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Original Article

Analysis of sagittal thoracolumbar spine and hip joint movements during sit-to-stand using a 2D image analysis freeware

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Abstract. [Purpose] This study aimed to verify the utility of an image analysis freeware in the evaluation of thoracolumbar spine and hip joint movements during sit-to-stand movement and show the importance of separately analyzing the movements of the thoracolumbar spine and the hip joint. [Participants and Methods] We used a two-dimensional image analysis freeware to analyze the kinematics of the thoracolumbar spine and the hip joint during sit-to-stand movements in seven healthy young males. We further examined the usefulness of the freeware by verifying the concordance of its angle measurements with those of a three-dimensional motion analysis device. Moreover, we evaluated joint coordination of the thoracolumbar spine with hip joint movements in pregnant female before and after delivery by measuring the relative phase angle. [Results] The trunk angle and relative phase angle between the thoracolumbar spine and the hip joint obtained using the two different analytical methods were fairly consistent. In the analysis of the pregnant female, the degree of thoracolumbar flexion prior to hip flexion tended to decrease. Similarly, the degree of hip extension tended to decrease during pregnancy. [Conclusion] This study shows that a two-dimensional image analysis freeware could be useful and meaningful in the calculation of thoracolumbar spine and hip joint movements and in the detection of synergistic patterns of these entities during sit-to-stand movement.

Key words: Sit-to-stand, Trunk movement, Two-dimensional image analysis

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INTRODUCTION

Rising from a chair is a motor task that is clinically assessed as a movement performed frequently during daily life activities. It is a complex task characterized by the transfer from a sitting position to a standing position with movements of all body segments except the feet[1)] and many elderly people experience difficulty completing this movement[2)]. The increased forward trunk lean during the initial stage of movement and lower speed of movement are known to be important elements of complex compensation[3)]. In previous study, various analyses have been performed that consider the forward trunk lean by the hip flexion as an angle formed between a line that connects the acromion with the greater trochanter and a line that connects the greater trochanter with the lateral epicondyle[4)]. A reason for this is that measurements of thoracolumbar spine movements have not been valued due to priority and complexity of measurements but the spinal column is susceptible to the impact of pain and age-related changes such as kyphosis and muscle weakness[5)]. Since the forward trunk lean includes some degree of thoracolumbar flexion on the pelvis[6)], it is desirable to quantify the movements of the thoracolumbar region and the hip joint included in trunk movement as required. Movement analysis using a digital camera and free image analysis software

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can be easily performed by anyone and the validity of using two-dimensional (2D) image analysis for trunk movement in the sagittal plane during rising has been reported7). However, movements of the thoracolumbar region relative to the pelvis and the hip joint have not been adequately verified using a digital camera and free image analysis software and the significance of evaluating them is also not fully understood.

The purpose of this study was to determine the usefulness and significance of free software that provides coordinate values of the images to assess the thoracolumbar spine and the hip joint angles during sit to stand (STS). We captured movements of the thoracolumbar region relative to the pelvis and the hip joint that are included in trunk movement during rising and verified their validity based on a comparison with the angle calculated using a three-dimensional (3D) movement analysis device. Moreover, we assessed their potential utility by capturing changes in the movement patterns of the thoracolumbar region and the hip joint during STS in a female in the third trimester of pregnancy and postpartum stage, when forward trunk lean is difficult due to enlargement of the abdomen and weight gain.

PARTICIPANTS AND METHODS

Seven young male (average age ± standard deviation (SD): 21.9 ± 1.4 years, average height ± SD: 171.7 ± 5.9 cm, average weight ± SD: 65.6 ± 8.1 kg) and healthy pregnant female (age: thirties, height: 156.0 cm) participated in this study. The study procedures were approved by the Himeji Dokkyo University Human Ethics Committee (No. 13-03), and the participants provided their informed consent prior to participation.

Each participant with bare feet was seated on a stool with neither armrest nor backrest while their feet placed flat and 10 cm apart at the heels. They were instructed to look forward with an upright posture, to hold their arms across the chest to avoid obstructing the camera's view of the markers and to rise freely at their comfortable speed from two different height stools (40-cm and 20-cm). All movements were demonstrated following two to three practice trials and each participant performed the action two times. The order of the testing was randomized. Infrared-reflecting markers were attached to the body surfaces: Top of the head, forehead, back of the head, midpoint of posterior superior iliac spines (PSIS), acromion, acromio-clavicular joints, lateral epicondyles of the humerus, midpoint of the suprastyloid crest of radius and ulnas, anterior superior iliac spines (ASIS), greater trochanters, lateral epicondyles of the femur, medial epicondyles of the femur, lateral malleolus, medial malleolus, the second metatarsal bones and heels. We captured the marker trajectories during STS movement using both a digital video camera (EX-ZR1000, CASIO Inc., Tokyo, Japan) at a sampling rate of 120 Hz and a 3D motion analysis system (MAC 3D system, nac Image Technology Inc., Tokyo, Japan) with eight infrared cameras at a sampling rate of 200 Hz. The digital video camera was placed at a distance of 160 cm perpendicular to the sagittal plane and with the center of the field of view at the height of 70 cm. Pregnant female is instructed to rise from the 40-cm stool with markers affixed to the right acromion, ASIS, greater trochanter, lateral epicondyle, lateral malleolus and PSIS. The STS motion was captured using a digital video camera at 6, 7 months of pregnancy and postpartum.

The video images of STS movements in the sagittal plane were analyzed using BMP_measure8) which is 2D image analysis free software acquiring coordinate values on the image9). The coordinate values of 6 markers; right acromion, ASIS, greater trochanter, lateral epicondyles of the femur, lateral malleolus and PSIS were acquired from the image picked on every 3 images. Trunk angle in the sagittal plane was calculated using trigonometric functions from the relative angles between the straight lines defined by acromion to greater trochanter and greater trochanter to lateral femoral epicondyle. Sagittal thoracolumbar angle was calculated from the relative angles between the straight line connecting acromion with center of the pelvis, which is the point where the perpendicular from the greater trochanter intersects the straight line connecting ASIS and PSIS, and the straight line connecting pelvis center with greater trochanter (Fig. 1). Sagittal hip angle was calculated from the relative angles between the straight lines connecting pelvis center with greater trochanter and the straight lines connecting greater trochanter with lateral femoral epicondyle. Moreover, the pattern of the joint coordination between thoracolumbar region and hip joint was assessed from relative phase angles10). The phase angles of the thoracolumbar region and the hip joint are defined as the inverse tangent of angular velocity/angular displacement of the trunk, pelvis and thigh segments obtained as line segments connecting the coordinates. The relative phase angle between two joint was quantified by subtracting the phase angle of one from the other. If the phase difference is negative, the hip is lagging behind the thoracic-lumbar movement, and if the phase difference is positive, then the hip movement is leading the lumbar-thoracic movement.

3D kinematic calculations were performed with the motion analysis software (Cortex-64 1.1.4, Motion Analysis Inc., Santa Rosa, CA, USA). The coordinates of the shoulder, pelvic and knee joint center were defined as the midpoint between right and left acromio-clavicular joints, ASIS and PSIS, the lateral and medial epicondyle of the femurs. The coordinates of the hip joint centers were calculated according the methods described in previous studies11). The linear distance between ASIS and the center of the hip joint, the sagittal linear distance between ASIS and the center of the hip joint and the angle between the vertical linear and the straight lines defined by ASIS and the center of the hip joint in the frontal plane required for calculation were estimated using the presumption value of healthy Japanese adults12). The trunk, pelvis and thigh segments were constructed by connecting these joint centers and the thoracolumbar angles with respect to the pelvis and the hip joint angles in the sagittal plane were calculated by the Euler angle (Fig. 1). The trunk angle was the sum of the thoracolumbar angle and the hip joint angle. Additionally, the relative phase angle was calculated from the difference between the phase angles of the thoracolumbar region and the hip joint as in the methods of 2D image analysis.

All data were filtered with a fourth-order zero lag, low-pass filter using a cutoff frequency of 2 Hz, and normalized to 200 data with an arithmetic program for natural third-order spline interpolation using Scilab 5.5.2 (INRIA, Rungis, France). The start of the motion was determined where the anterior-posterior components of the acromion marker start moving beyond the mean value at rest + 2 SD. The end of the STS movement was determined where trunk angular velocity first reached the 0°/sec[6)]. The average value of the two trials was used for data analysis. The degree of agreement of the trunk, thoracolumbar, hip joint and relative phase angles between two analyses methods were evaluated by the adjusted coefficient of multiple correlations (CMC)[13)]. The mean angle differences between two analysis methods for the thoracolumbar and the hip joint were calculated during the motion period before and after the buttock lift off the seat. The lift off was defined as the point where the vertical displacement of the large trochanter marker started to rise beyond the mean value at rest + 2 SD. In the analysis for pregnant female, the trunk, thoracolumbar, hip joint and relative phase angles were used to evaluate the effect of body shape changes associated with pregnancy on the joint coordination between the thoracolumbar with hip joint movements, and we show the significance of separating the trunk movement of the thoracic lumbar region and hip joint. Microsoft Office Excel 2007 (Microsoft Inc., Redmond, WA, USA) was used to perform the data analysis.

RESULTS

When rising from the 40-cm stool, the mean CMC ± SD were 0.97 ± 0.03 for the trunk, 0.85 ± 0.13 for the thoracolumbar, 0.94 ± 0.06 for hip joint angles and 0.98 ± 0.01 for relative phase angle (Fig. 2). The mean angle difference ± SD of thoracolumbar between two analysis methods were 6.7 ± 5.9° for pre-lift off and 0.5 ± 4.4° for post-lift off. The mean angle difference ± SD of hip joint between two analysis methods were 4.9 ± 9.0° for pre-lift off and 3.2 ± 5.8° for post-lift off. When rising from the 20-cm stool, the mean CMC ± SD were 0.98 ± 0.01 for the trunk, 0.91 ± 0.04 for the thoracolumbar, 0.91 ± 0.10 for hip joint angles and 0.99 ± 0.01 for relative phase angle (Fig. 2). The mean angle difference ± SD of thoracolumbar between two analysis methods were 9.3 ± 9.2° for pre-lift off and 1.4 ± 4.8° for post-lift off. The mean angle difference ± SD of hip joint between two analysis methods were 13.0 ± 8.3° for pre-lift off and 7.2 ± 6.8° for post-lift off.

In the analysis of pregnant female, the angle of trunk lean, thoracolumbar flexion and hip flexion during the standing up motion were 105°, 30°, 80° at 6 month (6M) of pregnancy, 97°, 28°, 72° at 7 month (7M) of pregnancy and 112°, 32°, 86°

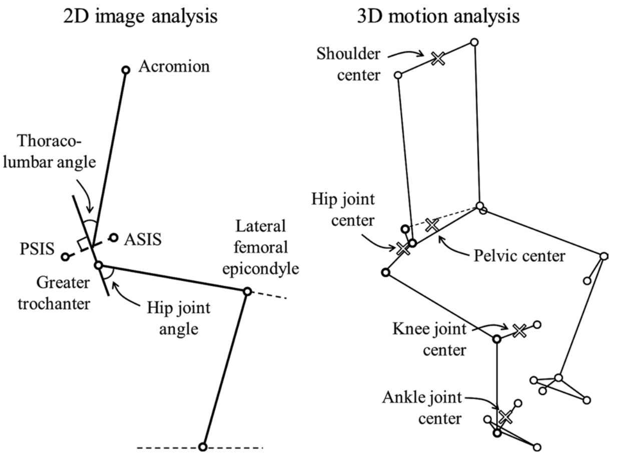

Fig. 1. Marker placement on body landmarks and joint centers calculating the thoracolumbar and hip joint angles in the 2D image analysis using BMP_measure (left) and 3D motion analysis using Cortex-64 1.1.4 (right).

ASIS: anterior superior iliac spine; PSIS: posterior superior iliac spine.

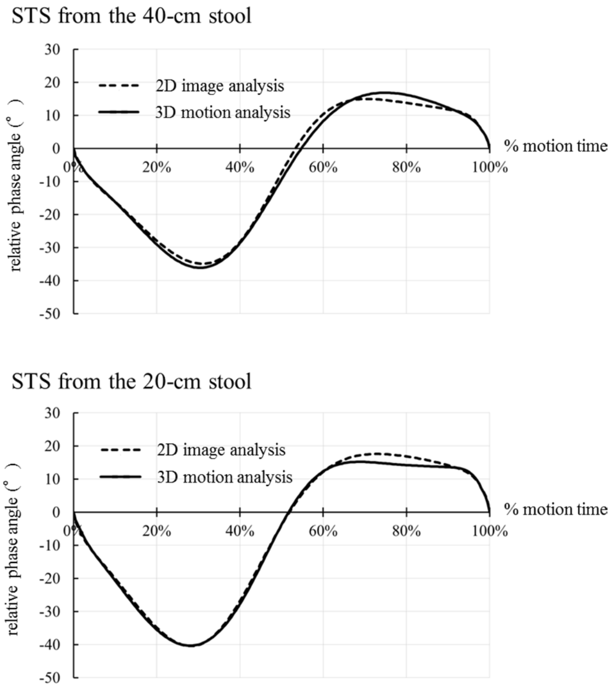

Fig. 2. A plot of mean relative phase angle vs. time for the sit-to-stand movement calculated by two different analysis methods in healthy male (N=7).

The dashed and solid line represents 2D image analysis and 3D motion analysis respectively. The top shows a rise from 40-cm stool and the bottom shows a rise from 20-cm stool. The relative phase angle between thoracolumbar region and hip joint represents the joint coordination.

at postpartum. During pregnancy, the thoracolumbar flexion prior to hip flexion tended to decrease and then the subsequent hip extension tended to decrease and the minimum and maximum values of the relative phase angle showed a decrease in the later stages of pregnancy (Fig. 3).

DISCUSSION

Although the utility of 2D image analysis for trunk movement during rising has been previously reported[6)], more verification is required on trunk kinematic analysis separating movements into those involving the thoracolumbar spine and the hip joint. In this study, we evaluated able-bodied individuals using free software that provided coordinate values of images and calculated the angle of the thoracolumbar region relative to the pelvis and the hip joint in trunk movement during STS. Using the joint center estimated by the 3D movement analysis device, we confirmed the consistency of the result with the angle calculated using Euler angles. The result showed that the trunk angles obtained through the two different analytical methods were quite consistent, confirming the validity of trunk movement analysis in the sagittal plane using the angle between the line that connects the acromion with the greater trochanter and the line that connects the greater trochanter with the lateral epicondyle. However, when the movement was separated into movements of the thoracolumbar region and the hip joint, the thoracolumbar flexion decreased whereas hip flexion increased at the start of movement in the 2D image analysis and agreement was not high compared to the trunk angle measurement. These angular differences are thought to be caused by the difference in the methods used to calculate the coordinate points and angles used for analysis and this point needs to be considered in the 2D image analysis of movements in the thoracolumbar region and the hip joint. On the other hand, a relative phase angle reflecting synergistic patterns of the thoracolumbar region and the hip joint presented similar waveforms to those reported in previous studies that involved able-bodied individuals[14)] regardless of the height of chairs, indicating a high level of consistency with the 3D movement analysis results as in those of the trunk angle. The relative phase angles calculated from the differences in phase angles of two time series data are characterized by the fact that the trajection in a two-dimensional space, where angle and angular velocity are the axes, can be quantified independent of the absolute value of amplitude and velocity[15)]. This study confirmed that, in 2D image analysis, relative phase angles could be used with high precision to detect synergistic patterns of the thoracolumbar region relative to the pelvis and the hip joint, which are included in trunk movement.

In this study, we compared changes in movement of the forward trunk lean by analyzing the movement of rising in pregnant female before and after delivery. This is because forward trunk lean becomes temporarily difficult due to the enlargement of abdomen and weight gain associated with pregnancy[16)], which subsequently improves after delivery. By examining the movements of the thoracolumbar region and the hip joint involved in trunk movement separately, we showed that the forward trunk lean angle during STS tended to decrease with pregnancy, which was due to the decrease of the hip flexion angle. It has been reported that there is no difference in the inclination of the straight line connecting the midpoint of the left and right acromion and the midpoint of the hip joint with respect to the vertical axis between pregnant females at the end of pregnancy and non-pregnant females when rising from the 40-cm stool[17)]. However, the trunk inclination angle is even if it is similar, there may be changes in the thoracolumbar region and the hip joint movements, and there may be a limit to understanding the difficulty in forward trunk lean experienced by pregnant females based on the trunk lean angle alone.

In able-bodied people, the thoracolumbar bend forward before the hip joint flexion at the start of the movement, followed by hip joint extension preceding the thoracolumbar retroflexion[14)]. In pregnant female, changes in the synergistic patterns of the thoracolumbar region and the hip joint appeared as a reduction in the thoracolumbar flexion before hip flexion and a delay in the hip joint extension preceded thoracolumbar retroflexion. The reason for this is that, in pregnant female, changes in body shape alter their end seating posture before the start of the movement itself. Since pregnant female perform the trunk lean movement with the thoracolumbar region fixed in the extended position to maintain upright position on the pelvis that leans forward due to the anterior protrusion of the abdomen, normal forward trunk lean becomes difficult. Thus, it is possible that by

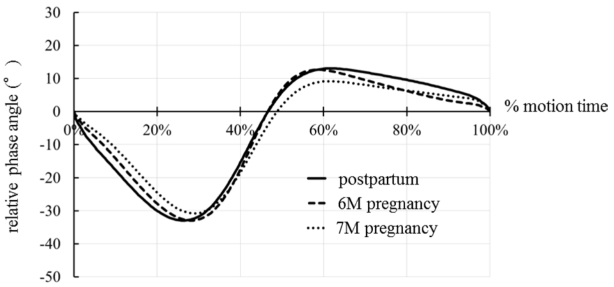

Fig. 3. A plot of mean relative phase angle vs. time for the sit-to-stand movement from the 40-cm stool in pregnant female.
The solid, dashed and dotted line represents postpartum, 6 months of pregnancy and 7 months of pregnancy respectively. The relative phase angle between thoracolumbar region and hip joint represents the joint coordination.

emphasizing the flexion of the head and neck, body weight began to shift forward and anterior tilt of the pelvis by hip flexion was exaggerated to move the trunk together as one mass. This trend is similar in the latter half of the STS movement. It was reported in previous studies that patients with back pain had delayed hip joint extension in lumbar extension in the latter half of the movement, compared to able-bodied individuals, to avoid stress on their lower back[14]. Similarly, it is possible that the trend of hip joint extension preceding to a lesser degree during the third trimester could be reflecting increased stress on the lower back. As the present study did not aim to elucidate this particular point, we cannot clarify the mechanism of changes in synergistic patterns. However, depending on the case, even if the trunk angles are similar while rising, the synergistic patterns of the thoracolumbar region and the hip joint could change. Therefore, this study demonstrated the importance of quantifying movements of the thoracolumbar region and the hip joint including the use of relative phase angles.

The limitations of this study include having to treat the spinal column as a rigid body segment for calculations because there is a limit to capturing the movement of individual vertebrae, which are included in the trunk movement, from the body surface. Thus, the extent of segmental evaluation performed depends on the amount of effort it takes for measurements and the objective of the study. In previous studies, the movement of the spinal column during STS movements was separated into movements of the thoracic region and the lumbar region for analysis[18]. With the start of the movement, the trunk leans forward, but it leans backward as the buttocks leave the chair, returning to an upright position. In that process, opposite to the lumbar region movement aimed to create such motions, there is a movement of the thoracic region, which extends slightly at the start and flexes slightly after the buttocks leaving the chair. As these movements are combined, smooth movement of the trunk is achieved. However, such measurement is time-consuming and requires specific skills, such as applying multiple markers on the spinous process. Additionally, movements of the thoracic and lumbar regions, measured as the angle between the lines that connect two vertebras, do not guarantee to present movements of the individual vertebral body that constitutes the whole. The analytical method used in this study aims to capture movements of the spinal column and the hip joint within trunk movement in as simple a manner as possible and separately. Thus, it appears to have a certain level of utility. However, there is an increased analytical burden dependent on the number of markers used in the free software that provides coordinate values. Therefore, a future challenge for research is conducting movement analysis in settings where more detailed assessments are required.

Funding and Conflict of interest

The authors have no conflicts of interest to declare.

REFERENCES

1) Mourey F, Pozzo T, Rouhier-Marcer I, et al.: A kinematic comparison between elderly and young subjects standing up from and sitting down in a chair. Age Ageing, 1998, 27: 137–146. [Medline] [CrossRef]
2) Ikeda ER, Schenkman ML, Riley PO, et al.: Influence of age on dynamics of rising from a chair. Phys Ther, 1991, 71: 473–481. [Medline] [CrossRef]
3) Doorenbosch CA, Harlaar J, Roebroeck ME, et al.: Two strategies of transferring from sit-to-stand; the activation of monoarticular and biarticular muscles. J Biomech, 1994, 27: 1299–1307. [Medline] [CrossRef]
4) Tully EA, Fotoohabadi MR, Galea MP: Sagittal spine and lower limb movement during sit-to-stand in healthy young subjects. Gait Posture, 2005, 22: 338–345. [Medline] [CrossRef]
5) Milne JS, Williamson J: A longitudinal study of kyphosis in older people. Age Ageing, 1983, 12: 225–233. [Medline] [CrossRef]
6) Schenkman M, Berger RA, Riley PO, et al.: Whole-body movements during rising to standing from sitting. Phys Ther, 1990, 70: 638–648, discussion 648–651. [Medline] [CrossRef]
7) Tsushima E: Reliability for motion analysis by image photographed in one digital video camera. J Jpn Phys Ther Assoc, 2009, 36: 187–191 (in Japanese).
8) BMP_measure. https://www.vector.co.jp/soft/win95/art/se323802.html (Accessed Jun. 12, 2022)
9) Yamanaka Y, Mizuno T, Ishikawa N, et al.: The validity of image analysis freeware in calculating physical angles in two dimensions. Rigakuryoho Kagaku, 2016, 31: 571–574 (in Japanese). [CrossRef]
10) Burgess-Limerick R, Abernethy B, Neal RJ: Relative phase quantifies interjoint coordination. J Biomech, 1993, 26: 91–94. [Medline] [CrossRef]
11) Davis RB, Ounpuu S, Tyburski D, et al.: A gait analysis data collection and reduction technique. Hum Mov Sci, 1991, 10: 575–587. [CrossRef]
12) Kurabayashi J, Mochimaru M, Kouchi M: Validation of the estimation methods for the hip center. J Soc Biomech Jpn, 2003, 27: 29–36 (in Japanese).
13) Kadaba MP, Ramakrishnan HK, Wootten ME, et al.: Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. J Orthop Res, 1989, 7: 849–860. [Medline] [CrossRef]
14) Shum GL, Crosbie J, Lee RY: Effect of low back pain on the kinematics and joint coordination of the lumbar spine and hip during sit-to-stand and stand-to-sit. Spine, 2005, 30: 1998–2004. [Medline] [CrossRef]
15) Kelso JA: Dynamic patterns: the self-organization of brain and behavior. Cambridge: MIT Press, 1995.
16) Sunaga Y, Anan M, Shinkoda K: Biomechanics of rising from a chair and walking in pregnant women. Appl Ergon, 2013, 44: 792–798. [Medline] [CrossRef]
17) Takeda K, Katuhira J, Takano A, et al.: Examination of the intervention effect of sit-to-stand in the third trimester. Rigakuryoho Kagaku, 2012, 27: 73–76 (in Japanese). [CrossRef]
18) Kuo YL, Tully EA, Galea MP: Kinematics of sagittal spine and lower limb movement in healthy older adults during sit-to-stand from two seat heights. Spine, 2010, 35: E1–E7. [Medline] [CrossRef]