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Combined multi-body and finite element investigation of the effect of the seat height on acetabular implant stability during the activity of getting up

Mario Kunze[a,*], *Andreas Schaller*[a,1], *Hanno Steinke*[b,2], *Roger Scholz*[a,1], *Christian Voigt*[a,1]

[a] *Laboratory for Biomechanics, Department of Orthopaedic Surgery, University of Leipzig, Leipzig, Germany*
[b] *Institute of Anatomy, University of Leipzig, Leipzig, Germany*

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ABSTRACT

An important question in assessing the stability of a total hip arthroplasty is the effect of daily physical activities of patients. The aim of this study is to examine these effects when standing up from three different seat heights. A musculoskeletal body model has been modified to simulate the three different seat heights. The calculated muscle forces have been transferred to a finite element model of a pelvis. The pelvis model was created from a hemipelvis CT dataset. As an implant component, a metal socket with a polyethylene insert was used. A primary implantation situation was modelled. For the analysed patient activities the highest hip contact forces and the highest micromotions occur at the beginning of the motion. The results of this study show that standing up from a certain seat height can have a significant influence on the micromotions in the implant–bone interface.

1. Introduction

In the western industrialized countries about 15% of the population at the age of 65 years and older suffer from a chronic degenerative disease of the hip joint. Total hip arthroplasty has helped many of these people in the past decades to improve their quality of life. The trend towards the treatment of younger patients and the rising life expectancy of the population raises the need for an increased service live of total hip implants. On this background the evaluation of implant stability is a major goal of biomechanical research today.

For the long-term success of an implant a stable fixation is essential [1]. In the post-operative state the stress stimulus induced by every-day physical activities, in general, has a beneficial influence on bone in-growth. Excessive micromotions at the implant–bone interface, however, prevent the formation of new bone and thus inhibit a solid in-growth of the surrounding bone into the macro-structured surface of

* *Corresponding author at*: Universität Leipzig, Orthopädische Klinik und Poliklinik, Labor für Biomechanik, Liebigstrasse 20, 04103 Leipzig, Germany. Tel.: +49 341 97 23223; fax: +49 341 97 23299.
E-mail address: mario.kunze@medizin.uni-leipzig.de (M. Kunze).
[1] Universität Leipzig, Orthopädische Klinik und Poliklinik, Labor für Biomechanik, Liebigstrasse 20, 04103 Leipzig, Germany.
[2] Universität Leipzig, Institut für Anatomie, Liebigstrasse 13, 04103 Leipzig, Germany.

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the implant. For optimum in-growth of bone the values of the micromotions at the implant–bone interface should not exceed 28 μm significantly [2,3]. In previous studies investigating the potential for long-term stability of implants the post-operative micromotions at the implant–bone interface were established as an adequate output quantity [4–8]. For realistic finite element analysis (FEA) muscle and joint forces are required as boundary conditions. In contrast to joint forces which can be measured in telemetric endoprostheses [9] muscle forces can only be determined by multi-body simulation which in turn requires input of kinematic data of the physical activities.

In the literature only few studies can be found which use multi-body simulation to evaluate muscle forces related to every-day physical activities [10,11]. The effects of the so evaluated muscle forces on the post-operative implant–bone stability have been investigated in studies concerning the jaw and the femur [12–15]. The influence of muscle forces on the amount of micromotions at the acetabular implant–bone interface was investigated in previous FE studies using simplified loadcases of the walking cycle [5–8].

Another interesting every-day activity according to Dalstra and Huiskes [16] is the motion of getting up from a seat. Hsu et al. [6] and Spears et al. [7] calculated micromotions in the acetabular implant–bone interface considering hip joint forces of the activity of getting up from a seat height of 50 cm according to Bergmann et al. [9] but without representation of muscle forces, whatsoever. Nadzadi [17] reported kinematic data for getting up from a low and a normal seat height but the model only consisted of femur and pelvis. However, the effect of muscle forces of the activity of getting up on the post-operative micromotions at the acetabular implant–bone interface has previously not been examined in the literature. Nevertheless, incorrect seating is known to cause a high economic burden to the health care system [18]. In the first weeks after total hip surgery, only light to moderate activities in the range of standing, walking and sitting are allowed. In the every-day routine it is recommended to use tools such as a seat or a shower stool, while the seat height should be at least 50 cm [19]. In other studies the seat height of 60 cm is especially recommended from an orthopaedic point of view [23]. However, the seat heights of 46 cm and 53 cm are standard seat heights in the industry [18,22]. Our hypothesis was that standing up from such a low sitting position could produce very high stresses on the implant–bone fixation.

The aim of this study was the determination of the muscle forces of the activity of getting up from different seat heights by multi-body simulation and the evaluation of the micromotions at the acetabular implant–bone interface during those activities. A sophisticated finite element model of the pelvic bone including the representation of ligaments at the pubic symphysis [20] was aimed for to generate realistic output quantities.

A working hypothesis of the current study was that if calculated joint forces from the multi-body simulation are of realistic magnitude, the magnitudes of the according muscle forces can be considered to be realistic as well. This working hypothesis is based on the fact that in the multi-body simulation quasi-static equilibrium is calculated at each timestep. For verification of the results of the current study the calculated resultant hip joint forces were compared to measured resultant hip joint forces from the literature [9].

2. Materials and methods

2.1. Multi-body simulation

The three-dimensional multi-body simulation software Anybody Modeling System, version 3.04, Anybody Technology Aalborg, Denmark was used [21]. The musculoskeletal full-body “Standing Model” was downloaded from the Anybody repository version 6.2. The multi-body simulation model consists of head, torso, upper and lower extremities (Fig. 1). Both lower extremities are divided into four rigid body segments: hip, femur, lower leg and foot, respectively [24]. The segments are connected by joints. The hip joint has three, the knee one and the ankle two rotational degrees of freedom. Each of the lower extremities consists of 35 muscles, type “Simple Constant Strength Muscle”, because the used MinMaxNRSimplex solver does not work with “Three-element Hill type Muscles” for extreme joint angles [25]. The MinMaxNRSimplex solver is a simplex solution routine in order to minimize the maximum muscle activity [26]. This optimization criterion uses all synergistic muscles in such way to spread the muscle force in order to minimize the maximum relative muscle force. The mathematical formulation of the optimization scheme of the muscle-recruitment approach is described in detail by Damsgaard et al. [21].

2.2. Multi-body kinematics

The boundary conditions of the multi-body model can be either defined by kinematic data from a motion analysis or by definition of angular displacements at the connecting joints between the segments of the model. Since in the literature there is no data available on the kinematics of the sit-to-stand movement for the complete body, the activity of getting up from a chair was modelled by adjusting the joint angles by common sense. The ischial tuberosity was defined as a reference point for the seat height. The height of the ischial tuberosity can be adjusted by varying the angles in the foot and in the knee joint. The femur of the model was aligned in level with the seat. The event of lift-off from the seat serves as the starting point of the simulation. To reach a balanced body posture the body center of mass has to be right above the standing point on the ground during lift-off. In the sitting position with the feet planted on even ground the hip angle was set to move the upper body forward to the point were the body center of mass was above the standing point on the ground. Thus, the joint angles at the starting position were assumed (Fig. 1). Final angles were set to an upright standing position. Thus, the model was driven to move from a sitting to an upright standing position by the drivers at the hip, knee and foot joint. At all three drivers the angular values were changed linearly and at a constant angular velocity beginning with the starting angle. During the sit-to-stand motion of the model the center of body mass was checked to keep its location right above the standing point to assure a balanced body posture at all timesteps during the motion cycle. Thus, the kinematics of getting up