Sit-to-Walk versus Sit-to-Stand or Gait Initiation: Biomechanical Analysis of Young Men

MUNETSUGU KOUTA1, 2), KOICHI SHINKODA1), NAOHIKO KANEMURA1)

1)Health Sciences Major, Graduate School of Health Sciences, Hiroshima University
2)Faculty of Health and Welfare, Department of Physical Therapy, Prefectural University of Hiroshima: Gakuen-cho 1-1, Mihama-city, Hiroshima 723-0053, Japan.
TEL & FAX +81 848-60-1225  E-mail: kouta@pu-hiroshima.ac.jp

Abstract. There are few papers about the biomechanical characteristics of sit-to-walk motion, although many researchers have written about the biomechanical analyses of sit-to-stand motion or gait initiation. The purpose of this study was to compare the biomechanics of sit-to-walk motion with sit-to-stand motion or gait initiation. The subjects were 9 healthy young men, who were instructed to perform sit-to-walk motion, sit-to-stand motion, and gait initiation. Kinematics and kinetics data were obtained using a 3D motion capture system and two force plates. The coordinates of reflective markers (RM)s, the coordinates and velocity of the center of gravity of the whole body (COG), the coordinates and velocity of the center of gravity of the head, arm and trunk (COG of HAT), each joint angle, and the ground reaction forces (GRFs) were calculated from the data. We found that the maximal horizontal velocity of HAT occurred later in a sit-to-walk motion than in sit-to-stand (p<0.05). On the other hand, there was no significant difference of timing between sit-to-walk motion and gait initiation. At the highest point of COG, it moved forward farther in sit-to-walk and moved upward higher in sit-to-stand. Maximal horizontal velocity of COG of HAT before seat-off was significantly higher in the sit-to-walk motion than in the sit-to-stand motion. The peak value of anterior-posterior GRF ($F_y$) at the heel strike was significantly greater in the sit-to-walk motion than in gait initiation (p<0.05). The COG moved forward over the base of support in the sit-to-walk motion, and then the COG moved forward with one-leg support. These results suggest that sit-to-walk motion is an unstable motion, and requires balance ability to perform. To create an impulsive force, it is important that horizontal velocity of COG of HAT is higher at seat-off in the sit-to-walk motion. Horizontal impulsive force created by HAT movement is suppressed at the first heel strike.

Key words: Sit-to-walk, Sit-to-stand, Gait initiation

INTRODUCTION

Although the sit-to-walk motion is frequently observed in daily living, few have studied the biomechanical characteristics of the sit-to-walk motion. The sit-to-walk motion is used to evaluate functional mobility. The “Get-Up and Go” test which was developed by Mathias et al.1) requires the subjects to stand up from a chair, walk 3 meters, turn around, walk back, and sit down again. A video recording of the test is used to determine the balance function during the test and is scored on a five-point scale. The score of the scale correlates well with gait speed and the sway of the center of pressure. The timed “Up and Go” (TUG) test, a timed version of the “Get-Up and Go” test, was
designed by Podsiadlo et al. 2). The timed score correlates closely with log-transformed scores on the Berg Balance Scale, gait speed and the Barthel Index of ADL. Additionally, the timed score appears to predict a subject’s ability to safely venture outdoors alone. The most important point is that evaluating the transition of standing to walking is included in both the “Get-Up and Go” test and the timed “Up and Go” test.

The importance of sit-to-walk was reported by Wall et al. 3). They evaluated the time of the components of TUG, that is sit-to-walk motion and walking straight motion. Elderly subjects with a risk of falling walked straight slower than young subjects and healthy elderly subjects. To compare the importance of the sit-to-walk component with the importance of the walking straight component for healthy elderly subjects and elderly subjects with a risk of falling, components and total time of TUG were normalized to the time of young subjects. Elderly subjects with a risk of falling required more time in sit-to-walk than in walking straight.

Little research has been done to clarify the biomechanical characteristics of sit-to-walk motion, using biomechanical analyses of sit-to-stand or gait initiation 4, 5). The purpose of this study was to compare the biomechanics of sit-to-walk with sit-to-stand and gait initiation motions. Previous studies about sit-to-stand, to identify the difference between the young and elderly people 6, 7), or healthy and physically disabled people 8, 9), dealt with the velocity of COG of HAT or angular velocity of hip flexion before seat-off since it was convenient to analyze. In gait initiation, other researchers thought that GRFs were convenient for differentiating between healthy young and healthy elderly people 10, 11), or healthy people and patients with stroke 12). Therefore, in the present study, we focused on COG, COG of HAT, and GRFs to clarify the biomechanical characteristics of sit-to-walk motion.

**METHODS**

**Subjects**

The subjects were 9 healthy young men whose mean age was 21.8 ± 2.5 years, mean height was 170.3 ± 4.9 cm and mean weight was 65.1 ± 6.8 kg. Each subject was informed of the purpose of this study and gave his consent to participation in this study.

**Procedures**

(1) Analysis of motions

Subjects were instructed to perform three tasks: sit-to-walk, sit-to-stand and gait initiation. Sit-to-walk and sit-to-stand were initiated from a chair sitting position. A chair without a backrest and armrest was used, and the seat height was adjusted to match the length of the lower leg. The starting position of sit-to-walk and sit-to-stand was set with the knee flexed at 90 degrees and the feet shoulder width apart. The starting position of the gait initiation was an upright standing position. The sit-to-walk and gait initiation tasks included walking 3 m. Sit-to-walk was analyzed from the starting movement of the acromions to the first heel contact after the first leg swing. Sit-to-stand was analyzed from the starting movement of the acromions to the highest point of COG. Gait initiation was analyzed from maximal loading on the swing leg before swing to the first heel contact. Each task was performed at a comfortable speed for the subject. The subjects practiced each task sufficiently to perform it smoothly and naturally.

Kinematic data was obtained by measuring the trajectories of 10 reflective markers (RMs) on the landmarks of the subjects’ bodies using a six camera motion capture system VICON 512 3D (Oxford Metrix Ltd.) at a sampling frequency of 120 Hz. RMs were attached to each landmark on both sides of the body: the acromions, greater trochanters, knee joints, lateral malleoluses, and the metatarsal heads of the fifth toe.

Kinetic data was obtained using two Kistler force plates (9287A 900 × 600 mm, Kistler Ltd.) at a sampling frequency of 600 Hz. The ground reaction force (GRF) data were $F_x$ as the right-left (right is plus), $F_y$ as the anterior-posterior (anterior is plus), and $F_z$ as the vertical (upper is plus).

(2) Data processing

The collected data were analyzed to determine the coordinates of the RMs, the coordinates and velocity of center of gravity of the whole body (COG), the coordinates and velocity of center of the gravity of the head, arm and trunk (COG of HAT), each joint angle and the ground reaction forces (GRFs). We used the Vicon Workstation running ver.4.6 (Oxford Metrix) and Microsoft Excel 2002 for Windows (Microsoft) as analytical software. Kinematic and kinetic data were filtered using a second-order Butterworth low-pass filter at 6 Hz and 50 Hz 13).
(3) Statistical analysis

To compare sit-to-walk with sit-to-stand, and sit-to-walk with gait initiation, for all statistical analysis, the paired t-test was adopted using the SPSS ver.12.0 for Windows (SPSS Japan). The statistical level of significance was set at p<0.05.

RESULTS

A comparison of the event times of each motion is shown in Table 1. To compare sit-to-walk with sit-to-stand motions, the time scale was normalized: t = 0 at the starting movement of the acromions and t = 100 [%] at the time of the highest point of COG. The timings of maximal horizontal velocity of HAT before seat-off and maximal vertical velocity of COG after seat-off compared. The timing when the horizontal velocity of HAT became the maximal value appeared significantly later in the sit-to-walk motion than in the sit-to-stand motion (p<0.05). To compare sit-to-walk with gait initiation, the time scale was normalized: t = 0 at the time of maximal loading of the swing leg before first swing, and t = 100 [%] at the first heel contact. The time of first toe off was compared. There was no significance difference in the time between sit-to-walk and gait initiation.

COG trajectory in sit-to-walk and sit-to-stand was compared. The typical pattern of COG trajectory is shown in Fig. 1. The COG at the sitting position before starting up was configured as the origin of the graph, and the horizontal-vertical excursion of the COG movement was drawn while the COG moved to its highest point. The horizontal distance normalized to body height was 0.329 ± 0.151 in sit-to-walk and 0.183 ± 0.025 in sit-to-stand. The vertical distance normalized to body height was 0.159 ± 0.014 in sit-to-walk and 0.167 ± 0.015 in sit-to-stand. There were significant differences in both the horizontal and the vertical distances (p<0.05). There was no significant difference of the maximal vertical COG speed between sit-to-walk and sit-to-stand, 0.67 ± 0.12 [m/s] and 0.64 ± 0.13 [m/s], respectively. When the vertical speed of COG became maximal, horizontal speed was 0.37 ± 0.18 [m/s] in sit-to-walk, 0.16 ± 0.06 [m/s] in sit-to-stand. The horizontal speed was significantly higher in sit-to-walk than in sit-to-stand (p<0.05).

The horizontal velocities of COG of HAT before the seat-off in sit-to-walk and sit-to-stand motions were compared. A typical pattern is shown in Fig. 2. The maximal horizontal HAT velocity before seat-off occurred almost simultaneously in both sit-to-walk and sit-to-stand. The maximal horizontal velocity was 0.72 ± 0.11 [m/s] in the sit-to-walk motion and 0.62 ± 0.09 [m/s] in the sit-to-stand motion. There was a significant difference between the motions.

In the comparison of sit-to-walk with gait initiation, we found that there was no significant difference of the peak $F_z$ at the first stance leg

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>Comparison of event times of the three motions</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Comparison of sit-to-walk and sit-to-stand</td>
<td></td>
</tr>
<tr>
<td>Time of maximal horizontal velocity of HAT [%]</td>
<td>Time of maximal vertical velocity of COG [%]</td>
</tr>
<tr>
<td>Sit-to-walk</td>
<td>41.5 ± 4.8</td>
</tr>
<tr>
<td>Sit-to-stand</td>
<td>37.7 ± 2.4</td>
</tr>
<tr>
<td>b) Comparison of sit-to-walk and gait initiation</td>
<td></td>
</tr>
<tr>
<td>Time of maximal loading of swing leg before swing [%]</td>
<td>Time of first toe off [%]</td>
</tr>
<tr>
<td>Sit-to-walk</td>
<td>65.4 ± 10.1</td>
</tr>
<tr>
<td>Gait initiation</td>
<td>54.9 ± 10.2</td>
</tr>
</tbody>
</table>

a) To compare sit-to-walk with sit-to-stand, time was normalized to 0 at the starting movement of acromions and 100 [%] at the time of the highest point of COG.

b) To compare sit-to-walk with gait initiation, time was normalized to 0 at the time of the maximal loading of the swing leg before swing and 100 [%] at first heel contact. Numbers enclosed within parentheses show values which were normalized as for sit-to-stand: 0 at the time of starting acromions and 100 [%] at the time of the highest point of COG.

*: p<0.05
between sit-to-walk and gait initiation, 108.2 ± 7.1 [%body weight] and 115.3 ± 4.1 [%body weight], respectively. The peak $F_y$ backward component at the first heel strike was significantly greater in sit-to-walk than in gait initiation (p<0.05), though there was no significant difference in the peak $F_y$ forward component (Fig. 3).

**DISCUSSION**

In the previous studies of sit-to-walk motion, Magnan et al.\textsuperscript{14)} reported that initiation of walking occurred around seat-off while subjects were still rising and COG of the body projection was close to or behind the ankles. They concluded that the task of sit-to-walk was heavily dependent on balance control. In another study, Kerr et al.\textsuperscript{15)} defined phases of sit-to-walk according to changes in GRF and COG. They defined four phases: flexion momentum (initiation–seat-off), extension (seat-off–peak vertical velocity), unloading (gait initiation–swing toe off) and stance (swing toe off–stance toe off).

In the current study, COG moved higher in sit-to-stand than in sit-to-walk (p<0.05), but moved a farther forward in sit-to-walk than in sit-to-stand (p<0.05). To successfully perform a sit-to-walk motion, a forward movement of the COG over the base of support is required and in addition, it is necessary to move forward with one-leg stance. So, sit-to-walk is an unstable motion and requires better balance ability. To create an impulsive force, it is important that the horizontal velocity of HAT is higher than in sit-to-walk at the seat-off (p<0.01). The horizontal impulsive force created by the HAT...
movement is inhibited by the first heel strike. This is indicated by $F_y$ (backward component) of GRF at the first heel contact. In sit-to-walk, to move the body forward smoothly and safely, HAT must create a forward impulse movement, and the first swing of the leg must inhibit the impulse movement. Thus, more advanced motor control ability is required to achieve sit-to-walk. Schenkman et al. reported that horizontal momentum is arrested early to limit the body’s forward displacement in sit-to-stand\(^{16}\). This is clearly different from the sit-to-walk motion, in which continuing horizontal velocity demands the timely forward movement of the foot to ensure stabilization of the body.

A limitation of this study is that it was done using only a few healthy young men. We should analyze the sit-to-walk motion in elderly people and/or physically disabled people such as those with hemiplegia or Parkinson’s disease in a future study.

**REFERENCES**

12) Tokuno CD, Eng JJ: Gait initiation is dependent on the function of the paretic trailing limb in individuals with...


