Dynamic Three-Dimensional Femoral Head Coverage in Total Hip Arthroplasty During Weight-Bearing Daily Activities

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INTRODUCTION: Femoral head coverage refers to the degree to which the femoral head in the hip joint is covered by the acetabulum. It is essential for maintaining the stability of the hip joint. Currently, coverage is considered to be the main feature of hip dysplasia, and insufficient coverage results in a smaller load-bearing surface of the hip joint and increased contact stress, leading to hip osteoarthritis (OA). Total hip arthroplasty (THA) is the mainstay of treatment for end-stage hip osteoarthritis, and one of the important goals is to improve coverage to restore the patient's functional mobility. In most cases, clinical diagnosis and surgical planning are guided by two-dimensional measurement assessment. However, these two-dimensional parameters are affected by imaging techniques. Previously, 3D data based on pelvic and femoral morphology have been used as a more accurate method of quantifying 3D coverage. However, these images are static and acquired in the supine position. Therefore, the aim of this study was to analyze the changes in coverage in THA patients during movements such as different postures or gaits.

METHODS: This study was approved by the ethics board (IRB). A total of 17 unilateral primary THA subjects (5 males, 12 females) were recruited and diagnosed with unilateral end-stage hip OA. The mean age was 59.7 (±8.8, range 47-73) years, and the body mass index (BMI) was 26.9 kg/m2 (±6.0, range 19.7-43.4). All participants underwent computed tomography (CT) scans from the fifth lumbar vertebra to the proximal femur. Manually select 30 landmark points evenly distributed on the edge of the acetabular cup, and then use the least square method to fit the 3D plane to determine the plane of the acetabular cup opening [1]. Two mobile fluoroscopes are set in almost orthogonal positions to form a dual plane fluoroscopic imaging system (DFIS), 30 snapshots per second, each patient walks at the implanted hip and the contralateral native hip at a self-selected walking speed Walk horizontally on the treadmill. A series of fluoroscopic images and 3D bone models were imported into a customized program (MATLAB, MathWorks, Natick, MA) to complete the 6-DOF registration of the models and fluoroscopic images. The registration results reproduce the in vivo spatial position of the hip joint during static standing and dynamic horizontal walking. Hip stability is affected by coverage in the gravitational plane, and we propose to quantify a patient's three-dimensional coverage during a gravitational plane-based gait. The gravity plane is determined by the gravity line and the center of the sphere, which is obtained by fitting the three-dimensional model of the native femoral head or the three-dimensional model of the implanted prosthetic femoral head. Therefore, we calculated the three-dimensional coverage of the femoral head based on the area covered by the femoral head above the plane of gravity and the plane of the acetabular opening. Normal distribution was verified using the Kolmogorov-Smirnov test. Pearson correlation was applied to determine the relationship between the three-dimensional coverage measured during gait and the static standing position for each patient, with the significance level set at $p<0.05$.

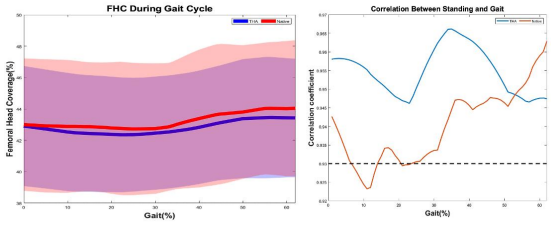
RESULTS SECTION: In the static standing position, the three-dimensional coverage of the THA side and the native side were 42.50±3.82% and 42.55±4.21%, respectively. The three-dimensional coverage of the THA side and the native side did not change much during gait, ranging from 42.35–43.45% and 42.72–44.04%, respectively, and the variation ranges were 0.08–2.57% and 0.10–3.09%, respectively (Fig. 1A). The difference between 3D coverage during gait and static standing position was small, with 15 subjects having a difference of less than 2.5%, and the correlation was high and significant during the gait cycle (THA side r=0.946~0.966, native side r=0.923~0.965) (Fig. 1B), there was no significant difference between the two groups ($p=0.4074>0.05$). The inter-observer analysis showed that the ICC of FHC on the THA side was between 0.9422 and 0.9555, with strong reliability, and the absolute difference between observers was 0.27-2.45%.

DISCUSSION: The current study quantified the dynamic changes in three-dimensional coverage based on the gravity plane during horizontal walking and static standing in patients after unilateral THA. We found that coverage measured in a static stance position can serve as a somewhat surrogate for coverage during gait. In this study, the coverage of the native side and the THA side varied in a very small range during gait. Coverage during static stance and gait was highly correlated and not significantly different. Our previous research showed that the displacement of the femoral head during THA and native side gait were: anterior/posterior (A/P) 0.75mm and 1.28mm, medial/lateral (M/L) 0.6mm and 1.23mm, 0.74mm and 1.30 mm in/out cup (I/O) orientation [2]. Such small central movements of the femoral head did not result in significant changes in 3D coverage during gait. However, it is worth noting that this conclusion is based on an analysis of patients with a functional hip prosthesis one year after THA and may change if patients with an unstable hip prosthesis are analyzed.

SIGNIFICANCE/CLINICAL RELEVANCE: This study quantifies gravity-based three-dimensional coverage during weight-bearing activities in patients with unilateral THA. During horizontal walking, there was no significant difference in coverage between the THA side and the contralateral native side. For patients with normal femoral head morphology or a well-functioning joint prosthesis after THA, the three-dimensional coverage during static stance can be compared to some extent during gait. However, this conclusion may change for patients with unstable hip prosthesis.

REFERENCES: [1] Tsai, Tsung-Yuan, et al. "Does total hip arthroplasty restore native hip anatomy? Three-dimensional reconstruction analysis." International orthopaedics 38 (2014): 1577-1583. [2] Tsai, Tsung-Yuan, et al. "Asymmetric hip kinematics during gait in patients with unilateral total hip arthroplasty: in vivo 3-dimensional motion analysis." Journal of biomechanics 48.4 (2015): 555-559.

IMAGES AND TABLES:



A **B**

Fig.1 Relationship between three-dimensional coverage in static standing position and horizontal walking in patients with unilateral total hip arthroplasty.