J. Phys. Ther. Sci. 34: 7–12, 2022

The Journal of Physical Therapy Science

Original Article

Effect of different seat heights on lumbar spine flexion during stand-to-sit motion

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Abstract. [Purpose] This study aimed to investigate the movement of the thorax, lumbar spine, and pelvis when healthy participants sit on a chair, and to identify the kinematic characteristics due to changes in the height of the seat. [Participants and Methods] Twenty healthy participants (14 males, 6 females; mean age, 29 ± 5 years) were recruited for this study. They performed stand-to-sit motion using one seat with a height of 100% that of the lower leg length (standard) and another with a height of 60% that of the lower leg length (lower). A three-dimensional motion analysis system and four force plates were used to analyze each joint angle. [Results] The mean lumbar spine flexion angle was significantly increased in the lower versus the standard seat. As a kinematic characteristic, the pelvis tilted posteriorly while the thorax tilted anteriorly, which increased the lumbar spine flexion angle. The pelvis was tilted posteriorly when the hip joint flexed about 60° regardless of the seat height. [Conclusion] The lumbar spine flexion angle increased in the lower seat stand-to-sit motion, which suggested an increase in the load on the lumbar spine. The lumbar spine flexion angle was influenced by the characteristic movements of the thorax and pelvis.
Key words: Stand-to-sit, Height of the seat, Lumbar spine flexion

(This article was submitted Aug. 12, 2021, and was accepted Oct. 5, 2021)

INTRODUCTION

Patients with low back pain repeatedly experience exacerbations and remissions while performing activities of daily living. A study of lumbar loads in daily life activities reported that the risk of low back pain increases with activities that require forward bending of the trunk[1)] and that activities that involve forward bending and rotation of the trunk increase the frequency of low back pain[2, 3)]. In particular, deep flexion movement of the lumbar spine strains the lumbar region. Previous studies have reported that lumbar spine flexion stretches the erector spinae muscles and increases the lumbar compressive force[4)], stretches the posterior lumbar tissues and increases the lumbar shear force[5)], and increases intradiscal pressure and erector spinae muscle activity[6)], resulting in lumbar spine flexion as a factor in low back pain. Sitting on a chair is a motion that involves lumbar spine flexion. In clinical practice, many patients complain of low back pain, especially when sitting on a lower seat. Clinicians often recommend that patients limit the range of motion of the lumbar spine and adjust their motion during stand-to-sit motions. However, the efficacy of simply limiting movement of the lumbar spine to ensure safe sitting in chairs of various heights remains questionable.

Research on the characteristics of stand-to-sit motion of patients with low back pain has described limited movement and speed of the lumbar spine and hip joints[7)], and decreased extension moment and power of the lumbar spine and hip joints[8)]. Moreover, the limited and synergistic movements of the lumbar spine and hip joints had also changed[7)]. A study that kinematically compared sit-to-stand movements of patients with low back pain to those of healthy participants reported no difference in the whole spine flexion/extension angle. However, a comparison of the movement of each vertebra revealed

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the specific movement pattern of patients with low back pain[9]. Therefore, a multisegmental analysis of the spine is recommended to clarify the movement characteristics of patients with low back pain[10]. However, no studies have examined the kinematic changes in the lumbar spine of stand-to-sit motion resulting from different chair heights in patients with low back pain. In a report on normal participants, the hip flexion angle was increased in lower seats, but no difference was noted in lumbar lordosis[11]. However, the height of the seat used in this study positioned the trunk and thighs at 90°, so the change in the lumbar spine angle in a lower seat is not known. A study on the sit-to-stand movement from a lower seat in healthy participants reported increased anterior tilt of the trunk and activity of the erector spinae muscles[12] and increased angles of flexion between the 5th lumbar vertebra and sacrum[13]. The kinematics of stand-to-sit motions in the sagittal plane are similar to those of sit-to-stand movements. However, stand-to-sit motions reportedly require more complicated posture control to accomplish the kinematics[14]. Therefore, it is necessary to increase our understanding of the kinematics of the lumbar spine in stand-to-sit motions for lower seats.

This study aimed to investigate the movements of the thorax, lumbar spine, and pelvis of healthy participants during stand-to-sit motions using seats of different heights and clarify the movements of lumbar spine flexion, which are thought to increase the load on the lumbar spine. Understanding the kinematic characteristics of the response to changes in seat height, instead of merely limiting the movement of the lumbar spine, will aid with effective functional training and movement guidance to increase safety and prevent low back pain.

PARTICIPANTS AND METHODS

Twenty healthy adults (14 males, 6 females; mean age, 29 ± 5 years; mean body height, 169 ± 7.9 cm; mean body weight, 64.2 ± 10.5 kg; mean body mass index, 22.4 ± 2.9 kg/m^2) were included in the study.

The participants were screened to exclude those with a range of motion limitation of the lower limbs that affected the stand-to-sit motion or a history of lumbar spine disease or pain in the hip, knee, or lower back.

The participants performed the stand-to-sit motion on two different seats. Seat height was adjusted to 100% (standard seat) or 60% (lower seat) of the knee-to-floor length. The 60% length was calculated based on the lower leg length, and the seat heights were set for each participant. The participants assumed a resting standing position with both elbows flexed to 90° beside the body. The feet position indicated the position in which the movement was easier to perform. The participants completed five trials with each seat and did not move their feet during the tasks.

A 3-dimensional motion analysis system consisting of 8 infrared cameras (VICON, Oxford, UK) and 4 force plates (AMTI, Watertown, MA, USA) was used to record the kinematic and kinetic data at a sampling frequency of 100 Hz. The chair was placed on the force plates and the floor reaction force was set to zero. When the seat height was adjusted, the floor reaction force gauge was reset. A total of 40 reflective markers were attached as follows: top of head, right/left (R/L) head, manubrium (STER), xiphoid process (XIPH), 7th cervical spinous process (C7), 10th thoracic spinous process (TH10), R/L anterior superior iliac spine (ASIS), R/L posterior superior iliac spine (PSIS), sacrum, R/L acromion, R/L epicondylus lateralis humeri, R/L processus styloideus ulnae, R/L hip joint (HIP), R/L thigh (THI), R/L medial knee (CON), R/L lateral knee (KNE), R/L shank, R/L medial malleolus, R/L lateral malleolus, R/L 2nd metatarsal bone, R/L 5th metatarsal bone, R/L heel, and R/L front of foot. To minimize the influence on the movement, 9-mm markers were used at the R/L medial knees, while 14-mm markers were used at the other sites.

The marker trajectory data were low-pass filtered using a Butterworth filter with a cut off of 6 Hz, while the force plate data had a cut off of 18 Hz. The x-axis was set in the lateral direction (right; +), the y-axis in the fore and aft direction (anterior; +), and the z-axis in the vertical direction (upward; +). For marker trajectories and force plate data processing, data calculation software (VICON Body Builder) was used to calculate the joint angle. This study focused on movement in the sagittal plane to investigate lumbar spine flexion angle movement.

Task initiation and termination was performed using the thoracic anterior tilt velocity defined by Anan et al[15]. Motion initiation was defined as the last instant of the transition from negative to positive angular velocity before the thorax angular velocity peaked. Motion termination was defined as the first instant of the transition from negative to positive angular velocity after the thorax angular velocity troughed. Buttock-on was defined as the point at which the vertical component of the floor reaction force exceeded 10 N.

The thoracic segment consisted of the markers attached to the STER, XIPH, C7, and TH10. The pelvic segment consisted of the markers attached to the R/L ASIS and R/L PSIS. The angles of the thorax and pelvis were the absolute angles of each segment. The lateral direction was defined as the x-axis, while rotation around the x-axis was defined as the anteroposterior tilt angle (posterior tilt; +). The relative angle of the thoracic segment to the pelvic segment was defined as the angle of the lumbar spine and calculated using the Euler angle (extension; +).

The femoral segment consisted of the markers attached to the HIP, THI, CON, and KNE. The angle of the femur was defined as the absolute angle of the femoral segment. The lateral direction was defined as the x-axis, while rotation around the x-axis was defined as the anteroposterior tilt angle (posterior tilt; +). The relative angle of the femoral segment to the pelvic segment was calculated using Euler angle. The mean angles of the right and left sides were defined as the hip joint angles (extension; +).

Joint and segment angles were set at zero degrees based on each participant's starting position, and the maximum angle was calculated for each during the analysis period. The maximum angle was the mean value of the three trials.

The period between the initiation and termination of the stand-to-sit motion was normalized to 100%, and we observed the changes in joint angle in a time series. To investigate the relationship between the movement of the thoracic and pelvic segments and the angle of the lumbar spine flexion, the points in time at which the anterior tilt angles of the pelvis and the thorax peaked were obtained, and the difference in the timing of the peak values was calculated. The value of the difference in timing was the mean of the three trials.

To analyze the relationship between the hip flexion angle and the anteroposterior tilt angle of the pelvis and the posterior tilt angle of the femur, we focused on hip joint angle at the point the pelvic tilt changed from anterior to posterior during the stand-to-sit motion.

The significance level was set at $p<0.05$ and SPSS Statistics version 21.0 (IBM, Chicago, IL, USA) was used for the statistical analyses. The Shapiro-Wilk test was used to check the normality of the calculated parameters. To compare the data for the standard and lower seats, corresponding t-tests were performed for normally distributed parameters, while Wilcoxon's signed rank test was used to examine non-normally distributed parameters.

This study was approved by the Ethics Committee of the International University of Health and Welfare (18-Ifh-094).

RESULTS

Changes over time in the mean and standard deviation (SD) lumbar spine flexion angle for all participants are shown in Fig. 1. Changes over time in the mean and SD thorax and pelvic anteroposterior tilt angles for all participants are shown in Fig. 2. The lumbar spine flexion persisted until the participants were seated upon both seats. The lumbar spine flexion angle was larger for the lower seat. The mean anterior tilt angle of the thorax was increased for the lower versus standard seat, whereas the mean anterior tilt angle of the pelvis did not differ. For both seats, the maximum anterior tilt of the pelvis was reached first, followed by the maximum anterior tilt of the thorax. There was a large difference in the timing of the maximum anterior tilt of the thorax and pelvis for the lower seat. In the standard seat, the anterior tilt angle of the thorax also reached its maximum immediately after the maximum anterior tilt angle of the pelvis. However, in the lower seat, the thorax continued to tilt forward even after the anterior tilt angle of the pelvis reached the maximum and the posterior tilt of the pelvis occurred. The lumbar flexion angle increased in the difference in timing between the maximum anterior tilt angle of the thorax and pelvis.

The results of comparing each parameter of the standard versus lower seat are shown in Table 1. The Shapiro-Wilk test revealed that the values of the anterior tilt angle of the thorax for the standard seat were non-normally distributed, while those of the other parameters were normally distributed. The normally distributed variables are shown as means and SD, while non-normally distributed data are shown as medians and interquartile range. The maximum angles of lumbar spine flexion, anterior tilt of the thorax, and posterior tilt of the pelvis increased significantly for the lower versus standard seat, and there was no significant intergroup difference in the maximum angle of the anterior tilt of the pelvis. The timing of the change in movement from an anterior to posterior tilt of the thorax was significantly delayed for the lower seat.

Changes over time in the mean and SD flexion and extension angles of the hip, anteroposterior tilt angle of the pelvis, and anteroposterior tilt angle of the thigh for all participants are shown in Fig. 3. Regardless of seat height, the pelvic movement changed from an anterior to posterior tilt when the hip flexed approximately 60° (mean −57.1 ± 8.9° for the standard seat

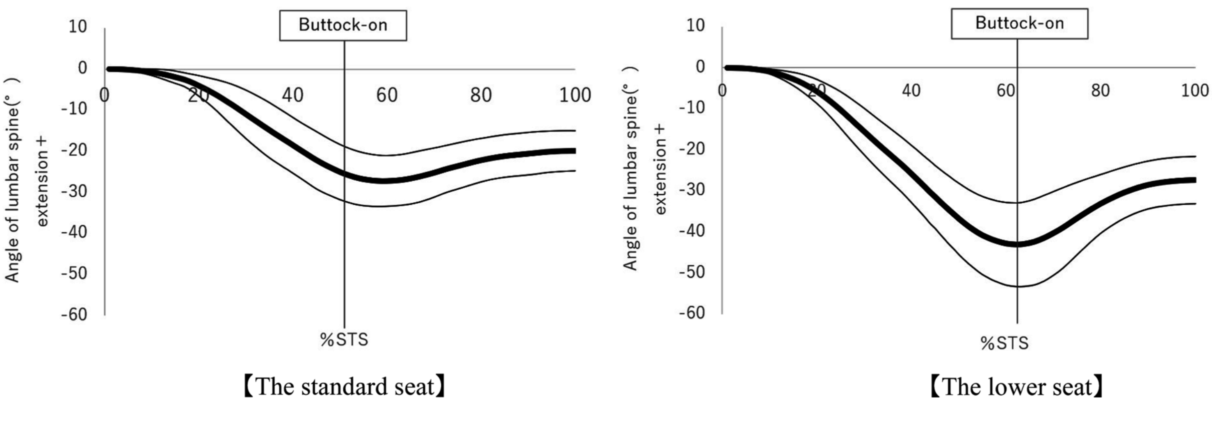


Fig. 1. The mean lumbar spine flexion angle.
Changes over time in the mean (thick solid lines) and SD (thin solid lines) values of lumbar spine flexion angle for all participants are shown (left: the standard seat, right: the lower seat). The vertical solid lines within the graph shows the buttock-on timing. The period between the initiation and termination of the stand-to-sit motion was normalized to 100%.

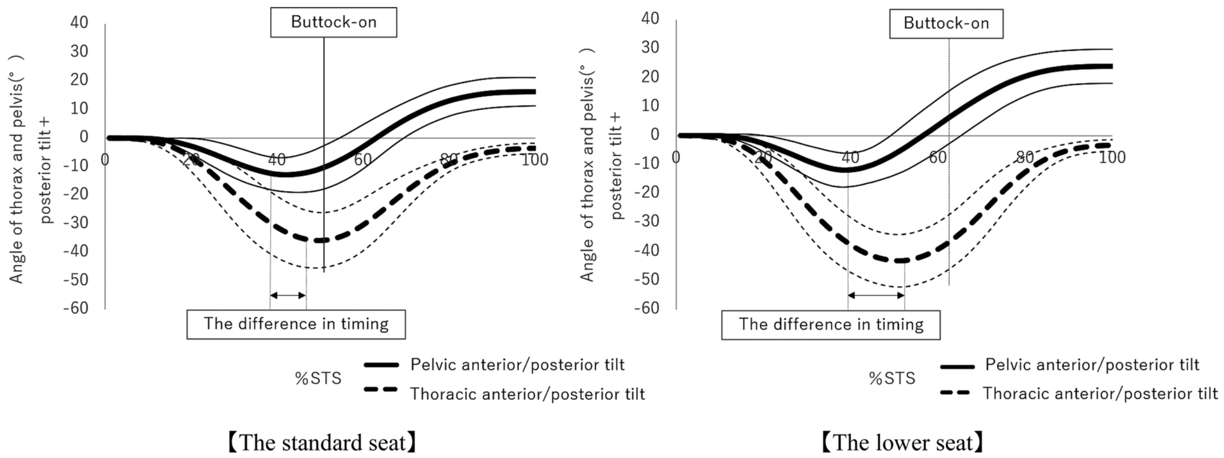


Fig. 2. The mean thorax and pelvic anteroposterior tilt angle.
Changes over time in the mean and SD values of thorax (the mean: thick dotted lines, SD: thin dotted lines) and pelvic (the mean: thick solid lines, SD: thin solid lines) anteroposterior tilt angle for all participants are shown (left: the standard seat, right: the lower seat). The difference in the timing when the maximum anterior tilt angle of the thorax and pelvis is reached is shown as the difference in timing (vertical dotted lines).

Table 1. Comparison of the maximum of each angle and timing for the standard seat versus the lower seat

	Standard seat	Lower seat
Lumbar spine flexion (°) ***	−29.6 ± 6.9	−45.1 ± 10.3
Thoracic anterior tilt (°) **	−35.5 (88.5)	−45.5 ± 9.4
Pelvic anterior tilt (°)	−15.3 ± 5.8	−14.4 ± 5.8
Pelvic posterior tilt (°) ***	16.6 ± 5.0	24.2 ± 5.9
Hip flexion (°) ***	−68.2 ± 6.7	−83.0 ± 9.5
Thigh posterior tilt (°) ***	69.1 ± 3.6	95.3 ± 6.3
The differences in timing (%) **	6.7 ± 4.1	9.9 ± 4.6
Hip flexion at peaked anterior pelvic tilt (°)	−57.1 ± 8.9	−58.8 ± 11.0

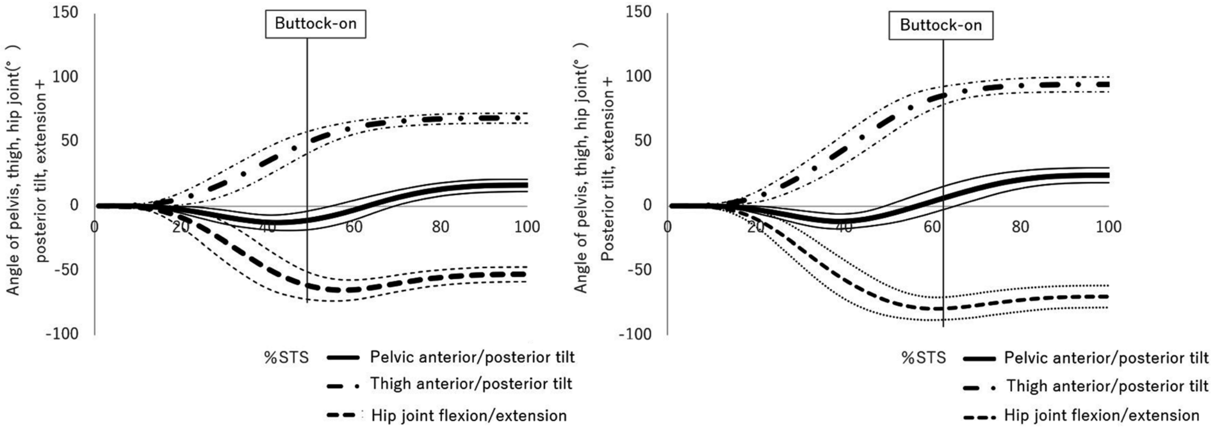
Normally distributed: Mean ± SD, non-normalized: median (IQR).
*p<0.05, **p<0.01, ***p<0.001.
+: extension, posterior tilt.
−: flexion, anterior tilt.
The difference in timing: The differences in timing when the angles of the anterior tilt of the thorax and pelvis peaked.

versus −58.8 ± 11.0° for the lower seat). For the standard seat, the hip flexion peaked at a mean 54.7 ± 6.13%, while the buttock-on point was reached at a mean 54.6 ± 5.7%. This finding suggests that the hip flexion angle peaked at almost exactly the moment the participant sat upon the seat. For the lower seat, the hip flexion peaked at a mean 59.7 ± 5.5%, while the buttock-on point was reached at a mean 54.6 ± 5.7%. The hip flexion peaked before a participant sat upon the seat, the hip movement changed to extension. The pelvis and the thigh continued to tilt posteriorly once a participant was sitting on the seat for both seats. The maximum angles of the hip flexion, the pelvis and the thigh posterior tilt were significantly increased on the lower seat versus the standard seat (Table 1).

DISCUSSION

This study aimed to investigate the movement of the lumbar spine on stand-to-sit motion and to identify the kinematic characteristics to respond to changes in the height of the seat. We found that lumbar spine flexion was increased on the lower versus standard seat and inferred that the increased lumbar spine flexion angle would increase the load on the lumbar spine according to previous researches[4–6].

When a participant sat on the lower seat, the movement to a posterior tilt of the pelvis occurred after the anterior tilts of the pelvis peaked, while the thorax continues to tilt anteriorly. The lumbar spine flexion increased as the pelvis tilted posteriorly, whereas the thorax continued to tilt anteriorly. In this situation, the pelvis tilted posteriorly, which may have resulted in a



【The standard seat】 【The lower seat】

Fig. 3. The mean flexion and extension angles of the hip, anteroposterior tilt angle of the pelvis, and anteroposterior tilt angle of the thigh.

Changes over time in the mean and SD values of flexion and extension angles of the hip (the mean: thick dotted lines, SD: thin dotted line dotted lines), anteroposterior tilt angle of the pelvis (the mean: thick solid lines, SD: thin solid lines), and anteroposterior tilt angle of the thigh (the mean: thick dashed lines, SD: thin dashed lines) for all participants are shown (left: the standard seat, right: the lower seat).

flexion movement starting at the inferior lumbar spine because the ilium and the 5th lumbar vertebra are tightly connected by the iliolumbar ligament. For this movement to be smooth, a centrifugal contraction of the multifidus muscle, which is segmentally attached to the lumbar spine as well as the erector spinae muscle is necessary[16, 17)]. A study of forward bending of the trunk reported that, compared to the movement in which the pelvis tilts anteriorly with the thorax, the movement in which pelvis tilts posteriorly with the thorax tilting anteriorly increased multifidus muscle activity as well as the compressive force on the intervertebral disc between L5 and S1[18)]. These results imply that an increased load on the lumbar spine occurs with sitting on the lower seat.

The timing of the change from an anterior to posterior tilt of the pelvis during the stand-to-sit motion did not differ between the two seat heights and occurred when the hip flexed at about 60°. This movement of the pelvis is necessary for controlling one's center of gravity during forward movements due to the hip flexion and thoracic anterior tilt and it is thought to be caused by the influence of the posterior tissues of the hip[19)], such as the resistance of the gluteus maximus muscle to the centrifugal contraction and the elongation of the hamstrings during the stand-to-sit motion. The posterior tilt of the pelvis and thigh, and flexion of the hip continued until the participants were sitting upon the seat. This finding suggests that this movement might hold the pelvis in place to prevent excessive relative posterior tilt of the pelvis caused by the posterior tilt of the thigh. Function of the iliopsoas muscle, which is a hip flexor, is necessary for this movement, and holding the pelvis and controlling the posterior tilt may prevent excessive flexion of lumbar spine and reduce the load on the lumbar spine.

In this study, we focused on the movement of the lumbar spine during the stand-to-sit motion using a standard versus lower seat. We found that lumbar spine flexion increased when a participant sat upon the lower seat versus the standard seat, suggesting that the load on the lumbar spine may have been increased. One of the characteristics of the movement was the need to flex the lumbar spine by tilting the pelvis posteriorly while maintaining anterior tilt of the thorax. These results suggested that the increase or decrease in the lumbar spine flexion angle during the stand-to-sit motion in a lower chair was influenced by the characteristic movements of the thorax and pelvis. We think that the knowledge of these movement characteristics will be necessary for movement guidance and environmental adjustment for patients with low back pain.

However, this study focused on joint angle and used lumbar spine flexion angle to represent lumbar spine load. Although, we estimated muscle activity, we did not actually use electromyography. In the future, it will be necessary to consider to the load of the lumbar spine including kinematic factors and analyze its effect on the lumbar spine during movement.

Funding and Conflict of interest

The authors declare no conflicts of interest directly relevant to the content of this article.

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