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Femoral Shape and Size Variability from segmented CT datasets for patient-specific THA planning

Abstract: Biomechanical functionality of artificial hips strongly correlates with quality of life of patients after total hip arthroplasty. As the numbers of total hip arthroplasty are growing due to increasing life expectancy, biomechanical research is of utmost importance to improve the implants used and the operative procedures applied. Multibody simulation is used to predict forces and moments inside the human body. Generic scaling is usually performed to adapt the human models used in multibody simulation to individual patients. However, since the shape and size of the bones can vary considerably, this type of scaling often is not sufficient. In this work various CT datasets were used to quantify differences of individual femoral shapes, especially with regard to important biomechanical hip parameters, such as the CCD angle or the femoral offset. Our results prove that multibody simulations should be modeled more patient-specific to be able to calculate articular forces and moments more precisely, and thus, to improve surgical planning.

Keywords: Total hip arthroplasty, Biomechanics, Segmentation, Multibody simulation, Subject-specific modeling, Surgery planning, Orthopaedics

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1 Introduction

Due to demographic change in sense of a progressively ageing population, cases of osteoarthritis especially of the hip and hence, the numbers of total hip arthroplasty (THA) are rising [1]. THA ensures the mobility of patients and thus, increases their quality of life [2].

Although THA was designated as one of the most successful operations of the 20th century, with a life rate of up to 95% after 10 years in patients older than 75 years, an increasing number of revision surgeries is expected in nearer future [3, 4].

Revision THA is characterized by the fact that it does not improve pain and function as well as primary THA [5, 6].

Hence, meticulous planning of hip surgery parameters, such as the femoral centrum-collum-diaphyseal (CCD) angle or the acetabular anteversion is of utmost importance to ensure functionality in case of revision THA. However, joint forces and moments as well as other important biomechanical factors are not considered in THA planning at all.

Multibody simulation (MBS) is essential to correctly estimate these parameters and hence, to improve surgical planning. MBS allow to simulate forces, moments and muscle activities in order to gain important information about human biomechanics [7, 8].

Models of the human body consisting of rigid bodies (bones), muscles and joints are mostly used for MBS purpose. In order to adapt these models individually to patients, height and weight can be adjusted. These adjustments are usually based on generic scaling.

However, important patient-specific information is usually lost or not simulated correctly. The purpose of this work is to quantify individual differences of important landmarks of the femur bone for biomechanical simulation to demonstrate the importance of an individualized adaption of these landmarks to human models. Due to adjustments of models to individual femur physiology, the muscle attachment points of the MBS-model and in consequence the calculated forces and moments of the hip joint will change [9].

2 Material and Methods

For this study, 7 CT-datasets were examined. Therefore, the DICOM-images were imported to Materialise Mimics

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Research (Materialise NV, Leuven, Belgium). First, important geometrical parameters with influence on the biomechanical function such as the CCD angle or the femoral offset were determined in 2D anatomical planes (Fig 1a). Second, the bony structures of the CT data were segmented. Then the femur was separated from the pelvis (Fig 1b) and a 3D reconstruction of the femur was performed (Fig 1c). Four different landmarks were set to the 3D femur model on the femoral center of rotation (COR), the proximal posterior greater trochanter point (PPTP), posterior femoral head point (PFHP) and the anterior femoral head point (AFHP). Distances were then measured between the COR and PPTP (d-COR-PPTP) and the PFHP and the AFHP (d-PFHP-AFHP).

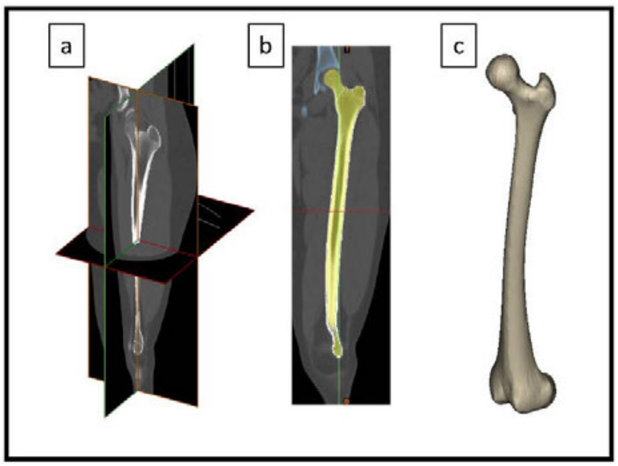

Figure 1: Segmentation workflow: a) Imported DICOM-Files of the CT-Scan b) Marking of bony structures and differntiation of pelvis (blue) and the femur (yellow); c) 3D reconstruction of the femur.

3 Results

The results of the measurements of the CCD angle and the femoral offset are shown in Table 1. The minimum measured CCD angle was 118.3° and the maximum angle was 139.5°. The mean value of the measurements gave a CCD angle of 130.1° ±7.2.

The femoral offset also showed significantly different values. The lowest femoral offset was 29.7 mm and the maximum 46.8 mm. The mean offset was 37.8 mm ±6.8 for the seven patients.

The mimimal distance of the d-COR-PPTP was 42.7 mm and the maximum 56.7 mm. The mean was 51.0 mm ±4.4. The distances for d-PFHP-AFHP were 34.0 mm (minimum), 49.9 mm (maximum) with a mean value of 43.9 mm ±5.2.

Table 1: Minimum, maximum and mean values of the CCD-angle and the femoral-offset for the 7 patients.

	Min	Max	Mean (± SD)
CCD-angle [°]	118.3	139.5	130.1 (±7.2)
Femoral-offset [mm]	29.7	46.8	37.8 (±6.8)
d-COR-PPTP [mm]	42.7	56.7	51.0 (±4.4)
d-PFHP-AFHP [mm]	34.0	49.4	43.9 (±5.2)

4 Discussion

The results show large differences for all measured parameters. If these different shapes and sizes of the femur were considered in a patient-specific way in MBS, muscle and tendon attachment points would change and thus, lead to more precise moments and forces of the hip joint. As a result, more realistic results of MBS could lead to a better understanding of hip biomechanics and thus, help to improve surgical planning of THA.

5 Conclusion

The large differences in the shape and size of bones and the need of patient-specific modelling have also been shown in other studies [10]. Differences in size and shape of the femur lead to changes in the tendon and muscle attachment points and hence, to more precise results in MBS.

Author Statement

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