Ankle, knee, and hip joint contribution to body support during gait

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Abstract. [Purpose] Support moment was defined as the sum of ankle plantar flexion, knee and hip extension moments. There are some mechanical relationships among the 3 joints. If these relationships were understood, it might be possible to determine which joint should be strengthened to improve gait. The aims of this study were to examine the mutual relationship among kinetic variables of the 3 joints during different phases. [Subjects and Methods] Twenty-five healthy subjects volunteered for this study. They were asked to walk on a platform at a self-selected speed. Correlation coefficients between support moment and vertical ground reaction force were calculated for each subject. Pearson correlation analysis was performed among the 3 joint moments and between each joint moment and vertical ground reaction force. [Results] Knee and hip extension moments showed negative correlation throughout the stance. Ankle moment had a positive with hip but a negative correlation with knee moment except in the initial contact and pre-swing. Hip moment in the initial contact, knee moment in the loading response, and ankle moment from the terminal stance to pre-swing had a high correlation with vertical ground reaction force. [Conclusion] The results may indicate which joint should be strengthened to improve gait pattern.

Key words: Gait analysis, Motion analysis, Biomechanics

INTRODUCTION

Support moment (SupM) was defined by Winter[1] as the sum of the ankle plantar flexion, knee extension, and hip extension moments. It revealed a consistent total limb pattern that supports the body against the ground. If the hip extension, knee extension, and ankle plantar flexion directions are positive, the SupM is always positive during single support. Winter found that mean knee and hip extension moments during stance showed a trade-off relationship both intra-individually and inter-individually[2]. Additionally, he found that the SupM was significantly correlated with vertical ground force[3]. In the first instance, ground reaction forces may be considered equivalent to the acceleration of the center of mass of the human body. Therefore, it is readily understandable how the vertical component of a ground reaction force (VGRF) is related to the SupM.

Subsequent to Winter’s work, we found that this concept applied not only to walking but also to squat motion[4]. We showed the SupM to be highly correlated with the VGRF during squat motion. Moreover, in an analysis of squat motion of patients with Osgood-Schlatter disease, the results showed relatively larger knee extension and smaller hip extension moments than those of normal subjects. If 1 of the 3 extension moments is small, the others are large because of the relationship between the SupM and the VGRF. This led to the idea that these patients may benefit from a larger hip extension moment. Indeed, after training of the hamstrings with a muscle strength exercise, they showed not only motion improvement but also decreased knee pain[5, 6]. In spite of these spatial features fittings the moment’s pattern, we have never examined support moment during different phases of stance. We assumed that the relationships among these three joints would depend on the
phase of stance. If the mutual relationships among these 3 joints during different phases of stance were understood, it might be possible to determine which joint should be strengthened to improve various gait patterns of patients.

The aims of this study were to examine the mutual relationships among kinetic variables of the 3 joints of the lower extremities during different phases of stance.

**SUBJECTS AND METHODS**

Twenty-five healthy subjects volunteered for this study. They ranged in age from 20 to 22 years, and the mean ± standard deviation (SD) age was 21 ± 0.7 years. Their mean ± SD height was 1.588 ± 0.031 m, with a range of 1.524 to 1.773 m, and their mean ± SD weight was 58.4 ± 5.0 kg, with a range of 48.6 to 66.0 kg. Thirty-five markers were attached to each subject’s body and captured by a 3-dimensional motion analysis system (Nexus; Vicon Motion Systems, Oxford, UK) with 8 MX cameras (sampling rate, 200 Hz) and a force platform (AMTI; AMTI Japan, Hiratsuka, Japan; sampling rate, 1,000 Hz). Three-dimensional coordinates of each marker and ground reaction force were analyzed by a plug-in gait model calculating the moments of the ankle, knee, and hip joints (hip extension, knee extension, and ankle plantar flexion taken as positive). Moment data and the VGRF were normalized by the subject’s mass; time was normalized by stance duration. After performing sufficient trials for familiarization with the force platform prior to data collection, subjects were asked to walk with the right foot on the platform at a self-selected speed. Five trials were performed for each subject, and three of them were averaged and used for analysis. Percentile data were used for Pearson correlation analysis. The analyses were performed for each percentile of the stance range, 100 pieces of data were used for analysis for each trial. Trials with incorrect foot contact on the platform were not used. All moments in this article were expressed as internal. All study participants provided written informed consent. Approval was obtained from the Ethics Committee of the Graduate School, Health Care Science, Bunkyo Gakuin University (approval number, 201011).

Data were analyzed as follows:
1. Correlation coefficients between SupM and VGRF during gait for each subject.
2. Pearson correlation analysis of the relationship among the 3 joint moments.
3. Pearson correlation analysis of the relationship between each joint moment and VGRF.
All data were analyzed with IBM SPSS Statistics 21.0 (IBM Japan, Tokyo, Japan). A p<0.01 was considered significant.

**RESULTS**

Figure 1 shows the average moments for 25 subjects of three trials. Correlation coefficients between SupM and VGRF for each subject ranged from 0.68 to 0.97 (p<0.001).

Knee and hip extension moments showed negative correlation throughout the stance (p<0.01) (Fig. 2). Correlation coefficients between ankle and knee moments, and correlation coefficients between ankle and hip moments depended on the phase of stance. Ankle moment had a positive correlation to hip moment but a negative correlation to knee moment, without initial contact (Fig. 2).

Hip moment at initial contact, knee moment at loading response, and ankle moment from terminal stance to pre-swing had a relatively high correlation to VGRF (Fig. 3).

**DISCUSSION**

SupM had a strong correlation with VGRF in all subjects. These results are very similar to the results of previous studies. This means that the extension moments of the 3 joints were coordinated and showed internal substitution. SupM, as the total extension moment changed in accordance with the change in VGRF.

The force vector from the posterior position of the heel tended to proceed in front of the knee and hip joints. The results showed a large dorsiflexion moment related to a large knee flexion and hip extension moments.

When the ankle moment was large, the knee moment was small and vice versa. Therefore, there was a compromise between the ankle and knee during mid stance.

Ankle and hip moments showed a positive correlation; nevertheless, hip flexion moment was seen during pre swing. This result is similar to previous research that suggested that increased ankle plantar flexion during gait helped to substitute for hip flexor weakness. Knee and hip extension moments showed a negative correlation. This correlation was particularly strong and stable during single leg support (mid stance and terminal stance). This results from the fact that the force vector of the ground reaction force always passed between the hip and knee joints. Whenever the vector was far from the hip joint, it was close to the knee joint. Whenever the vector was close to the hip joint, it was far from the knee joint. This vector may be related to a hip flexion or extension-dominant gait during the stance phase.

The main extension moments were as follows: hip extension moment in the initial contact, knee extension moment from the loading response to mid stance, ankle plantar flexion and knee extension moments in the mid stance, and ankle plantar flexion from the terminal stance to pre swing.
The main extensor differed depending on phase of stance. If the dominant muscle was the frontal thigh pertaining to hip flexion and knee extension moments (i.e., rectus femoris), we may need to focus on the back of the thigh (i.e., hamstrings). Simonsen reported that normal subjects could be separated by peak knee extensor moment exerted from the loading response to early mid stance\(^9\). Our research may help to identify therapeutic exercises for normalizing the gait pattern or preventing collapse.

There are some research limitations associated with the SupM. It may not provide useful information without single support because of the influence of the contralateral leg, and it may be inapplicable for subjects with knee hyperextension\(^9\). Extension of the metatarsophalangeal joint in the terminal stance may affect the SupM. Joint moments contribute not only to support but also to forward progression during gait\(^9\).

The internal extension moment has an important role in supporting and controlling the body during different phases of stance. It may indicate which joint should be strengthened to improve gait pattern as indicated by the SupM and VGRF.

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