

A Kinesiological Analysis of the Stand-to-Sit during the Third Trimester

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Abstract. [Purpose] The purpose of this study was to kinesiologically analyze of the stand-to-sit motion in the third trimester. [Subjects] Eight pregnant women in their third trimester and 8 non-pregnant women participated in this study. [Methods] Subjects were asked to sit-down on a 400-mm-high seat from the standing position. A 3D motion analysis system and a force plate were used to collect data. Measurements analyzed were (1) the time taken to sit down; (2) the leg joint moment; (3) the antero-posterior and vertical floor reaction forces; and (4) the range of motion of the lower limbs and trunk. Statistical analyses were conducted to compare the pregnant with non-pregnant women using the Mann-Whitney U test. [Results] For pregnant women, the time taken to sit down, the knee extension moment, as well as the posterior and vertical components of the motion were significantly higher. The ranges of motion of the other joints were not significantly different between the pregnant and non-pregnant women. [Conclusion] Pregnant woman have unstable posterior balance when sitting down due to the increase of the posterior floor reaction force. In the third trimester, the sit-down motion requires attention because of the impact of weight gain and the shift in the center of gravity.

Key words: Pregnancy, Stand-to-sit, Floor reaction force

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INTRODUCTION

Changes occur in body function and movement as pregnancy progresses. Furthermore, pregnant women experience changes in their musculoskeletal system, hormonal levels, and balance¹⁾. Specifically, weight gain²⁾, anterior and superior displacement of the center of gravity³⁾, increased joint laxity^{4, 5)}, alterations in skeletal alignment⁶⁾ and weakening of the abdominal muscles occur^{3, 7)}. Therefore, static balance^{8, 9)} and dynamic balance decrease during pregnancy¹⁰⁾. Butler et al.⁸⁾ reported increased postural sway during pregnancy. They also reported that the path length and radial sway increased when the eyes were closed. Jang et al.⁹⁾ reported that pregnant women showed increased anterior-posterior and radial sway, compared to non-pregnant women. McCrory et al.¹⁰⁾ reported that initial sway response, total sway, and sway velocity of pregnant women who suffered a fall were decreased, compared to those who did not fall, as well as non-pregnant women. Therefore, as pregnancy progresses, the likelihood of a fall increases. Dunning et al.¹¹⁾ reported that working pregnant women suffer an increased incidence of falling in the second trimester and the percentage is similar to that of women over the age of 70 years. In addition, they reported that environmental parameters such as a slippery floor, hurried movements, and walking while carrying objects were related to a many falls. Butler et al.⁸⁾ and Jang et al.⁹⁾ reported that the incidence of falls in pregnancy were 25% and 13%, respec-

tively. Falls during pregnancy causes bodily disruption of the fetus as well as the mother¹²⁾. To ensure a healthy pregnancy outcome, it is important to evaluate movements that could increase the likelihood of a fall. A number of previous studies have reported that pregnant women show a greater decline in anterior-posterior balance compared to lateral balance^{8–10, 13)}. However, the literature does not contain any studies which have analyzed movement from the viewpoint of balance in a pregnant woman's daily routine. The purpose of this study was to perform motion analysis at the time of sitting down on a chair. This movement is an antigravity motion directed downward and backward and it is difficult for pregnant women to control posterior balance during the third trimester.

SUBJECTS AND METHODS

The subjects were eight pregnant women in the third trimester (weeks of gestation, 35.1 ± 1.4 weeks; age, 28.3 ± 3.4 years; height, 159.4 ± 5.3 cm, weight: 63.3 ± 4.7 kg; pre-pregnancy weight, 52.4 ± 4.5 kg) and eight non-pregnant women (age, 21.4 ± 0.5 years; height, 160.0 ± 7.1 cm; weight, 52.1 ± 6.1 kg). The inclusion criterion was healthy women in their twenties or thirties. Subjects were excluded if they had any significant medical history involving their legs or hips. Consent was obtained from all the subjects after we gave oral and written explanations of the purpose and methods of the study, which included a guarantee of

personal information. For the measurements, a Vicon Peak 3D motion analysis system 612 (Vicon Peak, Oxford, UK), six force plates (Force Platform®, Advanced Management Technology Inc., MA, USA), and eight infrared cameras (sampling frequency: 120 Hz) were used. For the seat, a 400-mm-high seat (the standard height of a toilet seat for those with disabilities, specially made to decrease physical load and to provide assistance during sit-to-stand)¹⁴⁾ was used. The seat prevented the subjects from resting on the force platform plates. This prevented that a hip joint moment could not get an accurate value by receiving bearing surface the floor reaction force¹⁵⁾. Infrared reflective markers, 25 mm in diameter, were placed at 27 positions (vertex of the head, directly above each ear lobe, C7 spinal process, at each acromial process, xiphoid process, at each lateral epicondyle, at each ulnar styloid process, right metacarpophalangeal joint of the third finger, T12 spinal process, L5 spinal process, at each anterior superior iliac spine, at each posterior superior iliac spine, at each greater trochanter, at each midpoint of the anteroposterior knee joint diameter at the patella height, at each lateral malleolus of the fibula, and the interphalangeal joint of both fifth toes). A dummy marker was placed at the inferior angle of the right shoulder¹⁶⁾. The subjects stood in a resting upright position, which was maintained for three seconds. Then, on the signal given by the evaluator, they sat down at their own speed. This study was conducted in accordance with the principles of the Helsinki Declaration (approval was obtained from the Ethical Review Board of the International University of Health and Welfare). Moreover, to ensure that this study was performed safely, abdominal tension and fetal heart beat were confirmed before and after the measurements in the presence of a midwife. Because the stand-to-sit motion is a symmetric movement, it was decided to use the measurement item extracted unilateral data of the right leg in the analysis. The measurement items were: (1) the time taken to sit down (stand-to-sit time); (2) the maximum leg joint moment of the right side during stand-to-sit (max joint moment: hip flexion-extension, knee flexion-extension, ankle dorsiflexion-plantarflexion); (3) the floor reaction force of the right side at the maximum leg joint moment (FRF: anterior-posterior, vertical); (4) the range of motion of the right leg joint (ROM: hip flexion-extension, knee flexion-extension, ankle dorsiflexion-plantarflexion), and the trunk in the sagittal plane (ROM: trunk flexion-extension). To compare the joint moments between the subject groups which consisted of individuals of various heights and weights, we used the method of a previous study, which accounts for weight and muscular strength in proportional relationships, joint moment was normalized by weight¹⁷⁾. However, the weight gain of a pregnant woman (primarily due to the fetus, amniotic fluid, and increased body fat) never correlates with muscular strength increase. Consequently, the product of the height and weight of the pregnant group before pregnancy was used and compared with that of the non-pregnant group, whose values were used for the normalized joint moments¹⁸⁾. Similarly, for the floor reaction force, the weight before pregnancy of the pregnant group was normalized using that of the non-pregnant group at the time of testing. The hip joint angle was defined as

the angle of the femur relative to the vertical axis; the knee joint angle was defined as the angle between the femur and the tibia; and the ankle angle was defined as the angle between the tibia and the foot. The anterior-posterior angle of the trunk was measured against the vertical axis running through the midpoint between the acromial processes¹⁹⁾. Measurement items were compared between the pregnant group and the non-pregnant group using the Mann-Whitney U test ($p < 0.05$). SPSS statistics 17.0 (Windows) was used for the statistical analyses.

RESULTS

Stand-to-sit measurements are presented in Table 1. More time was required for the pregnant women to complete the stand-to-sit task (pregnant women, 0.96 ± 0.13 seconds; non-pregnant women: 0.84 ± 0.16 s; $p = 0.004$). The knee joint extension moments of the pregnant women increased more than those of the non-pregnant women (knee extension moment: pregnant, 4.83 ± 1.12 N/m·kg; non-pregnant, 3.96 ± 0.59 N/m·kg; $p = 0.014$). In addition, the posterior floor reaction force and the vertical floor reaction force of the pregnant women increased significantly more than those non-pregnant women (posterior FRF: pregnant, -0.32 ± 0.16 N/kg; non-pregnant: -0.19 ± 0.15 N/kg ($p = 0.004$); vertical FRF: pregnant, 6.46 ± 0.70 N/kg; non-pregnant, 5.50 ± 0.53 N/kg ($p = 0.001$). A significant difference between the groups was not found for either the right leg joint angle or the trunk angle, both of which influence the center of gravity of the upper trunk.

DISCUSSION

The literature contains many motion analyses of pregnant women^{20, 21)}. However, none of these studies addresses stand-to-sit motion. In this study, it was found that the center of gravity of a pregnant woman is displaced posteriorly in the stand-to-sit motion. The center of gravity backward displacement in the stand-to-sit motion of the pregnant women demonstrates the difficulty of controlling the body against gravity. Stand-to-sit is a movement in which the physical center of gravity is shifted downwards²²⁾. Senoo et al.²²⁾ reported that a kinematic characteristic of the initiation of a sitting movement is decreased control. In addition, it is characterized by a posterior displacement of the center of gravity, which is compensated for by a forward bend of the trunk. Therefore, trunk anteflexion and ankle dorsiflexion control the backward movement of the center of gravity, and contributing to a controlled sitting sequence. Compared to non-pregnant women, the pregnant women took more time to accomplish the stand-to-sit task. A significant difference between the groups was not found for either the lower leg joint or the trunk angle; however, the pregnant women exhibited a significant increase in the knee joint extension moment compared the non-pregnant women. Therefore, the pregnant women performed a stand-to-sit carefully with the knee extension muscles to avoid abrupt motion. In addition, our findings suggest that the pattern of the sitting movement does not change between the second and third

Table 1. Comparison of Stand-to-Sit between Pregnant and Non-Pregnant Women

	non-pregnant group	pregnant group
stand-to-sit time (s)	0.84 ± 0.16	0.96 ± 0.13 *
Max joint moment (Nm/m · kg)		
hip flexion-extension	4.27 ± 1.06	4.36 ± 0.94
knee flexion-extension	3.96 ± 0.59	4.83 ± 1.12 *
ankle dorsiflexion-plantarflexion	-0.41 ± 0.37	-0.47 ± 0.44
FRF (N/kg)		
anterior-posterior FRF	-0.19 ± 0.10	-0.32 ± 0.16 *
vertical FRF	5.50 ± 0.53	6.46 ± 0.70 *
ROM (°)		
hip flexion-extension	55.0 ± 4.67	54.2 ± 5.51
knee flexion-extension	71.3 ± 8.40	70.9 ± 6.93
ankle dorsiflexion-plantarflexion	7.17 ± 5.10	6.17 ± 7.40
trunk flexion-extension	39.7 ± 5.42	39.9 ± 4.42

Moment, ROM: flexion, dorsiflexion (+), FRF: posterior (-). *: $p < 0.05$

trimesters. In regard to the floor reaction force, that affects the joint moment, the posterior and vertical reaction forces significantly and simultaneously increased. The reason why the vertical floor reaction force of the pregnant women increased, is most likely due to the increase in maternal weight. The anterior-posterior floor reaction force is influenced by the acceleration of gravity; however, the finding that posterior floor reaction force increased despite the slower motion of the pregnant women, suggests that during the stand-to-sit movement, the center of gravity is located more posteriorly in a pregnant woman. The trunk bend in the stand-to-sit movement is a controlled movement which limits backward displacement of the center of gravity of the upper trunk (head, arms, and trunk; HAT). The center of gravity position of the HAT is 62.6% of the distance along a line running from the glenohumeral joint to the greater trochanter²³. This position is near the upper sternum. Thus, the center of gravity location of HAT is modified by forward bending of the trunk. In the third trimester, the enlarging abdomen shifts the center of gravity of the HAT forward²⁴. Compared to a non-pregnant woman, the center of gravity of the HAT is located lower and more forward in a pregnant woman; therefore, when she performs a stand-to-sit, the center of gravity moves backward to a greater degree than it does in a non-pregnant woman. The reason for the increased activity of the knee extension muscles of pregnant women is that the vertical floor reaction force increases, and that the distance of the floor reaction force's vector (lever arm) increases. The increase of the posterior floor reaction force correlates with the increase of the lever arm. Therefore, only the knee extension moment increased significantly. In a stand-to-sit movement, the center of gravity is displaced backward in the third trimester; therefore, a pregnant woman's balance becomes unstable to the rear, and stress is placed on the knee extension muscles. The results of our study suggest that the load on the knee extension muscles of pregnant women is approximately 1.2 times that of non-pregnant women. Between the second and third

trimesters, the pattern of the stand-to-sit movement does not change. However, the stand-to-sit movement requires close attention because of weight gain and changes in the center of gravity. The healthcare professional should recommend pregnant women to use an armrest or handrail to reduce the risk of a fall during a stand-to-sit. In addition, because the pregnant woman gains weight as the pregnancy progresses, the load on the lower limb muscles increases. Therefore, a pregnant woman should exercise those muscles to increase their strength.

REFERENCES

- de Groot RH, Adam JJ, Hornstra G: Selective attention deficits during human pregnancy. *Neurosci Lett*, 2003, 340: 21–24. [Medline] [CrossRef]
- Soltani H, Fraser R: A longitudinal study of maternal anthropometric change in normal weight, overweight and obese women during pregnancy and postpartum. *Br J Nutr*, 2000, 84: 95–101. [Medline] [CrossRef]
- Fries EC, Hellebrandt FA: The influence of pregnancy on the location of the center of gravity, postural stability, and body alignment. *Am J Obstet Gynecol*, 1943, 46: 374–380.
- Calguneri M, Bird HA, Wright V: Changes in joint laxity occurring during pregnancy. *Ann Rheum Dis*, 1982, 41: 126–128. [Medline] [CrossRef]
- Dumas GA, Reid JG: Laxity of knee cruciate ligaments during pregnancy. *J Orthop Sports Phys Ther*, 1997, 26: 2–6. [Medline]
- Ireland ML, Ott SM: The effects of pregnancy on the musculoskeletal system. *Clin Orthop Relat Res*, 2000, 372: 169–179. [Medline] [CrossRef]
- Fast A, Weiss L, Ducommun EJ, et al.: Low-back pain in pregnancy, abdominal muscles, sit-up performance, and back pain. *Spine*, 1990, 15: 28–30. [Medline] [CrossRef]
- Butler EE, Colon I, Druzin ML, et al.: Postural equilibrium during pregnancy: Decreased stability with an increased reliance on visual cues. *Am J Obstet Gynecol*, 2006, 195: 1104–1108. [Medline] [CrossRef]
- Jang J, Hsiao KT, Hsiao-Weckler ET: Balance(perceived and actual) and preferred stance width during pregnancy. *Clin Biomech (Bristol, Avon)*, 2008, 23: 468–476. [Medline] [CrossRef]
- McCrory JL, Chambers AJ, Daftary A, et al.: Dynamic postural stability in pregnant fallers and non-fallers. *BJOG*, 2010: 954–962. [Medline]
- Dunning K, Lemasters G, Levin L, et al.: Falls in workers during pregnancy: risk factors, job hazards, and high risk occupations. *Am J Ind Med*, 2003, 44: 664–672. [Medline] [CrossRef]
- Weiss HB, Songer T, Fabio A: Fatal deaths related to maternal injury. *JAMA*, 2001, 286: 1863–1868. [Medline] [CrossRef]
- McCrory JL, Chambers A, Daftary A, et al.: Dynamic postural stability during advancing pregnancy. *J Biomech*, 2010, 43: 2434–2439. [Medline] [CrossRef]

- 14) Nomura K, Hashimoto M: Residential environment for OT and PT. 2007, Tokyo: Miwa Shoten. pp 238–239.
- 15) The Clinical Gait Analysis Forum of Japan: Gait analysis by the joint moment. 1st ed. Tokyo: Ishiyaku Publishers. 2001, pp 25–31.
- 16) Conference for Clinical Gait Analysis (compilation). Gait data interface manual, proposal for the standardization of gait data format, 1st ed. Tokyo: Ishiyaku Publishers. 1992, pp 41–42.
- 17) McFadyen BJ, Winter DA: An integrated biomechanical analysis of normal stair ascent and descent. *J Biomech*, 1988, 21: 733–744. [[Medline](#)] [[CrossRef](#)]
- 18) Kerrigan DC, Todd MK, Della Croce U, et al.: Biomechanical gait alterations independent of speed in the healthy elderly, evidence for specific limiting impairments. *Arch Phys Med Rehabil*, 1998, 79: 317–322. [[Medline](#)] [[CrossRef](#)]
- 19) Yamamoto S, Ehara Y: An introduction to body dynamics, the gait and ankle foot orthosis for hemiplegics, 1st ed. Tokyo: Ishiyaku Publishers. 2005, pp 54–58.
- 20) Foti T, Davids JR, Bagley A: A biomechanical analysis of gait during pregnancy. *J Bone Joint Surg Am*, 2000, 82: 625–632. [[Medline](#)]
- 21) Lou SZ, Chou YL, Chou PH, et al.: Sit-to-stand at different periods of pregnancy. *Clin Biomech (Bristol, Avon)*, 2001, 16: 194–198. [[Medline](#)] [[CrossRef](#)]
- 22) Senoo K, Uchiyama Y: The quantitative analysis of the joint control and compensation movement mechanism. *Physical Therapy Japan*. 2006, 33: 741.
- 23) David AW: *Biomechanics and Motor control of Human Movement* third edition. Hoboken: John Wiley & Sons Inc. 2004, p 64.
- 24) Takeda K, Katuhira J, Takano A, et al.: The effect on the lumber of the pregnant women of the diachronic posture and Movement change. *J Phys Ther Sci*, 2007, 22: 281–285.