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ORIGINAL ARTICLE

Three-dimensional finite analysis of acetabular contact pressure and contact area during normal walking

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KEYWORDS
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Summary *Background:* This study aims to analyze the contact areas and pressure distributions between the femoral head and mortar during normal walking using a three-dimensional finite element model (3D-FEM).
Methods: Computed tomography (CT) scanning technology and a computer image processing system were used to establish the 3D-FEM. The acetabular mortar model was used to simulate the pressures during 32 consecutive normal walking phases and the contact areas at different phases were calculated.
Results: The distribution of the pressure peak values during the 32 consecutive normal walking phases was bimodal, which reached the peak (4.2 Mpa) at the initial phase where the contact area was significantly higher than that at the stepping phase. The sites that always kept contact were concentrated on the acetabular top and leaned inwards, while the anterior and posterior acetabular horns had no pressure concentration. The pressure distributions of acetabular cartilage at different phases were significantly different, the zone of increased pressure at the support phase distributed at the acetabular top area, while that at the stepping phase distributed in the inside of acetabular cartilage.
Conclusion: The zones of increased contact pressure and the distributions of acetabular contact areas had important significance towards clinical researches, and could indicate the inductive factors of acetabular osteoarthritis.

Conflicts of interest: All authors have no conflict of interest regarding this paper.

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1. Introduction

The acetabular joint is the main joint used in weight-bearing walking, carrying the pressure distributions of body weight, therefore, it is the key factor during the development of joint diseases, and the abnormal mechanical mechanism of articular cartilage is one of the main causes of osteoarthritis.[1–4]

Therefore, it is necessary to assess the contact pressure distributions and the peak values on the surface of the joint. Understanding the contact pressure distributions of the acetabular joint could help to understand the mechanical mechanisms of normal acetabulum and the pathological processes of articular cartilage under abnormal loadings.[5] Furthermore, assessing the contact pressure in daily activities would provide functional knowledge for preoperative planning and postoperative rehabilitation.

Since the beginning of the 1980s, researchers have conducted *in vitro* experiments and analysis on the maximum pressure of the acetabular joint.[6–8] *In vivo* experiments were also conducted, where researchers used the femoral head prosthesis, which was implanted with a pressure sensor, to analyze the acetabular maximum pressure during walking and when standing from seated. These maximum pressures changed over time during different active processes.[9–11] Though these acetabular pressure measurements could be performed accurately, it is still difficult to maintain the conditions under physiological status in *in vitro* experiments, and it is prohibited to implant pressure sensors into the human body in *in vivo* experiments.

Although the above researches obtained an insight of acetabular functions, there was no report about the characteristics of the contact area and contact pressure distribution during the entire normal walking cycle. Furthermore, these experiments were invasive and expensive, and multiple simulations in one single sample were impossible.

In recent years, finite element model (FEM) analysis has become the most widely used method for biomechanical analysis because it can perform high-precision simulation and accurate analysis of the complex structures of human organs.[2,3,12] In addition, FEM is noninvasive, low cost, and reusable when studying joint pressure. The purpose of this study was to firstly establish a three-dimensional (3D)-FEM of the acetabular joint, then preliminarily study the contact pressure distributions and contact areas of the acetabular bottom by simulating different phases during walking.

2. Methods

2.1. Patient

One healthy male adult volunteer (male, 40 years old, 62 kg, 170 cm) was selected, and underwent pelvic scanning with SOMATOM Volume Zoom multislice spiral CT (Siemens Medical Solutions, Germany) in January, 2016. The bone tissue window was scanned with a slice thickness of 0.6 mm to obtain the digital imaging and communications in medicine (DICOM) images of faults. The parameters of the pelvis were as follows: femoral head radius, 27.5 mm; pelvic height, 23.1 cm; and pelvic width, 29.2 cm. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Southern Medical University, Shenzhen, China. Written informed consent was obtained from the patient.

2.2. Establishment of 3D-FEM

Following the CT scan to obtain the DICOM images of acetabular faults, the DICOM data and Mimics16.0 software (Materialise Co., Belgium) were then used for the 3D reconstruction, combined with FEM analysis software PATRAN 2010 (MSC Software Co., USA). The 3D-FEM of the acetabulum was then established (Table 1 and Figure 1); a total of 113,028 units and 137,524 nodes were divided, and the material properties were obtained from related foreign literatures.[12,13]

On the basis of the 3D-FEM of the acetabulum, we assumed the femoral head and the acetabulum were spherical, and their articular cartilages were concentric circles, with the acetabular center point consistent with that of the femoral head. This meant the cartilage coverage on the acetabular surface could be determined, and the acetabular fossa had no cartilage coverage. Therefore, the possible 3D acetabular contact surface could be obtained, which was considered as uniform, and conventional mesh could be used to replace the acetabular contact surface. The diameter of the intermediate surface of the articular cartilage was the median value of the diameter between the acetabulum and the femoral head. Because the contact areas and the peak pressures would be involved in the mesh densities of the contact surface, the articular cartilages were further finely divided into 19,206 four-node tet10 mesh units to express the possible contact areas (Figure 1), which would not overly increase the calculation, but would express a smooth surface.

2.3. Forces on femoral head and mortar

Pedersen et al[13] detected the forces on the femoral head and mortar with an acetabular prosthesis equipped with electrical devices during normal walking (Figure 2). We used these data and calculated the relationship between the femoral head and mortar among 32 consecutive walking phases. The walking speed of the reported gait cycle was 0.89 m/s.[13]

Table 1 Material properties of finite element model.

Material	Elastic modulus	Poisson's ratio
Cortical bone	17 Gpa	0.3
Cancellous bone	100 Mpa	0.2
Cartilage	11.85 Mpa	0.45