Effects of Arm Swing Limitation on Knee Joint Moment during Walking –Biomechanical Analysis Using a 3D Motion Capture System–

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Abstract. [Purpose] The purpose of this research was to examine the biomechanical effects of arm swing limitation on knee joint gait. [Subjects] Subjects were 10 healthy males (mean age, 22 ± 0.8 years; mean height, 173.9 ± 5.9 cm; mean weight, 67.0 ± 6.4 kg). [Methods] Knee abduction normally shows a bimodal curve. The top of the primary curve was defined as val_m1 and that of the secondary curve was defined as val_m2. Knee abduction moment, knee extension moment, GRF range, trunk rotation range, and arm swing range were then calculated at val_m1 and val_m2. Measurements were performed without arm swing limitation on a 10-m walkway (no limitation condition), and with the subjects’ arms folded in front of their chests (limitation condition). [Results] Val_m1 was 10.9 ± 2.4% of the gait cycle. Val_m1 (65.3 ± 13.1 Nm) under the limitation condition was significantly lower than that (70.0 ± 13.0 Nm) under the no limitation condition (p<0.01). In addition, the knee extension moment (71.7 ± 21.1 Nm) under the limitation condition was significantly higher than that (62.6 ± 20.4 Nm) under the no limitation condition at val_m1 (p<0.01). [Conclusion] Arm swing limitation decreases knee abduction moment, but increases knee extension moment.

Key words: Arm swing, Knee joint moment, Three-dimensional analysis

INTRODUCTION

A large number of studies have been performed on the function of arm swing in human walking1,2, and its importance has been reported. Arm swing limitation and body rotation are gait characteristics of patients with hip and knee osteoarthritis3,4. Therefore, exercise instruction on intentional arm swing motion is often performed with the purpose of improving gait. However, no studies have examined the biomechanical effects of exercise instruction on the knee joint. The purpose of this study was to examine the biomechanical effects of arm swing limitation on knee joint gait.

SUBJECTS AND METHODS

The subjects were 10 healthy males (mean age, 22 ± 0.8 years; mean height, 173.9 ± 5.9 cm; mean weight, 67.0 ± 6.4 kg). All subjects provided their written informed consent before participating in this study. The experimental set-up consisted of a Vicon MX13 3-D motion capture system (Vicon Peak, UK) comprising 8 cameras and 6 force plates (AMTI, USA) operating at a frame rate of 200 frames/second. A total of 29 reflective markers3 were placed on the acromion, the lateral epicondyle of humerus, the styloid process of the ulna, the top of the crista iliaca, the superior anterior iliac spine, the superior posterior iliac spine, the hip joint (1/3 of the distance from the greater trochanter on a line connecting the greater trochanter to the superior anterior iliac spine), the outside knee joint, the inside knee joint, the lateral malleolus, the medial malleolus, the head of the first metatarsal bone, the head of the fifth metatarsal bone, the calcaneus on either side. In the first gait trial, subjects walked normally without arm swing limitation on a 10-m walkway (no limitation condition). Then, subjects walked with their arms folded tightly across their chests (limitation condition). Gait speed and step length were determined without limiting, and cadence was set at 60 steps/min.

Three-dimensional knee joint moments, ground reaction force (GRT) range in the frontal plane (X–Z plane), and trunk rotation range (the angle formed by two straight lines connecting both acromions and both the superior anterior iliacs in the horizontal plane) were computed from kinematic and kinetic data collected using the 3D motion capture system and force plates. The angle and joint moment data were analyzed according to the stance phase of the gait cycle, and were normalized against 100% of the stance phase. The internal knee joint abduction moment in the frontal plane in the stance phase of gait normally shows a bimodal curve. The top of the primary curve was defined as val_m1 and that of the secondary curve was defined as val_m2 (Fig. 1). The internal knee joint abduction moment, internal knee joint extension moment, knee joint flexion
range, GRF range, trunk rotation range, and arm swing range were calculated at val_m1 and val_m2. The right upper and lower limbs were the measurement targets. All data were analyzed using STATISTICA (StatSoft Japan, Japan). The paired t-test was used to analyze the differences between the no limitation condition and the limitation condition. P values of less than 0.05 were considered to be significant.

**RESULTS**

Table 1 shows the comparison of each measurement item of the limitation condition and the no limitation condition. Val_m1 was 10.9 ± 2.4% of the gait cycle. Val_m1 (65.3 ± 13.1 Nm) under the limitation condition was significantly lower than that (70.0 ± 13.0 Nm) under the no limitation condition (p<0.01). Val_m2 was 41.1 ± 1.6% of the gait cycle. Val_m2 (57.1 ± 3.3 Nm) under the limitation condition was significantly lower than that (62.7 ± 4.1 Nm) under the no limitation condition (p<0.01). The knee extension moment (71.7 ± 21.1 Nm) under the limitation condition was significantly higher than that (62.6 ± 20.4 Nm) under the no limitation condition at val_m1 (p<0.01). However, no significant differences were seen in knee extension moment at val_m2. The GRF range (3.1 ± 1.0°) in the frontal plane in the limitation condition was significantly lower than that (3.8 ± 0.9°) under the no limitation condition at val_m1 (p<0.01). However, no significant differences were seen in the GRF range in the frontal plane at val_m2. Trunk rotation range (6.4 ± 3.3°) in the frontal plane under the limitation condition was significantly lower than that (10.3 ± 2.7°) under the no limitation condition at val_m1 (p<0.01). However, no significant differences were observed in trunk rotation range in the frontal plane at val_m2. The arm swing range (3.6 ± 1.4°) in the sagittal plane under the limitation condition was significantly lower than that (32.7 ± 11.7°) under the no limitation condition during the gait cycle (p<0.01).

**DISCUSSION**

Arm swing range in the sagittal plane under the limitation condition was significantly lower than that under the no limitation condition during the gait cycle, and a decline in trunk rotation range was also observed. This shows that arm swing range and trunk rotation range have a profound relationship. Generally, the size of the arm swing range and walking speed are correlated. Our results also suggest a relationship with trunk rotation movement. Trunk rotation movement decreases in patients with OA, and there are thought to be two reasons for this. Fist, trunk rotation movement is limited because postural muscle tone is higher than in a healthy individual due to kinetic chain effects. Second, pelvic rotation movement is smaller, as pelvic rotation is produced in the opposite direction as trunk rotation in gait. Arm swing is then produced in the same direction as trunk rotation. Accordingly, if pelvic rotation is small, trunk rotation decreases, and arm swing range also decreases. In patients with OA, limited hip rotation and dysfunction of hip rotator muscles are major characteristics. Thus, trunk rotation decreases because pelvic rotation decreases, and gait in patients with OA shows a decrease in arm swing range. Internal knee abduction moment under the limitation condition was significantly lower than that under the no limitation condition at val_m1. This shows that when arm swing range is small, the dynamic load in the frontal plane decreases. Kito and others reported that the internal knee abduction moment of patients with knee OA is larger than that of healthy individuals during the stance phase. This

| Table 1. Comparison of each measurement item in the limitation condition and the no limitation condition |
|-----------------|------------------|------------------|
|                  | limitation group | no limitation group |
| knee abduction moment | val_m1 | -65.3 ± 13.1 | -70.0 ± 13.0 * |
|                   | val_m2 | -57.1 ± 3.3  | -62.7 ± 4.1 *  |
| knee extension moment | val_m1 | 71.7 ± 21.1  | 62.6 ± 20.4 *  |
|                   | val_m2 | 5.6 ± 15.0   | 2.7 ± 11.6     |
| GRF range | val_m1 | 3.1 ± 1.0    | 3.8 ± 0.9 *    |
|                | val_m2 | 4.1 ± 0.7    | 3.2 ± 1.1      |
| trunk rotation range | val_m1 | 6.4 ± 3.3    | 10.3 ± 2.7 *   |
|                | val_m2 | 4.7 ± 5.2    | 4.9 ± 4.7      |
| arm swing range | val_m1 | 3.6 ± 1.4    | 32.7 ± 11.7 *  |
|                | val_m2 | 4.7 ± 5.2    | 4.9 ± 4.7      |

*: p<0.01, mean ± SD
suggests that patients with the knee OA have a smaller arm swing range in order to avoid pain. One possible reason for the change in knee abduction moment is the change in the GRF range in the frontal plane. The GRF range in the frontal plane under the limitation condition was significantly lower than that under the no limitation condition at val_m1. Arm swing limitation decreases GRF angle, and this suggests that GRF passes the knee joint center more closely, leading to a decrease in the moment. However, although the internal knee abduction moment was lower, the knee extension moment showed a higher value under the limitation condition. Thus, arm swing limitation decreases knee abduction moment and increases knee extension moment.

In conclusion, this study showed that arm swing range in gait has an important effect on knee abduction moment. Thus, it is important to evaluate and maintain arm swing in gait.

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