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Dynamic hip kinematics in patients with hip osteoarthritis during weight-bearing activities

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ABSTRACT

Background: There is an interest in quantifying the hip kinematics of patients with end-stage hip disorders before total hip arthroplasty. The purpose of the present study was to obtain dynamic hip kinematics under four different conditions, including deep flexion and rotation, in patients with osteoarthritis of the hip.
Methods: Continuous X-ray images were obtained in 14 patients during gait, chair-rising, squatting, and twisting, using a flat panel X-ray detector. These patients received computed tomography scan to generate virtual digitally reconstructed radiographs. The density-based digitally reconstructed radiographs were then compared with the serial X-ray images acquired using image correlations. These 3D-to-2D model-to-image registration techniques determined the 3D positions and orientations of the pelvis and femur during the movement cycle of each activity.
Findings: For gait, chair-rising, and squatting, the maximum hip flexion angles averaged 22°, 64°, and 68°, respectively. The pelvis was tilted anteriorly by an average of around 7° during the full gait cycle. For chair-rising and squatting, the maximum absolute values of anterior/posterior pelvic tilt averaged 8°/17° and 6°/18°, respectively. Hip flexion showed maximum flexion angle on the way of movement due to further anterior pelvic tilt during both chair-rising and squatting. For twisting, the maximum absolute values of internal/external hip rotation averaged 3°/13°.
Interpretation: Patients with hip osteoarthritis prior to total hip arthroplasty demonstrated the limited ranges of coordinated motion of the pelvis, femur, and hip joint during each activity, especially in deeply flexed and rotated postures.

1. Introduction

Osteoarthritis (OA) of the hip joint is a frequent cause of pain and functional disability (Pua et al., 2009; Reijman et al., 2004). Patients with symptomatic OA often choose to undergo total hip arthroplasty (THA) to relieve pain, improve function, and return to high-level activities. As patients' function and ability are directly affected by joint kinematics, there is an interest in quantifying the hip kinematics of patients with end-stage hip disorders before THA. Of particular importance are pre-THA hip mechanics in deeply flexed and rotated postures, as patients expect to perform activities involving these positions after THA. Several reports have analyzed OA hip kinematics with video motion capture system providing valuable data (Eitzen et al., 2012; 2014), but lowest reliability and highest error due to soft tissue artifact were found in the measurements of the hip and knee transverse plane (Cappozzo et al., 1996; McGinley et al., 2009; Reinschmidt et al., 1997).

The accurate evaluation of kinematics under weight-bearing conditions has been achieved using 3D-to-2D model-to-image registration techniques (Hamai et al., 2009; Ishimaru et al., 2014; Komistek et al., 2003; Li et al., 2008; Moro-oka et al., 2008). Recently, these techniques have been applied to kinematic analyses of healthy hips (Hara et al., 2014) and THA (Koyanagi et al., 2011; Tanino et al., 2008; Tsai et al., 2013) with sufficient accuracy (root-mean-square errors: 0.3–2.2 mm and 0.4–1.3° for translation and rotation, respectively) for many clinically relevant measurement scenarios. Our previous study demonstrated activity-dependent kinematics of healthy hip joints with coordinated pelvic and femoral dynamic movements (Hara et al., 2014) (e.g. maximum hip flexion angles during chair-rising and squatting: 81° and 102° on average, respectively). On the other hand, hip kinematics in patients after THA showed smaller hip flexion angles than those in healthy subjects (Koyanagi et al., 2011; Tanino et al., 2008; Tsai et al., 2013) (e.g. maximum hip flexion angles during squatting: 86° on

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average). Previous gait analyses using optical motion capture revealed significantly reduced hip flexion angles in patients with OA of the hip (Eitzen et al., 2012; Kubota et al., 2007). However, to the best of our knowledge, no direct measurement of skeletal kinematics has yet been done to demonstrate how end-stage hip disorders affect kinematics during activities. The purposes of the present study were to evaluate the kinematics of OA hips prior to THA during gait, chair-rising, squatting, and twisting using density-based, 3D-to-2D model-to-image registration techniques. These activities, which included deep flexion and rotation, are fundamental and commonly encountered during daily living. In the present study, we sought to address specific questions: 1) How do the hip joints of patients with OA move during different functional activities?, 2) How much different is the kinematics of squatting from chair-rising in patients with OA? and 3) How much is axial rotation restricted during twisting in patients with OA?

2. Methods

2.1. Subjects

The present study consisted of 14 patients who were scheduled to undergo unilateral THA for treatment of severe OA. The American College of Rheumatology criteria were used to classify and report OA of the hip: pain in the hip, radiographic femoral and/or acetabular osteophytes, and radiographic joint space narrowing (Altman et al., 1991). Inclusion criteria were: (1) the ability to perform at least three of four activities, including gait, chair-rising, squatting, and twisting; (2) no neuromuscular disorders; (3) no previous surgery of the analyzed hip; (4) no previous surgery of other joints or spine; and (5) Kellgren and Lawrence scale (Kellgren and Lawrence, 1957) grade III or IV. There were 14 eligible OA patients, including 12 females and two males with an average age of 65 years (standard deviation (SD) 7, range 56–77), height of 154 cm (SD 8, range 137–164), weight of 54 kg (SD 9, range 40–73), and body mass index of 23 kg/m^2 (SD 4, range 18–31). According to the Kellgren and Lawrence scale (Kellgren and Lawrence, 1957), three hips were classified as grade III, a Board-approved study, and were informed of the risks and 11 hips were classified as grade IV. The mean Harris hip score (Harris, 1969) was 48 (SD 10, range 26–59). All subjects gave informed consent to participate in this Institutional Review of the radiation exposure required. The procedures followed were in accordance with the ethical standards of the Helsinki Declaration of 1975, as revised in 2000.

2.2. Kinematic analysis

Continuous radiographic images during gait, chair-rising, squatting, and twisting motions were recorded using a flat-panel X-ray detector (Ultimax-I, Toshiba, Tochigi, Japan), with an image area of 420 mm (H) × 420 mm (V) and a resolution of 0.274 mm × 0.274 mm/pixel, 0.02 s pulse width, 80 kV and 360 mA (Fig. 1). The frame rate was set at 3.5 frames/s to acquire high-resolution images. For gait, subjects walked on a level treadmill at 1.0 km/h. For chair-rising, subjects rose from a seated position on a chair of 46.5-cm height. For squatting, subjects stood from a position with maximum hip flexion. For twisting, subjects rotated their trunks contralaterally and ipsilaterally in a standing position while keeping their feet on the floor. Six subjects (six hips) did not participate in squatting because of hip discomfort and limited range of motion (RoM).

The 3D positions and orientations of the pelvis and femur during the movement cycle of each activity were determined by a density-based, 3D-to-2D model-to-image registration techniques using image correlations. Each subject was scanned by computed tomography (CT; Aquilion, Toshiba, Tochigi, Japan) with a 512 × 512 image matrix, a 0.35 × 0.35 pixel dim, and a 1-mm thickness spanning from the superior edge of the pelvis to below the knee joint line. A 3D digital image was constructed in a virtual 3D space using the CT data, and the anatomical coordinate systems of the pelvis and femur were embedded in each density-based volumetric bone model (Hara et al., 2014). Then, computer simulation of the radiographic process was carried out to generate virtual digitally reconstructed radiographs (DRRs), in which the light source and projection plane parameters were set identical to the actual flat-panel X-ray detector imaging conditions. The density-based DRRs were then compared with the serial X-ray images acquired using the flat-panel X-ray detector. Correlations of the pixel values between the DRRs and real X-ray images were used to fine-tune the 3D model. Specifically, multiple image windows that spanned the bone edge

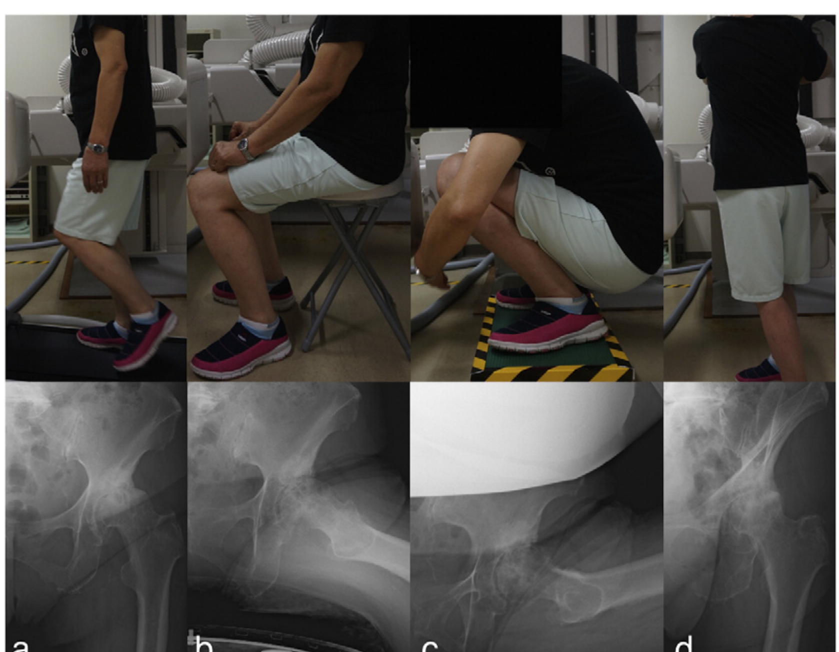

Fig. 1. Patients with osteoarthritis of the hip joint walked on a level treadmill at 1.0 km/h (a), got up from a chair (b), stood from a position with maximum hip flexion (c), and rotated the trunk bilaterally from a neutral standing position (d) under radiographic surveillance.