Gait & Posture 66 (2018) 214–220

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Early clinical evaluation of total hip arthroplasty by three-dimensional gait analysis and muscle strength testing

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ARTICLE INFO

Keywords:
Dynamic three-dimensional gait analysis
Portable gait rhythmograph (PGR)
Hip muscle strength
Total hip arthroplasty (THA)
Clinical evaluation

ABSTRACT

Background: As improvement of gait is an important reason for patients to undergo total hip arthroplasty (THA) and they generally tend to evaluate its success based on postoperative walking ability, objective functional evaluation of postoperative gait is important. However, the patient's normal gait before osteoarthritis is unknown and the changes that will occur postoperatively are unclear. We investigated the change in gait and hip joint muscle strength after THA by using a portable gait rhythmograph (PGR) and muscle strength measuring device.

Patient and methods: The subjects were 46 women (mean age: 65.9 years) with osteoarthritis of the hip. Gait analysis and muscle strength testing were performed before THA, as well as 3 weeks and 3 months after surgery. We measured the walking speed, step length, and gait trajectory using PGR prospectively. PGR is attached to the patient's waist and records signals at a sampling rate of 100 Hz. Isometric torque of hip flexion and abduction were measured by using a hand-held dynamometer.

Results: There was no improvement at 3 weeks postoperatively, but the walking speed, stride length and muscle strength were clearly showed improvement at 3 months postoperatively. The walking trajectory was not normal preoperatively, since the trajectory was not symmetrical and did not intersect in the midline or form a butterfly pattern, and abnormality of the trajectory tended to persist postoperative 3 months despite resolution of hip joint pain after surgery.

Conclusion: Since postoperative improvement of gait is an important consideration for patients undergoing THA, it seems relevant to evaluate changes in the gait after surgery and three-dimensional analysis with a PGR may be useful for this purpose.

1. Introduction

Patients with severe osteoarthritis of the hip have gait disturbance due to hip joint pain, restricted range of motion, and weakness of the hip joint muscles, all of which are considerably improved by total hip arthroplasty (THA). Improvement of gait is an important reason for patients to undergo surgery and they generally tend to evaluate its success based on postoperative walking ability. Moreover, the majority of patients undergoing THA are elderly, and whether they can walk safely unaided is an important issue for both their families and the medical/welfare system. Considering these points, it seems necessary to evaluate the recovery of gait when assessing postoperative hip joint function.

Whether the gait is symmetrical or not represents an important aspect of walking. In general, normal gait is considered to be symmetrical and asymmetry is regarded as a sign of gait abnormality. Standard methods of gait analysis include multi-camera motion capture systems and electronic walkways. While these methods provide accurate and reliable information, they are time-consuming and expensive because of the requirement for special equipment. Recent advances in microelectromechanical systems technology have led to development of wearable inertial sensors, including accelerometers and gyroscopes, which can be applied for monitoring gait in the clinical setting. The major advantages of inertial sensors are their small size, low cost, and long operating life, which allow unobtrusive monitoring of the walking pattern without interfering with natural movement. Based on such sensor technology,

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https://doi.org/10.1016/j.gaitpost.2018.08.037
Received 8 May 2018; Received in revised form 24 July 2018; Accepted 27 August 2018
0966-6362/

researchers have developed effective methods for quantifying gait asymmetry [1,2]. The most common methods used to define gait asymmetry are the Symmetry Index, the Symmetry Ratio, and statistical approaches [3]. Quantitative measures are essential for assessment of gait, but using algebraic and statistical indices can make it difficult for both clinicians and patients to interpret the effects of intervention and rehabilitation. On the other hand, visual input such as 3D images could be incorporated into the presentation of gait analysis to facilitate understanding of a patient's progress. Accordingly, gait data were employed to draw walking trajectories in this study, rather than simply comparing numerical values.

. In addition, lower limb muscle strength has a marked influence on daily activities, and recovery of muscle strength is closely related to postoperative improvement in activities of daily living. Accordingly, we investigated the change in gait and hip joint muscle strength after THA by using a portable gait rhythmograph and muscle strength measuring device.

2. Patients and methods

The subjects were 46 women who received THA at our hospital from March 2016 to June 2017. All operations were performed via the posterior approach with the patient in the lateral decubitus position. The surgical procedure, operating room staff, and prostheses were similar in all operations. Patients were allowed to walk with full weight bearing and performed exercises for hip joint muscle strengthening from the day after surgery. They were all able to undergo gait analysis and measurement of hip joint muscle strength. Their mean age was 65.9 ± 10.3 years (range: 43 to 91 years), and the hip disease was osteoarthritis in all 46 patients. Mean height and body weight was 152 ± 5.1 cm and 54 ± 9.4 kg, respectively. When the contralateral hip joint was assessed according to the Kellgren and Lawrence classification, it was ≤ grade 2 in 18 patients (normal group) and ≥ grade 3 in 12 patients (severe OA group), while THA had already been performed in 16 patients (implant group). Three healthy women with an average age of 25 years (24 to 26 years) were used as a control group. Their mean height was 156 cm and mean body weight was 53 kg. Gait analysis and muscle strength testing were performed before THA, as well as 3 weeks and 3 months after surgery.

For gait analysis, we used a portable gait rhythmograph (MG-M 1110, LSI Medience Corporation, Tokyo, Japan). This is a small device (8 × 6 × 2 cm, weight; 80 g) housing an accelerometer. As reported previously [4,5], gait-induced acceleration is extracted from limb and trunk movements by using an automatic gait detection algorithm ("pattern matching method"). The portable gait rhythmograph performs three-dimensional (ax, ay, az) measurement of acceleration associated with voluntary limb and trunk movements, as well as acceleration induced by heel strike and toe-off when walking. The accelerometer device was secured at the patient's waist by using a belt. When the patient was standing in the anatomical position, the three acceleration axes (X, Y, and Z) were oriented in the mediolateral, vertical, and anteroposterior directions, respectively. Thus, a positive X values represented acceleration to the left, a positive Y value indicated upward acceleration, and a positive Z value meant forward acceleration. Data were collected at a sampling frequency of 100 Hz and were stored on a microSD card in the device for subsequent analysis. When recording is completed, the absolute values of the acceleration vectors are calculated and displayed graphically on a PC [6]. We studied normal walking (walk at a normal pace) and fast walking (walk as fast as possible but without falling) for a distance of 10 m in the 46 patients by measuring the walking speed, step length, and gait trajectory.

Investigation of gait was carried out in a large indoor space. Subjects were asked to wear shoes that were easy to walk in and were requested to walk straight along a 10 m walkway without assistance. An extra distance (approximately 2 m) was added before and after the walkway to minimize the effect of acceleration and deceleration. The 10 m walking time and step count were measured by an experimenter. While the subject was walking, an experimenter with a stopwatch followed slightly behind. The distance markers were clear enough for the experimenter to see when using the stopwatch, but were not prominent enough to influence the walking style of the subjects.

Maximum voluntary bilateral hip flexion strength and abduction strength were measured by using a hand-held dynamometer (Isoforce GT-300, OG Giken Co. Ltd., Okayama, Japan) during isometric contraction for 3 s against manual resistance, as reported previously [7]. The subject rested in the supine position with the hip and knee in the neutral position for flexion/extension and the hip in the neutral position for abduction/adduction. The sensor of the dynamometer was placed at the proximal border of the patella when assessing hip flexion and the "lever arm" for calculating hip flexion torque was the distance from the patellar border to the anterior superior iliac spine. In addition, the sensor was placed 5 cm proximal to the proximal border of the lateral malleolus when assessing hip abduction; hence, the lever arm for calculating hip abduction torque was the distance from this point to the anterior superior iliac spine. Torque was calculated as force multiplied by the lever arm and was expressed as a percentage of body weight (Nm/kg). The affected side / contralateral side ratio (%) was determined in each patient for comparison of muscle strength.

The significance of differences in mean walking speed, walking stride, and muscle strength between before THA and 3 month postoperatively was evaluated with the unpaired *t*-test for normally distributed data. Statistical analysis was performed with StatView Ver. 5.0 software for Macintosh (SAS Institute Inc., North Carolina) and a p value < 0.05 was considered to indicate statistical significance.

Informed consent was obtained from all subjects and the study procedures were conducted in accordance with the guidelines of the Ethics Committee of our institution. And this research has been approved by the IRB of the authors' affiliated institutions.

3. Results

In the normal group of patients, the mean preoperative normal walking speed and fast walking speed was 3.16 ± 0.7 km/h versus 4.19 ± 1.1 km/h (52.7 ± 11.9 m/min versus 69.8 ± 18.0 m/min), respectively. Also, the preoperative normal and fast walking speeds were 2.55 ± 0.8 km/h versus 3.23 ± 1.1 km/h (42.4 ± 13.4 m/min versus 53.8 ± 18.0 m/min) in the severe OA group and 2.57 ± 0.9 km/h versus 3.53 ± 1.1 km/h (42.8 ± 15.6 m/min versus 58.9 ± 18.1 m/min) in the implant group. In all 3 groups, there was no improvement at 3 weeks postoperatively, but the walking speed was clearly faster at 3 months postoperatively. The mean normal and fast walking speeds at 3 months postoperatively were 4.09 ± 0.6 km/h versus 5.20 ± 0.7 km/h (68.1 ± 10.7 m/min versus 86.7 ± 11.2 m/min) in the normal group, 3.09 ± 0.8 km/h versus 3.71 ± 1.1 km/h (51.5 ± 13.6 m/min versus 61.9 ± 18.2 m/min) in the severe OA group, and 3.75 ± 1.1 km/h versus 4.72 ± 1.4 km/h (62.5 ± 18.3 m/min versus 78.6 ± 23.5 m/min) in the implant group. A significant difference was noted in the normal and fast walking speeds between before THA and 3 months postoperatively in the normal group ($P < 0.01$ at both normal and fast speeds) and in the implant group ($P < 0.05$ at both normal and fast speeds).

With regard to changes in the stride length, the mean preoperative normal and fast walking stride length was 47.7 ± 6.5 cm versus 54.0 ± 5.8 cm in the normal group, 41.4 ± 6.5 cm versus 45.5 ± 7.9 cm in the severe OA group, and 43.9 ± 13.6 cm versus 51.3 ± 14.0 cm in the implant group. Similar to the walking speed, there was no improvement in the 3 groups at 3 weeks postoperatively. However, the stride length clearly showed improvement at 3 months after surgery, when the mean normal and fast walking stride length was 57.5 ± 5.9 cm versus 62.6 ± 8.9 cm in normal group, 46.7 ± 8.1 cm versus 50.5 ± 8.6 cm in the severe OA group, and 54.2 ± 10.9 cm versus 59.7 ± 15.0 cm in the implant group. A significant difference