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Improving the Finite Element Simulation of Wear of Total Hip Prosthesis' Spherical Joint with the Polymeric Component

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Abstract

The advanced model of wear in the spherical joint of total hip prosthesis comprising an acetabular cup of ultra-high molecular weight polyethylene (UHMWPE) in combination with a metal or ceramic femoral head is developed. The wear model is based on the classical Archard-Lancaster equation in common with all other studies reported in literature. The finite element solution of the contact problem between the cup and the head was employed under the loading and angular motions conditions according to the ISO 14242-1 demands. The polymer wear in terms of cumulative linear and volume wear when the wear factor is chosen to be a function of contact pressure is first evaluated.

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Keywords: Total hip prosthesis; wear; ultra-high molecular weight polyethylene; finite element simulation; spherical joint

1. Introduction

As shown by the medical practice, the main factor contributing to prolonging the lifespan of artificial joint replacements is to reduce the wear and wear particles in the bearing couple [1]. This is especially important for modern total hip replacements (THR), which include the acetabular cup of ultra-high molecular weight polyethylene in combination with a metal or ceramic femoral head, because currently there is a serious trend towards younger patients who are on indications needed a hip replacement. It is obvious that a lifespan of such prosthesis must be extended up to a maximum of 20 years or more. Thus, the study of wear becomes essential important for the development of new bearing couples, evaluation of designs and function of the existing joint prostheses. In these

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clinical studies, the evaluation of retrieved implants are implemented in terms of penetration depth of the femoral head into the cup, using the X-ray technique, and experimental laboratory studies using simulators for the wear test under replaying more realistic conditions of loading and motion [2]. But such experimental studies are expensive and time consuming to carry them out, although necessary for the preclinical assessment of the wear parameters. To reduce the amount of laboratory experimental studies, there is a well-known theoretical approach to modelling of wear, first pioneered by Maxian et al [3], which was then developed by other researchers [4] and in recent works [5,6]. This approach allows to pre-select the designs, materials, highlight the different variables and to investigate the influence of individual factors on the parameters of wear and thus generate data to perform further only limited experimental tests. The basis of most theoretical studies reported in the literature, is the finite element method for definition of the contact pressure at the articulating surfaces [7], because the advantage of the method lies in its flexibility and the opportunity of studying a variety of design, technological and operational factors of the prosthesis elements, including elastic-plastic deformation of the UHMWPE material [8]. But in almost all known cases of further wear definition, the simulation model is simplified for reduction the complexity of the calculations, thus reducing the reliability of the results.

The aim of this study is to improve the existing method of wear simulation of the bearing couple in a spherical joint of total hip prosthesis comprising a cup of ultra-high molecular weight polyethylene (UHMWPE), which is based on the solution of the contact problem using finite element analysis, taking into account the parametric dependence of wear factor on the contact pressure that has not been studied before.

2. Materials and methods

2.1. Hip prosthesis, loading and motion

The present study examined the hip joint prosthesis with a solid femoral head of cobalt-chromium alloy or ceramics (alumina or zirconia) employed against a soft (UHMWPE) acetabular cup. The elasticity modulus E of titanium shell is about two orders of magnitude greater than that of the cup, so further the outer surface of the cup is assumed fully constrained for the finite element model. The radius of the femoral head is R_1 = 16 mm, which corresponds to the most frequently used its standard diameter of 32 mm for a given combination of materials in the couple. The inner radius of the acetabular cup is R_2 = 16.15 mm, so that the radial clearance equals to $R_2 - R_1$ = 0.15 mm [9]. The thickness of the cup wall was chosen as 8 mm to provide its necessary rigidity. The elasticity modulus E and Poisson's ratio ν were chosen as 1.4 GPa and 0.46 respectively [10] for the cup and 210 GPa and 0.3 respectively for the head.

Demands to the implant, its positioning, creation of the load and motions specified in the joint, correspond to ISO 14242-1 test standard [11]. The right hip joint, defined in anatomical fixed coordinates $x'y'z'$ and shown in Fig. 1, where the axis z' is directed superior, x' medial and y' posterior perpendicular to the plane of the drawing, was represented as a model.

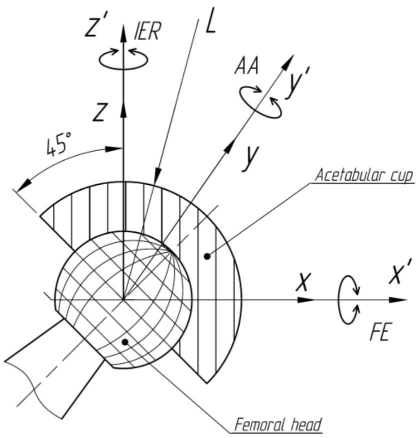

Fig. 1. Front view of the right hip joint with the specified directions of rotation (**L** is the resultant load vector).