, they do not exceed the physiological resistance of tissues and can stimulate bone formation processes.

Key words: hip resurfacing, modelling, FEM analysis.

1. Introduction

The solutions which could provide an alternative to total hip replacement have been searched for several years. One of such solutions is Birmingham Hip Resurfacing (BHR) System. It was first implanted in July 1997, and was approved for use in the United States by the Food and Drug Administration in 2006 [3]. The anatomical setting of neck and head of femur in the acetabulum is maintained, and the zone of pressure between the acetabular and femoral components is similar to one in the natural joint. The distant clinical observations and analysis of wear of artificial joints show that hip resurfacing has limitations [7, 8, 11, 14, 15].

Contraindication to the classical surgery of hip resurfacing are avascular necrosis (AVN), large femoral cysts, or patients with anatomical difficulties such as hip dysplasia or Perthes disease [12, 13, 16, 19]. A new method of Birmingham Mid Head Resection (BMHR) is available worldwide from May 2009 and in Poland from July 2009. The modified hip resurfacing differs primarily in the preparation of the femoral head and the fixation of the stem in the neck of the femoral bone. The range of the resection of femoral head is larger and the conical stem is stabilized on the basis of osseointegration. The modified hip resurfacing is still a surgery that leaves the tissues uninjured unlike the total hip resurfacing [1, 2].

2. The aim of the work

The aim of the work is the method that allows to predict the biomechanical state of an operated hip on the basis of strength analysis using finite element method (FEM). It was carried out in the same virtual hip joint supported by the hip resurfacing: classical and modified.

On the basis of numerical simulation, prior to the planed hip resurfacing, it is possible to compare both reconstruction systems of hip joint and indicate that construction which in the lap belt of a patient is a better solution in the strength and tribological aspects, taking into account the quality of the bone structures and the diagnosis resulting from the patient's age.

3. Material and methods

The research material were implanted prostheses: BHR and BMHR. The material for FEM analyses was a clinical case of a patient with the indication to the reconstruction of the right hip joint. Preoperative strength procedures were carried out on the numerical model of the hip belt, reconstructed on the basis of the computer tomography CT (Fig. 1a).

The mapping of anatomical osteoarticular system was carried out on the basis of clinical diagnostics CT. The imaging in the spiral technique was made using 64-row camera Siemens Sensation Cardiac for the smallest possible width of scans equal 0.4 mm. The scans were performed in the horizontal plane with DICOM standard. The mapping precision was specified on the basis of results of imaging which secured the quality of the numerical model. Two global models of research on which one imposed spatial constraints and quasistatic loads in the standing conditions, were created. The author's model of loads is based on the Bergman and Będziński model (Fig. 1b) [4, 5, 20].

Due to existence of differences between individuals in the osteoarticular system, to the application of analysed systems, the procedure of optimal positioning

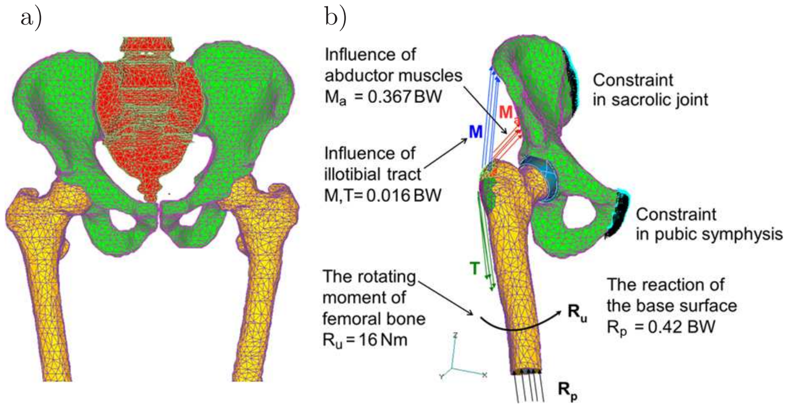

FIG. 1. The numerical model of hip belt: a) reconstruction on the basis of CT, b) the loads and constraints conditions.

of the prosthesis on the basis of identification of geometric-anatomical parameters was used [17, 18].

On the basis of this identification the selection, modelling and targeted application of systems of Smith&Nephew firm: BHR (BHR ACETABULAR CUP 74120150, BHR FEMORAL HEAD 74121150) and BMHR (BHR ACETABULAR CUP 74120150, BMHR FEMORAL HEAD 74432050 BMHR VST HAP CEMENTLESS STEM 74431313) to the same numerical model of hip belt was performed (Fig. 2). The material and tissues parameters, depending on the qua-

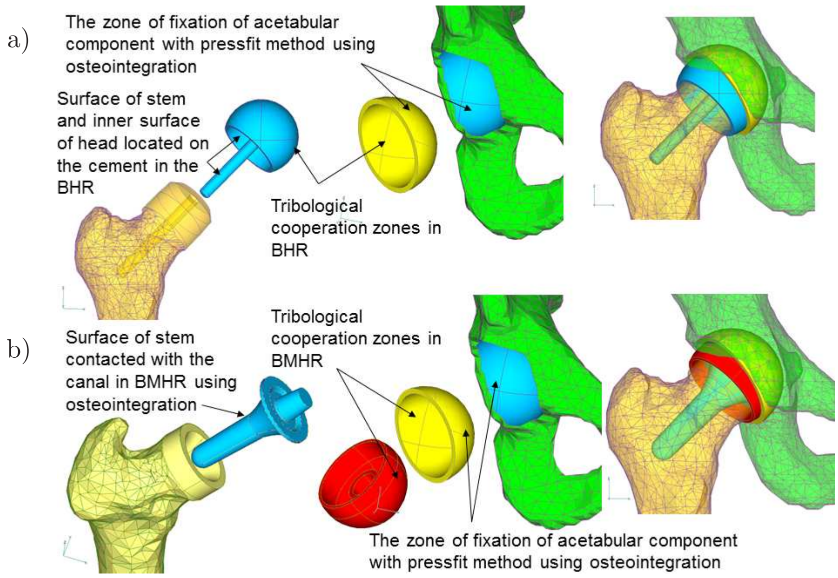

FIG. 2. The modelling and application of systems: a) BHR, b) BMHR.

lity of the bone structures and especially on their density assessed in CT [6, 9, 10, 17, 18] were taken for testing. Correlation of Young's modulus and Poisson's ratio with the density of bone structures and their adaptation to the conditions of the diagnosed patient is possible in that procedure. Modelling and the strength analysis was carried out using Femap NE/Nastran v.8.3. To identify and estimate the stresses of the hypothesis HMH was taken. In the functional assessment of BHR and BMHR prostheses one focused on the analysis of stress distribution in the construction of endoprostheses and periarticular tissues. The fixings zones of elements of endoprostheses and the movement contact zones were considered especially important.

4. Results of simulation

The distribution of stresses in two global models of the hip belt in terms of standing on two legs conditions were designated after discretization of research objects, designation of contact zones (constrains, loads and material and tissues parameters) and performing calculations. The selected type of locomotion loads influences unfavourably on the tribological contact of elements of the endoprosthesis in comparison to realisation of loads in the motion conditions [4, 5]. Better biomechanical simulation of pelvic girdle can be noticed when using BMHR hip resurfacing as compared to BHR (Fig. 3). In both models, one finds asymmetric zones of maximal stresses localized in the neck of femoral bone, wherein in the BHR the zones are much larger of values of 8 MPa both in the view in the standing position and from the bottom. The maximal stresses in the BMHR system take the value of 6.5 MPa.

The homogenous stress concentration of much larger values in the construction BMHR than BHR is visible after the sections for both systems and periarticular structures (Fig. 4). Stress concentration in the construction of BMHR is accompanied by a reduction of peripheral stresses in the neck of femoral bone, unlike the BHR system which is characterized by stress concentration in the outer layer of the neck and in the half-length of stabilizing pin.

The stress distribution in the pelvis bone resulting from the given loads and the contact of acetabular component with the pelvis bone in BMHR indicates that the bone structures are stimulated more intensively to the osseointegration process and the values of stresses are more homegenous (Fig. 5). When using BHR extensively stress-shielding zones and the concentration of stresses in the zones of contact of acetabular component with pelvis bone are visible.

The stress distribution in the specially prepared femoral head and neck – resulting from the determined loads and the contact after fixation of the femoral component on the cement in the BHR application – points to the characteristic stress shielding which may not stimulate the process of bone formation in the head and neck and may deepen necrosis of tissue and bone arthropy (Fig. 5).

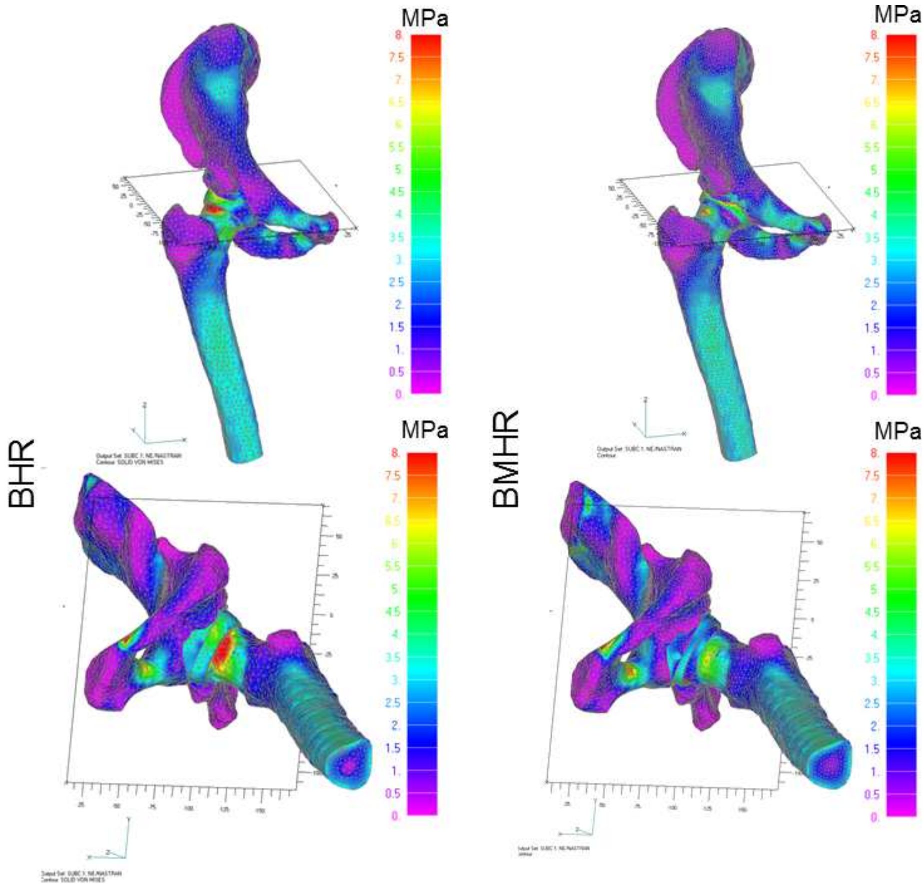

FIG. 3. The maps of distributions of reduced stresses in the models using BHR and BMHR systems.

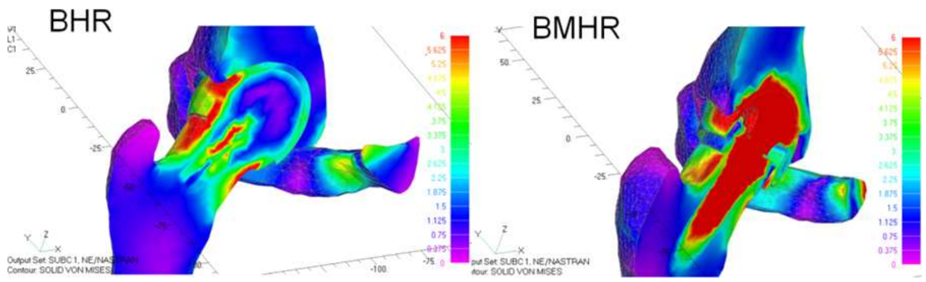

FIG. 4. The maps of reduced stress distribution in the section through the axis of tested systems BHR and BMHR as well as periarticular structures.

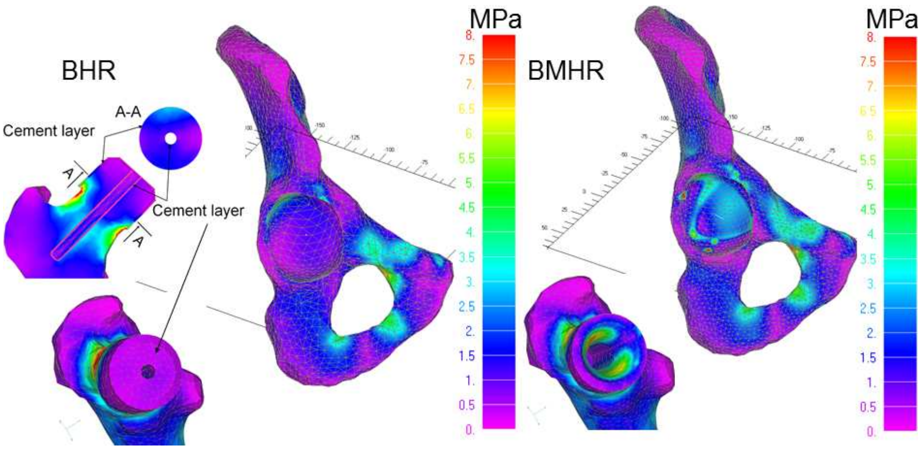

Fig. 5. The maps of reduced stress distributions in the pelvis bone contacting with the acetabular component for the tested BHR and BMHR systems as well as in the proximal end of femoral bone contacting with the femoral component in BHR system (view and section) and in BMHR system (view).

In the hip resurfacing conditions using BMHR in bone structures there occurs more favourable stress distribution which stimulates the bone to osseointegration processes, due to regular circumferential contact stresses of 6.5 MPa and using the cover of the conical part of stem with hydroxyapatite.

In the femoral and acetabular components in BMHR, in the tribological contact zone, the stress concentrations on higher values and much wider range than in BHR occur (Fig. 6). The peripheral asymmetry of pressures unfavourably

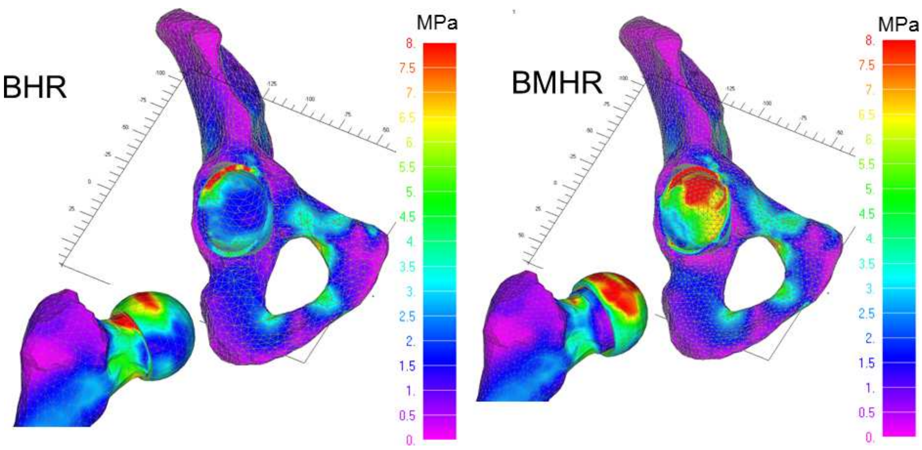

Fig. 6. The maps of reduced stress distributions in the tribological zones of BHR and BMHR prostheses as well as in the bone structures of the reconstructed joints.

influences the tribological wear process of elements in the movement contact. In both constructional solutions ovalization of acetabular and femoral components may be present. Worse tribological contact conditions have been found in BMHR. The higher values of contact pressures can cause negative effects in the form of generating the wear products, in this case the pulp of CrCoMo which may accumulate in the periarticular tissues. In the constructional solutions of BMHR system, the contact of femoral and acetabular components made from ceramics is also used.

5. Conclusions

FEM analysis of BHR and BMHR systems allows for:

- Favouring BHR for young people, as the treatment is carried out with the greatest tissue sparing. The threat is the femoral head necrosis and much greater stress concentrations at the femoral neck which may be broken.
- Indication of BMHR for the elderly people, due to the sparing procedure as compared to the total hip replacement, significantly lower risk of fracture of the neck than in the BHR and better ossointegration. The unfavourable process is the occurrence of stress concentration in the tribological contact zone.

The pre-surgery numerical simulations of the presented method may predict the biomechanical state in operated hip and answer the question about the distant prognosis. The results of analyzes show that the distribution of reduced stresses in the classical hip resurfacing and modified hip resurfacing both in BHR and BMHR systems for individual case do not exceed the threshold of physiological resistance of tissues.

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