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Root mean square of lower trunk acceleration during walking in patients with unilateral total hip replacement

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ABSTRACT

Although several studies have described abnormal trunk motion before and after total hip arthroplasty (THA) surgery, few studies have examined trunk motion using accelerometry. The aim of this study was to determine whether abnormal trunk motion persisted after THA using accelerometry.

A total of 24 female patients (61.0 ± 6.9 years) and 20 healthy female subjects (59.9 ± 6.8 years) participated in this study. Patients were assessed at 1 month prior to surgery and 12 months after surgery. Trunk acceleration during gait was measured using a triaxial accelerometer attached to the L3 spinous process. We calculated the root mean square (RMS) and RMS ratio (RMSR) in the vertical (VT), medio-lateral (ML), and anterior–posterior (AP) directions.

Results revealed that the RMS in the VT and AP directions postoperatively was greater than that preoperatively, whereas there was no difference in the RMS in the ML direction. In addition, the preoperative RMSR in the ML direction was significantly greater compared with that of healthy individuals and the postoperative RMSR. There was no difference in the RMSR in the ML direction between healthy individuals and postoperatively.

These findings suggested that the trunk motion in the frontal plane prior to surgery had improved and was comparable to that of healthy individuals following THA.

1. Introduction

Hip osteoarthritis (OA) is a common and chronic musculoskeletal disease that is a cause of musculoskeletal pain and functional disability [1]. The prevalence of hip OA increases with age and the burden of hip OA is likely to become a major problem for health systems globally [2]. Total hip arthroplasty (THA) is the most common surgical intervention for end-stage hip OA . THA offers patients pain relief and functional recovery and enhances their quality of life [3,4].

Even though patients obtain these post-operative improvements, they walk slower than healthy age-matched controls [5,6]. In addition, prior studies have revealed that patients with THA exhibited different gait kinematics from that of healthy controls [6,7]. In particular, patients with hip OA showed the characteristic trunk motion in the frontal plane (i.e, Trendelenburg gait and Duchenne gait), which may persist one year after THA surgery [7]. Persistent abnormal trunk motion leads to asymmetrical loading, which may result in a slow recovery on the operated side [8] and the development and progression of joint degeneration on the contralateral side [9]. Furthermore, abnormal lateral trunk motion decreases walking efficacy in forward propulsion [10]. Thus, the trunk motion during walking should be evaluated in patients with THA. Previous studies have investigated gait kinematics in patients after THA using a three dimensional gait analysis system. However, this three dimensional gait analysis system is particularly expensive and requires laboratory equipment; therefore, it is difficult to apply to clinical settings, such as orthopedic hospitals.

An accelerometer has been proposed as a useful gait analysis technique for clinical settings, and the reliability of gait analysis using an accelerometer has been examined and confirmed [11]. The benefits of gait analysis using accelerometers include: (1) they are non-invasive, (2) they are small and light, (3) and they do not require a special technique; thus, usage is straightforward in the clinical and rehabilitation settings. To date, the validity of the accelerometer in patients with hip OA and total hip arthroplasty has been confirmed [12,13]. However, to the best of our knowledge, few studies have examined the trunk motion before and after THA using accelerometry.

The objectives of this study were to describe the characteristics of patient gait before and after THA using acceleration in comparison with

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healthy controls, and to determine whether abnormal trunk motion prior to THA persisted. We hypothesized that patients showed greater trunk motion in the frontal plane before THA compared with healthy controls. In addition, we hypothesized that the gait pattern persisted following THA.

2. Methods

2.1. Subject

A total of 24 female patients with hip OA participated in this study, and were assessed at 1 month preoperatively and 12 months postoperatively. Patients had undergone the anterolateral approach in the supine position and the directed anterior approach, which were performed by two surgeons (K.M. and S.N.). Inclusion criteria were: (1) primary unilateral osteoarthritis of the hip, and (2) ability to walk without a cane. Exclusion criteria were as follows: (1) aged > 80 years, (2) had musculoskeletal dysfunction other than unilateral hip OA that limited their physical function, (3) diagnosed with rheumatoid or other systemic arthritis, and (4) had neurological or other orthopedic conditions affecting their ambulatory ability. We examined hip OA on radiographs of both sides, and we confirmed that the patients had no hip OA on the contralateral side. Preoperative and postoperative radiographic leg length discrepancy (LLD) was measured, using the perpendicular distance between the inter tear-drop line and the most prominent part of the lesser trochanter. Harris hip scores were measured in patients before and after THA. Hip abductor strength was measured as the peak isometric hip abduction torque (Nm/kg) using a hand-held dynamometer (μTas F1; ANIMA, Chofu, Japan), as described in a previous study [14]. The peak torque was estimated as the product of force, and it was converted to Nm by multiplying it by the lever arm distance and then normalizing it to body mass (Nm/kg). Two attempts were allowed, and the larger measurement of the two attempts was recorded. A total of 20 healthy age-matched female individuals were recruited via telephone interviews. All procedures in the present study were approved by the ethics committee of our hospital. Participants were informed about the study procedures before testing and provided written informed consent prior to participation.

2.2. Apparatus

One tri-axial accelerometer (MA3-04AC, MicroStone Co., Nagano, Japan) was used. The accelerometer was attached over the L3 spinous process using a Velcro™ belt to measure the acceleration in the vertical (VT), medio-lateral (ML), and anterior–posterior (AP) directions. Before each measurement, subjects were maintained in a standing position during the ∼10 s required to conduct revisions and calibration of the accelerometer gravitation. Acceleration was sampled at 500 Hz.

2.3. Measurements

Participants were instructed to walk on a smooth, horizontal, 16-m walkway with a 3-m space before each end of the walkway for acceleration and deceleration. All participants wore the same type of shoes to the controls to avoid the potential confounding influence of shoes. Subjects walked at their self-selected normal speed and walking time was recorded to measure gait velocity. A numeric rating scale was used to quantify leg pain during gait.

2.4. Analysis of the acceleration data

Following analog-to-digital conversion, signals were collected in a data logger (MVP-RF8-S; Microstone Co.) and immediately transferred to a laptop computer through a Bluetooth personal area network. Signal processing was performed using Matlab Release R2013a (MathWorks, Natick, MA, USA). Before analysis, all acceleration data were low-pass filtered with a cutoff frequency of 20 Hz. All analyses were performed using data from the middle 8 strides of the steady walk. Following transformation of a data sequence, acceleration data were analyzed by the following tools.

The root mean square (RMS) acceleration was calculated at the L3 spinous process in the VT, ML, and AP directions. The RMS of acceleration is frequently used in gait analysis research [11–13]. This parameter showed the magnitude of acceleration, and several studies have demonstrated that the RMS is affected by walking speed [15,16]. Thus, it is necessary to deal with the walking speed appropriately when the RMS is used for assessing gait movement. However, it is difficult to control the gait speeds in clinical practice. Furthermore, controlling the gait speed should influence the gait parameters in patients with hip OA [17]. In recent years, the RMS ratio (RMSR) has been proposed to evaluate gait abnormality [18]. The RMSR represents the ratio between the RMS in each direction and the RMS vector magnitude. In a previous research study, Sekine et al. reported that the RMSR provides information for gait abnormality considering the difference of individual walking speed [18]. Therefore, we calculated the RMSR using the following equations:

$$RMS_T = \sqrt{RMS_{AP}^2 + RMS_{ML}^2 + RMS_V^2}$$

$RMSR_X = RMS_X/RMS_T$ where x represents the direction of acceleration.

2.5. Statistical analysis

The Kolmogorov-Smirnov test was used to determine normality of the distribution. The non-paired *t*-test was used to identify differences in demographic data between patients with hip OA and age-matched healthy subjects (significance set at $p < 0.05$). The non-paired *t*-test was also used to compare the acceleration-derived gait parameters of the patients with that of healthy subjects using the Bonferroni correction (significance set at $p < 0.025$). In addition, the paired *t*-test and Mann-Whitney *U* test were used to compare the LLD, abductor strength, and acceleration-derived gait parameters before and after the operation (significance set at $p < 0.05$).

Additionally, we investigated correlations of the RMSR, LLD, and abductor strength in the preoperative and postoperative phases. Moreover, in the case that the LLD or abductor strength was significantly correlated with the RMSR-ML, we examined relationships between the preoperative value, postoperative value, and difference between the preoperative value and postoperative value with respect to the LLD or abductor strength (significance set at $p < 0.05$).

Statistical procedures were performed using the SPSS 21.0 statistical analysis package (IBM SPSS, Armonk, NY, USA).

3. Results

3.1. Baseline characteristics

Table 1 summarizes the characteristics of the patients and healthy individuals. There was no significant difference in these baseline characteristics between the two groups.

3.2. Acceleration data

Gait speed and the acceleration-derived gait parameters are summarized in Table 2. Patients due to undergo THA walked slower than healthy individuals prior to THA. Although the patients walked faster after THA than preoperatively, their walking speed was significantly slower than healthy individuals. The postoperative RMS in the VT and AP directions was greater than preoperatively, whereas there was no difference in the RMS in the ML direction. With regard to the RMSR, the preoperative $RMSR_{VT}$ in patients who underwent THA was significantly smaller than in healthy individuals. The preoperative $RMSR_{ML}$ was

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