Examination of center of pressure displacement and muscle activity of the hip girdle muscles on lateral movement in the sitting position, focusing on kinematic features before and after the start of exercise

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Abstract. [Purpose] This study aimed to evaluate the kinematic characteristics at the start of lateral movement in the sitting position, for application in physical therapy. [Subjects and Methods] Eleven healthy male subjects (mean age, 24.8 ± 3.7 years) were included in the study after they provided informed consent. The electromyographic activities of the tensor fascia lata, gluteus medius, and rectus femoris, and the center of pressure (COP) displacement during lateral reach in the sitting position were measured. The task was recorded on video for analysis. [Results] In almost all subjects, before the beginning of the task, the electromyographic activity in the opposite side of each studied muscle was recorded, and the opposite and anterior displacement of the COP was observed. The video analysis revealed that all subjects showed lateral displacement of the thoracic part of the trunk after the start of the task. However, the lumbar region and pelvis maintained their starting positions. [Conclusion] COP displacement occurred in the reverse reaction before the task, and this involved the hip girdle muscles of the opposite side. A reverse reaction displaced the pelvis to the opposite side to ensure instability of posture through side tilting of the trunk at the beginning of the task.

Key words: Lateral movement in the sitting position, Reverse reaction of COP displacement, Hip joint

INTRODUCTION

The elements of lateral movement in the sitting position are included in many sitting activities of daily living (ADL). Furthermore, this movement is often used in physical therapy. Lateral movement in the sitting position requires that the load-side buttock holds pelvic inclination and that the opposite-side buttock is raised from the bearing surface. These movements involve attitude adjustment of the trunk through activity of the trunk and hip girdle muscles. Therefore, lateral movement in the sitting position is impaired by weakness of the trunk and hip girdle muscles1–3). For example, after total hip arthroplasty or femoral neck fracture, the hip girdle muscles become weak. In addition, post-cerebral infarction hemiplegic patients have low muscle tone of the trunk and hip girdle muscles on one side. In such cases, it is observed that these patients have difficulty in improvement of ADL because lateral movement from a sitting position at the time of practice does not occur.

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Therefore, the previous study has examined the activity of the hip girdle muscles at the time of lateral movement in the sitting position using electromyography (EMG). As a result, features of the hip girdle muscle and pelvic tilt on lateral movement in the sitting position suggested the following. 1) When the subject initiates lateral movement in the sitting position, the pelvis tilts backward by hip extension with body weight transfer to the sciatic portion of the moving side, and this movement controls the hip flexion action of the rectus femoris (RF) muscle on the moving side. 2) On the moving side, hip internal rotation of the tensor fascia latae (TFL), gluteus medius (GM), and gluteus maximus (upper fibers) muscles is aggressively involved in lateral pelvic tilt on lateral movement in the sitting position.

The above mentioned movement mechanisms are related to the control of weight shift at the time of execution of lateral movement in the sitting position. However, the muscle activity on initiation of lateral movement from the start position is though not clear. A driving force at the start of lateral movement from the rest sitting position, reverse reaction of center of pressure (COP) has been reported to be involved. Reverse reaction of COP begins when the COP is displaced to the opposite side from a state that is commensurate with the floor reaction force of the seat surface and the center of gravity. The direction of the floor reaction force changes to the moving side through this phenomenon, and the center of gravity in response to this is the driving force that causes movement toward the moving side.

Further, when reverse reaction of COP occurs on lateral movement in the sitting position, it reportedly allows lateral pelvic tilt on the opposite side by upper elevation of the pelvis on the movement side from the starting position. However, reports on EMG at the time that reverse reaction of COP occurs are scattered. Also, anticipatory postural adjustments (APA) to control trunk lateral tilt before initiating the movement have been reported. Therefore, the kinematics before and after the start of movement, including reverse reaction of COP on lateral movement in the sitting position, remain largely unknown.

In this study, COP and surface EMG of the hip girdle muscles on lateral movement in the sitting position were measured, and video analysis of displacement of the trunk and pelvis during the task was also evaluated. Further the study has examined the kinematic features of lateral movement in the sitting position before and after the start of motion.

**SUBJECTS AND METHODS**

The study subjects consisted of 11 healthy male (mean age: 24.8 ± 3.7 years, height: 170.3 ± 2.1 cm). Sufficient explanation was provided to the subjects regarding overview and management of personal information in this study. The experiment was carried out on the subjects who agreed to participate in the study. This study was approved by the ethical review board at Hachimine Clinic (No.0015-01) and the experiments were conducted in accordance with the Declaration of Helsinki.

The electrodes, electromyography transmitter (telemetry muscle electrocardiograph MQ-Air, Kissiicom), and markers were attached to the subjects before the start of the experiment. The electrodes were attached to both sides of the TFL, GM, and RF muscles (Fig. 1). The negative electrode of the TFL was placed on the midpoint of the line connecting the anterior superior iliac spine and the leading edge of the greater trochanter, and the positive electrode was placed 2 cm proximal to the negative electrode. The negative electrode of the GM was placed on the proximal one-third of the line connecting the iliac crest and greater trochanter, and the positive electrode was placed 2 cm proximal to the negative electrode. The negative electrode of the GM was placed on the proximal one-third of the line connecting the iliac crest and greater trochanter, and the positive electrode was placed 2 cm proximal to the negative electrode. 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The negative electrode of the GM was placed on the proximal one-third of the line connecting the iliac crest and greater trochanter, and the positive electrode was placed 2 cm proximal to the negative electrode. The negative
electrode of the RF was placed on the proximal one-third of the line connecting the anterior inferior iliac spine and the top edge of the patella, and the positive electrode was placed 2 cm proximal to the negative electrode. Furthermore, electrodes were placed on both sides of the middle finger to clarify the timing of the start and end of the motor task. The markers were attached to Th1, Th7, Th12, and L4 of the spine and both upper posterior superior iliac spines (PSIS). The measurement plate of the body sway meter (gravity balance system JK-101 II, Unimec) was then placed on the table, and the video camera (Handycam, Sony) for video analysis was placed on the rear side at 175 cm from the center of the measurement plate and at a height of 110 cm from the floor. The subject sat on the measurement plate with both shoulders abducted to 90 degrees (Fig. 2).

The subjects carried out the lateral reach task from this sitting position. The provision of the motor task was for the subject to reach 15 cm to the lateral side on the goal plate, maintain the position for 1 second, and return to the rest sitting position for 1 second. The thigh and lower leg of the moving side were moved without tilting during the task, and the bottoms of both feet were kept on the ground. However, tilting of the opposite lower leg was allowed. The subjects performed the lateral reach task on both sides for a total of six times. Surface EMG, COP, and video data were evaluated during the task. The measurement methods for each set of each data were as follows.

Measurement of the EMG recordings was performed with Vital Recorder 2 software (Kisseicom). EMG analog signals were digitized at a sampling frequency of 1,000 Hz. COP data were measured using simple measurement software of the body sway meter (Unimec) at a sampling frequency of 20 Hz. The video camera was synchronized with the EMG measurement software and video data was recorded along with the surface EMG.

The selected analysis data were the times closest to 1 second of the lateral reach task in three measurements. EMG and COP data of 22 cases were subjected to synchronization processing using the Bimtas-Video analysis software (Fig. 3). The analysis interval of this study was set at 100%, from 300 ms before the start of the task to the opposite side maximum COP displacement by the reverse reaction. Muscle activity start time, COP displacement, and marker displacement were examined in the analysis interval. The analysis method of each data set is as follows.

The start time of muscle activity was measured from the recorded EMG waveform. In this study, the start time of muscle activity referred to a report on the start reference of muscle activity. The measured surface EMG was changed to a full-wave rectified waveform and the start time of muscle activity was the EMG amplitude value exceeding the maximum amplitude value of the start position.

COP analysis examined the amount of displacement from the mean values of the x-axis and y-axis respective coordinates. The mean value of the respective coordinates was calculated from the data with the 5-second hold at the start position. In the present study, the definition of COP displacement referred to the report of Kudo et al. Displacement in the constant direction of the COP occurs when the displacement of the COP has exceeded twice the maximum displacement at the start position.

The recorded video was converted to 30 sheets of still images per second. Video analysis examined the amount of marker displacement of the second and subsequent sheet images from the marker of the first still image. In this study, for the analysis the amount of marker displacement, 1 pixel of the image was 1.3 mm. Furthermore, marker displacement in a certain direction was defined as marker displacement exceeding 5 mm. The marker displacement analysis used the image-processing software Image-J (free software).

**Fig. 2.** Schematic diagram of the experimental environment Video was recorded from the rear and included the head, trunk, and pelvis of the subjects.

**Fig. 3.** Example of surface EMG and COP Results showing reach movement to the right, 500 ms before and 1,500 ms after the start of the movement.
RESULTS

The motor task started from between the 60% and 70% intervals in all subjects. However, each data changed from before this interval (Tables 1–3). The values in each table represent the data at the time of arrival of each analysis interval.

The EMG waveform amplitude at the start of the opposite side TFL and GM muscle activity was between the 40% and 50% intervals in all subjects. In 13 cases, the opposite side TFL had continued muscle activity at the 90% interval from after the start of the task. In 15 cases, the opposite side GM had continued muscle activity at the 100% interval from after the start of the task. RF on both sides began muscle activity from just before the start of the task or after the start of the task. In 5 cases, the opposite side RF and in 6 cases, the moving side RF started muscle activity before the start of the task. In 15 cases, the opposite side RF and in 13 cases, the moving side RF started muscle activity after the start of the task.

COP of the x-coordinate was the opposite side displacement from the time that was more than the 20% interval. COP of the y-coordinate was the anterior displacement from the time that was more than the 30% interval in all subjects (Table 1).

Th1 and Th7 marker displacement on the moving side was between the 50% and 60% intervals in all subjects. Th12 marker displacement on the moving side was from the time that exceeded the 60% interval. L4 and bilateral PSIS marker was displacement to moving side from the time that exceeded the 80% interval (Table 2). Moreover, PSIS marker was displacement to upward from the 80% interval (Table 3).

DISCUSSION

Opposite-side TFL and GM and bilateral RF confirmed the start of muscle activity in the analysis section. The study discusses the action of each muscle before or after the start of lateral movement in the sitting position as follows.

Opposite side TFL and GM showed muscle activity starting from when it exceeded the 40% interval. This result is consistent with COP being largely displaced to the opposite side (Table 1). In addition, in more than half of the cases, there

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**Table 1. Amount of COP displacement [mm]**

|       | 10%    | 20%    | 30%    | 40%    | 50%    |
|-------|--------|--------|--------|--------|--------|
| X coordinate | −0.39 ± 0.66 | −0.6 ± 0.66 | −0.88 ± 0.74 | −1.39 ± 0.98 | −2.19 ± 1.31 |
| Y coordinate | 0.2 ± 1.38 | 1.09 ± 2.83 | 1.16 ± 2.91 | 1.3 ± 3.09 | 1.52 ± 3.43 |
|       | 60%    | 70%    | 80%    | 90%    | 100%   |
| X coordinate | −3.26 ± 1.67 | −4.49 ± 2.03 | −5.7 ± 2.24 | −6.58 ± 2.41 | −6.84 ± 2.5 |
| Y coordinate | 1.82 ± 4.03 | 2.18 ± 4.77 | 2.63 ± 5.43 | 3.09 ± 5.88 | 3.62 ± 5.78 |

Values are mean ± standard deviation. A positive value of the x-coordinate indicates moving-side displacement and a positive value of the y-coordinate indicates anterior-side displacement. The x-coordinate shows opposite displacement from the 20% interval. The y-coordinate shows anterior displacement from the 30% interval.

**Table 2. Marker displacement of x-coordinates [mm]**

|       | 10%    | 20%    | 30%    | 40%    | 50%    | 60%    | 70%    | 80%    | 90%    | 100%   |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Th1   | 0      | 0      | 0      | 0      | 1.73 ± 2.22 |
| Th7   | 0      | 0      | 0      | 0.13 ± 0.31 | 1.6 ± 1.7 |
| Th12  | 0      | 0      | 0      | 0.1 ± 0.25 | 0.47 ± 0.95 |
| L4    | 0      | 0      | 0      | 0      | 0      |
| Moving side PSIS | 0      | 0      | −0.2 ± 0.08 | −0.33 ± 0.53 | −0.2 ± 0.69 |
| Opposite side PSIS | 0      | 0      | 0.00   | −0.2 ± 0.2  | −0.2 ± 0.33 |
|       | 8.02 ± 4.77 | 16.98 ± 7.62 | 30.87 ± 10.18 | 45.6 ± 11.8 | 63.1 ± 13.02 |
| Th7   | 6.67 ± 4.42 | 15.07 ± 7.22 | 27.67 ± 10.15 | 41.27 ± 12.09 | 57.6 ± 13.97 |
| Th12  | 3.2 ± 3.37 | 8.47 ± 5.35 | 17.27 ± 8.4 | 28.1 ± 10.66 | 42.2 ± 12.76 |
| L4    | 0.4 ± 1.37 | 1.73 ± 3.34 | 5.4 ± 5.18 | 11.8 ± 7.61 | 16.08 ± 9.2 |
| Moving side PSIS | −0.13 ± 0.7 | 0.87 ± 2.76 | 4.07 ± 3.5 | 10.07 ± 5.17 | 14.53 ± 6.1 |
| Opposite side PSIS | −0.13 ± 1.33 | 1.2 ± 3.14 | 4.2 ± 3.21 | 10.2 ± 5.15 | 14.93 ± 7.17 |

Values are mean ± standard deviation. A positive value shows moving-side displacement. The thoracic spine showed moving-side displacement from the time that was more than the 50% interval. The lumbar spine and pelvis showed moving-side displacement from the 80% interval.
was continuity in muscle activity even after the start of the task. This also is consistent with continued COP displacement to the opposite side after the start of the task. From these results, it is considered that the TFL and GM on the opposite side were related to the occurrence of the reverse reaction of COP. In a previous study, it was reported that TFL and GME in the sitting position had actions of medial rotation of the hip joint\(^4,5,11\). In other words, the study considered that the pelvis was displaced to the opposite side by medial hip rotation of the TFL and GM on the opposite side. This is in agreement with report of Fujisawa et al\(^8\), who stated that the pelvis was tilted to the opposite side in the reverse reaction of COP. While opposite side displacement of the pelvis could not be confirmed within the provisions of this present study, coordinate values of the pelvis markers showed a slight tendency toward opposite side displacement (Table 2). Therefore, this study considered that the pelvis was displaced to the opposite side by medial hip rotation of the TFL and GME on the opposite side in the reverse reaction of COP. Bilateral RF activity was confirmed in the analysis interval. Forward pelvic tilt is reportedly decreased in the sitting position compared to the standing position\(^12,13\). Also in our previous studies, COP was confirmed to be displaced to the posterior side in accordance with displacement of the movement side during lateral movement in the sitting position. The start time of muscle activity of RF on both sides was more often after rather than before the start of the task. Furthermore, the anterior displacement of COP showed a tendency toward increased displacement after the start of the task. Therefore, it was considered that hip flexion was involved in the anterior displacement of COP.

COP of the x-coordinate confirmed opposite side displacement from the time of more than the 20% interval. COP of the y-coordinate confirmed anterior displacement from the time of more than the 30% interval. The study discusses the COP displacement direction of each coordinate as follows.

From the results of the COP displacement of the x-coordinate, it was considered that the subjects transferred the pelvic load of the opposite side from the sitting position just before the start of the task. Furthermore, COP displacement of the opposite side of the x-coordinate increased even after the start of the task. This indicated that subjects held the pelvic load of the opposite side even after the start of the task. This result of the reverse reaction of COP on lateral movement in the sitting position was similar to other studies\(^6-8\). The reverse reaction of COP occurred on lateral movement in the sitting position, the reason for which will be described later together with consideration of marker displacement in the next section. COP of the y-coordinate confirmed anterior displacement. As previously mentioned, it is easy to tilt the pelvis backward in the sitting position, and our previous study confirmed posterior side displacement of COP on lateral movement in the sitting position. The study considered that anterior displacement of COP in the sitting position was due to forward pelvic tilt by hip flexion motion, when transferring load to the opposite side of the pelvis, it was also considered that the subject avoided backward displacement of COP with backward pelvic tilting. It is thought that this phenomenon is to facilitate load transfer from the opposite side to the moving side.

On checking each marker’s displacement time, the Th1, Th7, and Th12 markers were displaced to the moving side in the 60% interval from the 50% interval just before the start of the task. The L4 and bilateral PSIS markers were displaced to the moving side when exceeding the 80% interval. Furthermore, the PSIS marker of the opposite side confirmed upward displacement when it exceeded the 80% interval. The marker displacement of the thoracic portion indicated that lateral Table 3. Marker displacement of y-coordinates [mm]

|     | 10%    | 20%    | 30%    | 40%    | 50%    | 60%    | 70%    | 80%    | 90%    | 100%    |
|-----|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|
| Th1 | 0      | 0      | 0      | 0      | -0.13 ± 0.33 | 0.07 ± 0.61 | 0.13 ± 0.94 | 0.13 ± 1.16 | 0.4 ± 1.32 | 0.8 ± 1.51 |
| Th7 | 0      | 0      | 0      | 0      | 0.07 ± 0.24 | -0.07 ± 0.43 | 0.13 ± 0.6 | 0.27 ± 0.66 | 0.93 ± 1.17 | 1.13 ± 1.58 |
| Th12| 0      | 0      | 0      | 0      | 0      | 0.33 ± 0.58 | 0.73 ± 0.68 | 0.8 ± 1.01 | 1.4 ± 1.36 | 1.67 ± 1.8  |
| L4  | 0      | 0      | 0      | 0      | 0      | 0.07 ± 0.94 | 0.2 ± 1.73 | 0.93 ± 2.1 | -0.53 ± 2.26 | 0.47 ± 4.12 |
| Moving side PSIS | 0 | 0 | 0.00 | 0.031896 | 0.07 ± 0.24 | 0.07 ± 0.24 | 0.1 ± 0.49 | -0.2 ± 0.88 | -0.21 ± 1.12 | -0.64 ± 1.69 |
| Opposite side PSIS | 0 | 0 | 0.00 | 0.031896 | 0.07 ± 0.24 | 0.07 ± 0.24 | 0.1 ± 0.49 | -0.2 ± 0.88 | -0.21 ± 1.12 | -0.64 ± 1.69 |

Values are mean ± standard deviation. A positive value indicates upward side displacement. The PSIS of the opposite side from when it exceeded the 80% interval showed upward displacement.
movement in the sitting position was initiated by lateral flexion of the thoracic spine. In addition, marker displacement of L4 and the pelvis indicated that these markers began moving-side displacement by lateral pelvic tilt when it exceeded the 80% interval. The results of the lumbar and pelvic marker displacement are similar to that for COP of the x-coordinate with continued opposite displacement. In other words, it was considered that the lumbar and pelvic parts maintained the start position even after the start of the task. From the results of the COP displacement of the x-coordinate and the displacement of each marker, further the role of the reverse reaction of COP is as follows.

There are two hypotheses for the role of the reverse reaction of COP on lateral movement in the sitting position. One is the theory of a mechanism to stabilize the postural upset caused by the start of lateral movement in the sitting position\(^6\). \(^7\). The other is the theory of driving the pelvis and trunk by the ground reaction force for starting lateral movement in the sitting position\(^9\). However, in this present study, the lumbar and pelvic markers were displaced to the moving side later than the thoracic markers. Furthermore, COP maintained opposite side and anterior displacement even after the start of the task. If the reverse reaction of COP drives the pelvis and trunk in order to start the task, it was thought that the pelvis and trunk displace to the moving side by the ground reaction force generated through the pelvis almost simultaneously. For this reason, it is considered that the reverse reaction of COP is a mechanism to adjust the attitude at the start of the task. Lateral movement in the sitting position begins by the thoracic portion succumbing to the moving side. The lumbar portion and pelvis hold the load to the opposite side in order to control for trunk tilt to the moving side at that time. Therefore, moving side displacement of the lumbar spine and pelvis is slower than the thoracic portion.

From the results of the present study, to encourage the lateral tilt of the pelvis for causing the lateral movement in the sitting position, it is necessary to consider the following points. When the before or after the start of lateral movement in the sitting position, there is a need for the opposite side tilt of the pelvis to control the movement side slope of the trunk. This phenomenon is involved the medial rotation action of hip girdle muscles of opposite. The kinematic interpretation of lateral movement in the sitting position must be considered the motion of the hip joint with the flexed position and the understanding of the shape of the pelvis. Therefore, it is necessary to repeated measure the more data in the future.

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