

Changes in balance strategy in the third trimester

KANAME TAKEDA, RPT, MS^{1)*}, KIYOMI SHIMIZU, MW²⁾, MASUMI IMURA, MW³⁾

¹⁾ Division of Physical Therapy, Department of Rehabilitation Sciences, Faculty of Allied Health Sciences, Kansai University of Welfare Sciences: 3-11-1 Asahigaoka, Kashiwara City, Osaka 582-0026, Japan

²⁾ Department of Nursing, Faculty of Nursing, Josai International University, Japan

³⁾ Master's Program in International Health Care and Midwifery, The Japanese Red Cross College of Nursing, Japan

Abstract. [Purpose] The purpose of this study was to elucidate changes in balance strategy during pregnancy from a kinematics perspective. [Subjects] Eight pregnant women and eight non-pregnant women participated. [Methods] A 3D motion analysis system, two force plates, and 10 infrared cameras were used to measure the kinematics of the balance strategy. The 3D motion analysis system was used to analyze performance of the functional reach test (FRT). Parameters were compared between non-pregnant women and pregnant women during each trimester, and between pregnant women in the second and third trimesters. [Results] The FRT of pregnant women was shorter than that of non-pregnant women. Bilateral hip joint extension moments were smaller in pregnant women in the second and third trimesters compared to non-pregnant women. Bilateral ankle plantar flexion moments were larger in pregnant women in their third trimester compared to non-pregnant women. In pregnant women, the right ankle plantar flexion moment was larger in the third trimester than in the second trimester. [Conclusion] These results suggest that forward reach distance is reduced, and that the ankle joint strategy takes precedence over the hip joint strategy in maintaining balance during pregnancy compared to non-pregnancy.

Key words: Joint moment, Balance strategy, Functional reach test

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INTRODUCTION

The center of gravity of pregnant women is displaced anteriorly and superiorly, compared to non-pregnant women¹⁾. Furthermore, changes are seen in body shape²⁾. Because the volume of the lower trunk increases structurally, it becomes unstable. Nagai et al. reported that the postural sway of anterior-posterior movements increased during pregnancy because of the increase in the abdominal circumference³⁾.

Previous studies have shown that the resulting kinematic changes cause an increase in the load on the musculoskeletal system during pregnancy⁴⁻⁶⁾. A study that compared the muscle strength of pregnant women in their first and second trimesters versus that of non-pregnant women found a decrease in the strength of the back muscles and quadriceps of pregnant women⁷⁾. From the perspective of the musculoskeletal system, it can be readily seen how movement becomes difficult and balance function declines in pregnant women. It is manifested by a decrease in the muscle strength of the

trunk and leg muscles that have to support the increased body weight.

Balance function is an important factor for determining stability when standing and walking. Balance function is the ability to maintain balance by keeping the center of gravity within the base of support or restoring it to that position under the force of gravity⁸⁾. When maintaining a standing posture, the ankle joint strategy, hip joint strategy, and step strategy are the three movement strategies used to counter anterior-posterior translational motion⁹⁾. As the base of support shifts from the center outwards, control becomes primarily maintained through the ankle joint, hip joint, and step strategies¹⁰⁾. The center of gravity undergoes anterior and superior displacement during pregnancy, and it is possible that the trunk tends toward extension. Thus, the balance strategy is expected to change during pregnancy.

The decline in static and dynamic balance ability experienced during pregnancy may cause pregnant women to fall when performing ADL. A United States study found that approximately 26% of employed pregnant women fell during their pregnancies, a ratio that nearly matches that of falls by elderly people aged ≥ 65 years¹¹⁻¹³⁾. Dunning et al. reported that most falls occur during the second trimester¹¹⁾. These studies reported that physical changes during pregnancy are associated with a stronger predisposition to falls. Falls during pregnancy account for 17–39% of all trauma-related injuries to pregnant women requiring treatment. Furthermore, serious falls in which balance was lost account for 3–7% of fetal

*Corresponding author. Kaname Takeda (E-mail: takeda@fuksi-gak-u.ac.jp)

deaths^{14, 15}). These statistics also illustrate the importance of fall prevention during pregnancy.

Quantitatively expressing changes in balance during pregnancy compared to non-pregnant women may provide insight into fall prevention for pregnant women performing activities of daily living. The purpose of this study was to analyze and clarify by kinetics the joint moment changes that affect balance during pregnancy.

SUBJECTS AND METHODS

The study subjects were comprised eight pregnant women in their second trimester (mean gestation: 35.1 ± 1.4 weeks) and eight non-pregnant women (Table 1). The pregnant women were followed throughout their third trimester. The inclusion criteria were a healthy woman in her twenties or thirties. The exclusion criteria were a significant medical history relating to the legs or lower back, and women pregnant with a multiple gestation or gestational diabetes. Consent was obtained from all subjects after they had been given oral and written explanations of the study's purpose and methods. Confidentiality of personal information was guaranteed. To ensure the physical health of the mother and fetus, a midwife checked vital signs, fetal heartbeat, and abdominal tension in pregnant subjects before and after the measurements. The measurement protocol was approved by the Ethics Committee of the International University of Health and Welfare (approval no. 11P-11).

A Vicon Nexus 3D motion analysis system (Vicon Peak Oxford, UK), two force plates (AMTI MA, USA), and 10 infrared cameras (sampling frequency: 120 Hz) was used to measure the kinematics of the balance strategy. Infrared reflective markers 25 mm in diameter were placed on 15 positions on the right and left side of the body (at each acromial process, each lateral epicondyle, each ulnar styloid process, 1/3 of the distance below each line joining the greater trochanter and the anterior superior iliac spine, each midpoint of the antero-posterior knee joint diameter at the mid-patella excluding the thickness of the patella, each lateral malleolus of the fibula, the metatarsophalangeal joint of both fifth metatarsal bones, and a dummy marker at the inferior angle of the right scapula). These locations are recommended for measurements by the Clinical Gait Analysis Forum of Japan¹⁶).

The functional reach test (FRT) was performed to assess static balance. The FRT is a standing balance test that involves a simple movement, and it has both high reliability and validity^{17, 18}). The initial foot position for the FRT was a barefoot static standing posture on the force plates. Subjects were instructed to maintain a standing posture with their feet shoulder-width apart, with both arms hanging down at their sides, and their eyes focused horizontally forward. From this static standing posture, they then lifted their right arm forward to 90 degrees, and from that position reached as far forward as possible without losing their balance. At their own pace, they returned their arm back to the initial position and returned to the static standing posture. The FRT was repeated three times. In order to assess temporal changes in balance strategy, the pregnant women were tested one time during both the second trimester and the third trimesters.

Table 1. Subject characteristics

	Non-pregnant	Pregnant	
Age (yrs)	21.3 \pm 0.9	28.3 \pm 3.4	
Height (cm)	160.9 \pm 4.9	159.4 \pm 5.3	
Weight (kg)	50.0 \pm 3.6	pre-pregnancy	52.4 \pm 4.5
		2nd trimester	53.3 \pm 5.4
		3rd trimester	55.8 \pm 5.3

The measurement items were: the maximum FRT distance (FRT max), the leg joint moments (hip, knee, and ankle) at FRT max, the ground reaction force (GRF) of the legs (vertical and anterior) at FRT max, the anterior center of pressure (COP) displacement at FRT max, and the leg and trunk angles in the sagittal plane at FRT max. Each value was measured three times and the means were calculated. FRT max was the maximum anterior displacement of the right wrist marker from the origin, with the origin being the position of the right wrist marker with the right arm raised to 90 degrees in the static standing posture. Anterior COP displacement at FRT max was calculated as the distance of anterior COP displacement from the anterior displacement coordinates of the right and left ankle markers. In order to compare joint moments of subjects of varying heights and weights, joint moment was normalized using the product of height and current weight for non-pregnant subjects or pre-pregnancy weight for pregnant subjects¹⁹). FRF was similarly normalized using pre-pregnancy weight²⁰).

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 joint angle was defined as the angle between the tibia and the foot. Flexion and dorsiflexion were positive for all angles. The anterior-posterior angle of the trunk was expressed as the angle relative to the vertical axis of the line joining the midpoint between the right and left acromial processes and the midpoint between the right and left hip joints²¹).

SPSS 13.0 J software was used for statistical analyses. The F-test was used to evaluate the homogeneity of the variance of between non-pregnant women and pregnant women in each trimester. The Mann-Whitney U test was performed to compare parameters between the non-pregnant women and the pregnant women in each trimester ($p < 0.05$). To examine the difference in balance strategy based on gestational weeks, the Wilcoxon signed-rank test was conducted to compare differences in each parameter between the second trimester and the third trimester ($p < 0.05$).

RESULTS

FRT max was significantly smaller in pregnant women in their second and third trimesters compared to non-pregnant women. Hip joint extension, knee joint flexion, and ankle plantar flexion moments were generated in both legs at FRT max. At FRT max, both hip joint extension moments were smaller and the left ankle plantar flexion moment was larger in pregnant women in their second trimester compared to non-pregnant women. In addition, both hip extension mo-

ments were smaller and both ankle plantar flexion moments were larger in pregnant women in their third trimester compared to non-pregnant women.

At FRT max, the posterior FRF of the right leg was smaller and the vertical FRF of the left leg was larger in pregnant women in their second trimester compared to non-pregnant women. In addition, the posterior FRF of the right leg was smaller and the vertical FRF of both legs were larger in pregnant women in their third trimester compared to non-pregnant women. At FRT max, anterior COP displacement of the left leg was smaller in pregnant women in both their second and third trimesters compared to non-pregnant women. In the static standing posture, the knee joint of all subjects showed hyperextension; the hip joint also showed extension in the vertical axis. When comparing leg and trunk angles in the sagittal plane at FRT max, both hip joint extension angles and left knee joint extension angle were larger, and both ankle plantar flexion angles and trunk flexion angle were smaller in pregnant women in their second trimester compared to non-pregnant women. In addition, both hip joint extension angles were larger and both ankle dorsiflexion angles and trunk flexion angle were smaller in the pregnant women in their third trimester compared to non-pregnant women. No other significant differences in parameters were found between the groups.

In pregnant women, the right ankle plantar flexion moment was significantly larger in the third trimester than it was in the second trimester. The posterior FRF and vertical FRF of the right leg were larger in the third trimester than they were in the second trimester. The right ankle joint dorsiflexion angle, the left knee joint extension angle, and the trunk flexion angle were all smaller in the third trimester. No other significant differences in parameters were found between the two groups (Table 2).

DISCUSSION

The results of the FRT suggest that pregnant women have difficulty reaching forward. Regarding ADL, Kanto et al. reported that 10% of pregnant women in the 16th week of pregnancy and onward have difficulty hanging laundry on a clothesline, an action that requires frequent anterior and superior reaching movements²²). Jonsson et al. found that forward movement of the trunk influences FRT distance more strongly than COP displacement²³). The center of gravity undergoes anterior and superior displacement during pregnancy, compared to non-pregnancy¹). It is possible that the trunk extends in order to maintain balance; thus, resulting in a reduction in flexion as well as the functional reach distance. The joint moment results suggest that when pregnant women reach forward, they use their hip joint extensors less and their ankle plantar flexion muscles more. Regarding FRF, the posterior FRF of the right leg was smaller in the pregnant women in both their second and third trimesters compared to non-pregnant women. In addition, the vertical FRF of the left leg was larger during the second trimester and was larger for both legs during the third trimester. The increase in vertical FRF in pregnancy suggests the influence of the body mass of the pregnant women.

Comparing leg angles showed that the right and left hip

joint extension angles were larger and the trunk flexion angle smaller in the pregnant women in their second and third trimesters compared to non-pregnant women. This phenomenon shows that hyperextension of the knee angle increased during FRT, and that the hip also became extended. This finding reveals that pregnant women position their hip joints further forwards when performing the FRT than non-pregnant women. The reason for the decrease in right and left hip joint extension moment during pregnancy may be a decrease in anterior COP displacement combined with a reduction in the lever arm distance of the FRF vector with the hip joints. However, the ankle plantar flexion moment increases during pregnancy, despite the fact that the lever arm distance of the FRF vector with the ankle joints becomes shorter due to the decrease in anterior COP displacement and posterior FRF. This may be caused by the increased vertical FRF of the left leg in the second trimester and of both legs in the third trimester. When pregnant women reached forward, the trunk flexion angle was smaller, resulting in less anterior displacement of the center of gravity. This suggests that they favored an ankle joint strategy for maintaining balance. If pregnant women are unable to apply a hip joint strategy, they may experience difficulty controlling movement during abrupt positional changes, large-scale wobbling, or when walking on uneven surfaces. This may be one factor causing an increase in falls during pregnancy. In the third trimester, the right ankle plantar flexion moment and posterior FRF and vertical FRF of the right leg all increased. This suggests that pregnant women in their third trimester control movement through greater use of their right ankle plantar flexion muscles. The increase in right ankle plantar flexion moment in the third trimester may be a result of the increase in vertical FRF caused by a decrease in the lever arm of the FRF vector and the ankle joint from the increase in posterior FRF. As their pregnancy advances, women may rely more heavily on the ankle joint strategy for movements that cause an anterior displacement of their center of gravity. Reliance on the ankle joint strategy indicates that they would have difficulty controlling movement as the base of support shifts from the center outwards¹⁰). This suggests that pregnant women may have difficulty controlling anterior displacement of the center of gravity. In this study, we clarified the changes in movement strategy during pregnancy from a kinematics perspective. The results suggest that forward reach distance is reduced and that the ankle joint strategy takes precedence in maintaining balance during pregnancy compared to non-pregnancy. The significance of these findings for pregnancy is that we can educate pregnant women regarding the fact that balance ability decreases from the second trimester to the third trimester, and propose areas that need to be strengthened for fall prevention. Controlling movement by relying on the ankle joint strategy means that pregnant women require more mobility in their ankle joints and need to maintain more muscle mass in their ankles.

A limitation of this study was the unavoidable inconsistency in subjects' age. Further studies are needed to analyze how falls relate to balance ability and changes in strategy, and to examine changes in movement strategy in the postpartum period.

Table 2. Comparison of the results of the pregnant and non-pregnant groups

	Non-pregnant	2nd trimester	3rd trimester		p:non-pregnant group -2nd trimester	p:non-pregnant group -3rd trimester
FRT max (anterior+)	394.81 ± 72.30	307.37 ± 46.18	284.70 ± 38.33	*†	*	*
Moment						
Right hip (ext+)	2.80 ± 0.75	1.88 ± 0.63	1.83 ± 0.66	*†	0.001 *	0.001 *
knee (ext+)	3.78 ± 0.64	3.54 ± 0.70	3.49 ± 0.86		0.174	0.187
ankle (plantar-flex+)	3.89 ± 0.49	4.08 ± 0.54	4.39 ± 0.47	†§	0.242	0.001 *
Left hip (ext+)	3.68 ± 0.81	2.84 ± 0.66	2.76 ± 1.18	*†	0.001 *	0.001 *
knee (ext+)	4.14 ± 0.77	4.41 ± 0.49	4.14 ± 0.79		0.193	0.865
ankle (plantar-flex+)	3.77 ± 0.55	4.35 ± 0.46	4.44 ± 0.55	*†	0.001 *	0.001 *
FRF						
Right Fx (anterior+)	-1.17 ± 1.16	-0.15 ± 0.48	-0.33 ± 0.40	*†§	0.001 *	0.012 *
Fz (vertical+)	50.03 ± 6.78	53.76 ± 5.20	57.88 ± 5.36	†§	0.059	0.001 *
Left Fx (anterior+)	0.16 ± 0.64	0.07 ± 0.43	-0.11 ± 0.29		0.521	0.093
Fz (vertical+)	44.49 ± 5.98	52.74 ± 4.74	54.62 ± 5.01	*†	0.001 *	0.001 *
Right COP-ankle (anterior+)	0.13 ± 0.02	0.13 ± 0.01	0.13 ± 0.02		0.124	0.273
Left COP-ankle (anterior+)	0.14 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	*†	0.002 *	0.001 *
ROM						
Right hip flex-ext (flex+)	-7.37 ± 4.01	-12.36 ± 2.85	-12.38 ± 4.89	*†	0.001 *	0.001 *
knee flex-ext (flex+)	-8.05 ± 4.42	-9.18 ± 3.56	-7.79 ± 6.99		0.234	0.97
ankle dorsi flex-plantar flex (dorsi-flex+)	-8.50 ± 3.07	-4.28 ± 1.94	-3.54 ± 2.86	*†§	0.001 *	0.001 *
Left hip flex-ext (flex+)	-4.83 ± 3.44	-10.42 ± 2.53	-9.32 ± 5.36	*†	0.001 *	0.001 *
knee flex-ext (flex+)	-6.67 ± 5.22	-10.48 ± 3.08	-7.90 ± 5.04	*§	0.007 *	0.317
ankle dorsi flex-plantar flex (dorsi-flex+)	-11.69 ± 2.40	-7.31 ± 2.39	-6.57 ± 2.26	*†	0.001 *	0.001 *
trunk flex-ext (ext+)	-48.66 ± 10.61	-27.07 ± 6.49	-24.73 ± 7.93	*†§	0.001 *	0.001 *

The Mann-Whitney U test was performed to compare parameters between the non-pregnant women and the pregnant women in each trimester ($p < 0.05$).

The Wilcoxon signed-rank test was conducted to compare differences in each parameter between the second trimester and the third trimester ($p < 0.05$).

FRTmax: (cm), Moment: Nm/m/kg, FRF: N/kg, COP-ankle (m), ROM: deg

$p < 0.05$, *: non-pregnant group-2nd trimester †: non-pregnant group-3rd trimester §: 2nd trimester-3rd trimester

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