博士論文

Differences in trunk control between early and late pregnancy during gait.

(妊娠前期と後期での歩行時体幹制御の違い)

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Differences in trunk control between early and late pregnancy during gait.

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Abstract

The aim of this study was to compare gait characteristics, including the functional ability of the trunk, between women before and during the third trimester of pregnancy. Gait measurements were performed on 27 pregnant women, who were divided into two groups using the threshold of 28 gestational weeks. The subjects were instructed to walk at their preferred speed. In addition to stride-time coefficient of variation, root mean square (RMS) and autocorrelation coefficient, coefficient of attenuation (CoA) of acceleration was computed as an index to assess the functional ability of the trunk. Differences of gait characteristics between the groups were determined by the Mann-Whitney U test. Gait characteristics that showed a significant difference between the groups were further analyzed with adjustment by age, height, weight and gait velocity by using multiple regression analysis. Women during the third trimester of pregnancy showed significantly smaller RMS in the anteroposterior direction at the lower trunk than those before the third trimester of pregnancy, even after adjusting for age, height, weight and gait velocity [$\beta = 0.47$; 95% confidence interval (CI) 0.07–0.25]. CoA in the anteroposterior direction was also significantly lower in women during the third trimester of pregnancy than in those before the third trimester of pregnancy after adjustment by age, height, weight and gait velocity ($\beta = 0.44$; 95% CI 0.39–18.52). The present cross-sectional study suggests the possibility that the functional ability of the trunk during gait declines in late pregnancy.

Key words: Accelerometer, Gait, Pregnant women

1. Introduction

Women experience a number of physical changes during pregnancy. Hormonal changes affect joint laxity, which has been associated with an increase in the range of motion of the pelvis joints [1]. Additionally, weight distribution in the whole body changes dramatically during pregnancy. The total weight that is gained is generally around 12–16 kg [2], which includes the developing fetus. The fetus grows rapidly in both size and weight mainly during the third trimester [3]. In conjunction with this development, the uterus enlarges and the center of mass (COM) shifts forward and downward, which might cause changes in gait [4]. Understanding the gait characteristics of pregnant women is essential because walking is one of the most common physical activities and contributes to reducing weight gain, particularly the excessive weight gain that can occur during pregnancy.

The influences of pregnancy on gait characteristics were reported in other studies as follows: decreases in single-support time and stride length [5,6], and increases in double-support time and step width [5,6]. The lower trunk has significantly greater rates of change in both size and weight than all other body segments during pregnancy [7], so trunk movement should also change during the course of pregnancy. Several studies have reported changes of trunk movement in pregnant women during gait. It was reported that there was a difference of maximum anterior pelvic tilt during gait between late pregnancy and postpartum [5]. Another study reported a linear trend of a decrease in the range of motion of the pelvis in the transverse and coronal planes, as well as a decrease of the range of motion in the thoracolumbar region [6]. However, these studies were undertaken in a limited experimental environment, such as a laboratory; as an alternative to this restrictive approach, it is possible for subjects to wear sensors, such as accelerometers, that are small and lightweight, which would enable the assessment of gait in an unrestricted environment.

The prevalence of lower back pain is high in women during pregnancy [8]. The relationship between stiffness of the trunk and lower back pain has also been reported in the non-pregnant population [9]. Pregnant women, particularly in the third trimester, exhibit an increase in abdominal volume,

which would cause a decrease in the range of motion of the trunk [10]. It is thus likely that the trunk of pregnant women would be relatively stiff [4]. The body can be considered to have two functions, namely, "passenger" (head, neck, trunk, and arms) and "locomotor" (lower limbs and pelvis), in the context of assessing gait movement in a clinical setting [11]. The trunk acts mainly to attenuate oscillations in order to help to maintain the body's equilibrium during walking [12]. Considering the stiffness of the trunk during pregnancy, the functional ability of the trunk during gait may decrease in women in late pregnancy. The aim of this cross-sectional study was thus to compare the differences of gait characteristics, including the ability to control trunk movement assessed using accelerometers, between women in early pregnancy and those in late pregnancy.

2. Methods

2.1 Subjects

We recruited our subjects from among outpatients at a local obstetric clinic; a total of 27 women participated in this study. No subjects carried multiple fetuses. They were categorized into two groups: the early group (EG) and the late group (LG), using the threshold of 28 weeks of gestation ("before the third trimester": ≤ 27 gestational

Table 1

Subject characteristics between groups.

		EG (n = 16)	LG (n = 11)	*P*–value
Age	[years]	30.4 ± 5.1 (24.0–41.0)	31.4 ± 3.2 (25.0–37.0)	.58
Gestational week	[week]	17.1 ± 3.2 (13.0–23.0)	33.6 ± 3.1 (28.0–37.0)	< .01
Height	[m]	1.58 ± 0.06 (1.47–1.70)	1.60 ± 0.04 (1.54–1.68)	.27
Mass	[kg]	52.0 ± 6.1 (44.0–68.0)	60.4 ± 5.1 (52.0–68.0)	< .01

The data are shown as mean ± standard deviation (range).
EG, early pregnancy group; LG, late pregnancy group.
Significant *P*–values are < 0.05.

weeks, “during the third trimester”: ≥ 28 gestational weeks). Exclusion criteria included the following medical conditions: lupus, rheumatoid arthritis, gestational diabetes mellitus, hypertension, musculoske- letal or neurologic abnormalities, and any other medical condition that affects postural stability. The subjects’ characteristics are shown in Table 1. The number of gestational weeks of LG was significantly higher than that of EG ($P < 0.01$); similarly, women in LG were significantly heavier than those in EG ($P < 0.01$). Ethical approval for the study was given by the Ethics Committee of Kobe University Graduate School of Health Sciences, on 18 October, 2011 (no. 113), and informed consent was obtained from all subjects in accordance with the Declaration of Helsinki before their participation.

2.2 Gait measurement procedure

Subjects were instructed to walk at their preferred speed along a 15-m smooth, horizontal corridor in the clinic. A 10-m section of the walkway was marked off by two lines, positioned 2.5 m from each end, to allow space and time for acceleration and deceleration. Walking time in the middle 10 m was measured with a stopwatch, and gait velocity was expressed in meters per second. Trunk and lower-limb movement during gait was measured by using two wireless motion-recording-sensor units (MVP-RF-8; Microstone Co., Nagano, Japan) and one piezo-resistive triaxial accelerometer (MA3-10AC; Microstone Co., Nagano, Japan). This wireless motion-recording-sensor unit contains a piezo-resistive triaxial accelerometer and a triaxial gyroscope. One wireless motion-recording-sensor unit was attached to the posterior surface of the right heel with surgical tape and the other one was fixed to a belt at the level of the L3 spinous process representing the lower trunk. Acceleration and angular velocity could thus be measured without restricting the subject’s movement. The accelerometer was attached with surgical tape to the C7 spinous process because that is the upper geometrical limit of the trunk [13]. We considered it likely that these apparatuses attached to the body would be in variable states of inclination caused by the body’s curvature. To correct for any potential effects of this inclination, we calibrated these apparatuses before each walking trial to take into account the static gravity component. All signals were sampled at 200 Hz and synchronously wirelessly transferred to a personal computer via a

Bluetooth personal area network.

2.3 Data analysis

Signal processing was performed with MATLAB (Release 2008b; The MathWorks Japan, Tokyo, Japan). Before the analysis, all acceleration data were high-pass-filtered with a cut-off frequency of 1 Hz and then low-pass-filtered with a cut-off frequency of 20 Hz. The acceleration signals in the VT direction from the wireless motion-recording-sensor unit attached to the heel showed the typical sharp peak, indicating the event of contact between the heel and the floor, which was identified from zero following negative acceleration. These events were used to calculate the time of each stride and to compute the mean stride time. Stride length was computed by multiplying mean stride time by gait velocity. We used the coefficient of variation (CV) of stride time as an index of the variability of lower-limb movement during gait. The CV was calculated by using the following formula: CV = (standard deviation/mean) × 100. We analyzed other measures by using the acceleration data from the acceleration signals from the other wireless motion-recording-sensor unit fixed at the L3 level as an index of the variability of trunk movement. An unbiased autocorrelation procedure was used in this study to assess the variability of trunk movement at the L3 level in vertical (VT), mediolateral (ML) and anteroposterior (AP) directions [14]. An unbiased autocorrelation coefficient (AC) is an estimate of the regularity of a time series by cross-correlation with itself at a given time shift; it is independent of the amount of data managed. A perfect replication of the gait cycle signal between neighboring strides will return an AC of 1, and no association will give a coefficient of 0. To evaluate the ability of trunk control, we first computed root mean square (RMS) of acceleration, which provides information on the average magnitude of acceleration at the L3 and C7 levels in each direction. To quantify the ability to attenuate the acceleration at the trunk segment, we calculated the coefficient of attenuation in each direction (CoA-VT, CoA-ML and CoA-AP) as follows: CoA [%] = 100 × (1 - RMS at C7/RMS at L3) [15]. Namely, CoA is obtained as the difference between the RMS of the L3 level and that of the C7 level, and expressed as a percentage of the RMS of the L3 level. Greater CoA values mean that oscillation generated by gait movements is attenuated efficiently by

the whole trunk segment, whereas smaller CoA values mean that oscillation generated by gait movements is attenuated less efficiently.

2.4 Statistical analysis

The significance of differences of subjects' characteristics between groups was determined using Student's *t*-tests for parametric variables and the Mann-Whitney U test for nonparametric variables. Age and gestational week are nonparametric variables, while height and mass are parametric ones. All gait parameters were nonparametric, so comparisons of them between groups were conducted by using the Mann-Whitney U test. Gait parameters calculated from the acceleration data are influenced by gait velocity [16], so further analyses were performed after adjustment for age, height, weight and gait velocity by using multiple regression analysis. Gait parameters that showed a significant difference between groups were employed as independent variables. The level of significance for all analyses was set at $P < 0.05$. All analyses were performed with JMP11.0J software (SAS Institute Japan, Tokyo, Japan) for Windows XP.

3. Results

Table 2 provides basic gait parameters and the indices of gait variability (stride-time CV and ACs in three directions) for each group and compares them between groups. None of these variables differed significantly between the groups.

Subjects in LG showed a significantly smaller RMS value in the AP direction at the L3 level than those in EG (median [minimum–maximum] EG: 1.55 [1.03–1.97]; LG: 1.30 [0.71–1.99], $p = 0.01$) (Figure 1), even after adjusting for age, height, weight and gait velocity ($\beta = 0.47$; 95% confidence interval [95% CI] 0.07–0.25). No significant differences were found in other RMS values between the groups. CoA-AP was significantly worse in LG than in EG (EG: 40.3 [3.7–60.5], LG: 16.4 [-15.9–64.0], $p < 0.01$), whereas CoA-VT and CoA-ML were not significantly different between the groups (Figure 2). CoA-AP still showed significant differences between the groups after adjustments for age, height, weight and gait velocity ($\beta = 0.44$; 95% CI 0.39–18.52).

Table 2.

Comparisons of gait velocity, stride time, stride length and the index of gait variability between groups.

		EG (n = 16)	LG (n = 11)	*P*–value
Gait velocity	[m/sec]	1.07 ± 0.15 (0.74–1.33)	1.05 ± 0.24 (0.59–1.45)	.98
Stride time	[sec]	1.09 ± 0.09 (0.98–1.25)	1.16 ± 0.19 (0.98–1.62)	.69
Stride length	[m]	1.10 ± 0.11 (0.83–1.25)	1.13 ± 0.12 (0.95–1.33)	.50
Index of gait variability				
Stride time CV	[%]	2.51 ± 1.07 (0.69–4.75)	2.70 ± 1.08 (1.90–5.05)	.73
AC				
VT		0.71 ± 0.13 (0.44–0.91)	0.68 ± 0.14 (0.32–0.82)	.49
ML		0.55 ± 0.17 (0.24–0.85)	0.54 ± 0.12 (0.37–0.72)	.80
AP		0.81 ± 0.10 (0.58–0.95)	0.80 ± 0.08 (0.58–0.89)	.76

The data are shown as mean ± standard deviation (minimum – maximum).
EG, early pregnancy group; LG, late pregnancy group; CV, coefficient of variation; AC, autocorrelation coefficient; VT, vertical; ML, mediolateral; AP, anteroposterior.
Significant *P*–values are < 0.05.

4. Discussion

The primary purpose of this study was to compare the differences of gait movement between EG (before the third trimester) and LG (during the third trimester). No differences were found between these groups in gait velocity, stride time, stride length and gait variability measured using CV and ACs. On the other hand, pregnant women during the third trimester, compared with those before this stage, exhibited significantly lower acceleration and ability to control trunk movement in the AP direction. These differences were also significant even after adjusting for age, height and gait velocity.

No differences were found betwe-en pregnant women before the third trimester and those in the third trimester in terms of

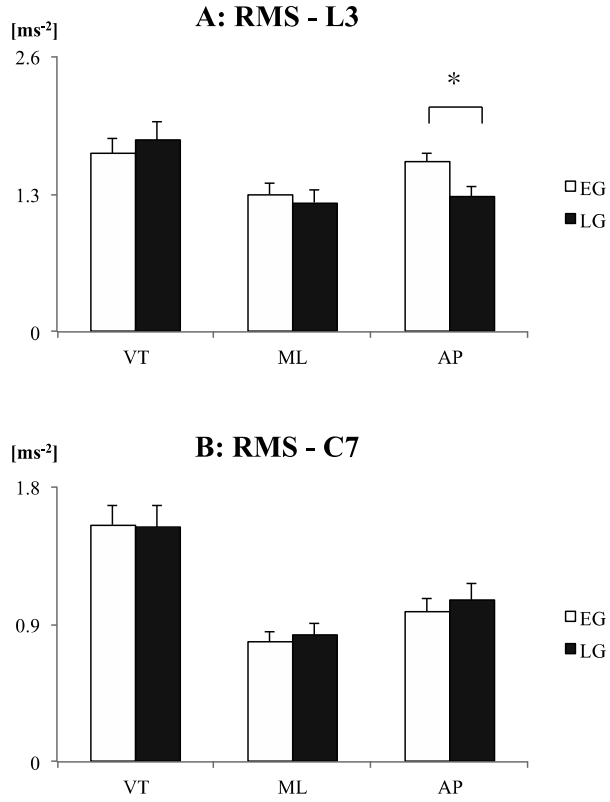

Fig 1. Acceleration RMS values at L3 (Figure 1-A) and C7 (Figure 1-B). The figure shows mean ± SE values of the RMS of the accelerations computed for the two groups (EG and LG). Figure 1-A is at L3 level and Figure 1-B is at C7 level. Squares represent mean values and error bars represent SE. Value of RMS-AP at L3 level was significantly different between groups (P = .01). EG, early pregnancy group; LG, late pregnancy group; RMS, root mean square; VT, vertical; ML, mediolateral; AP, anteroposterior. Significant P–values are < 0.05.
*: $P < 0.05$.

the basic gait parameters of gait velocity, stride time and stride length. Other studies that have explored gait changes during pregnancy longitudinally have reported that neither gait velocity nor stride time changed in the course of pregnancy [17]. Our results about basic gait parameters agree with previous studies, except for the case of stride length. It is widely assumed that women gradually show the characteristic gait called "waddling gait" with the progression of pregnancy, as compensation for physical changes, in order to maintain stability [5]. The characteristics of a "waddling gait" are as follows: an increase in external foot progression angle, pelvic obliquity, pelvic rotation and a dynamic base of support. An expanded dynamic base of support would cause a decrease in stride length. Stride length would decrease in a linear manner throughout pregnancy [6]. However, in this previous study [6], the mean values of stride length at 24 and 32 gestational weeks were almost the same (stride length [cm]: 141.1 ± 12.5 and 141.1 ± 11.5, respectively). Additionally, our study was cross-sectional, so we could not detect the change with the progression of pregnancy.

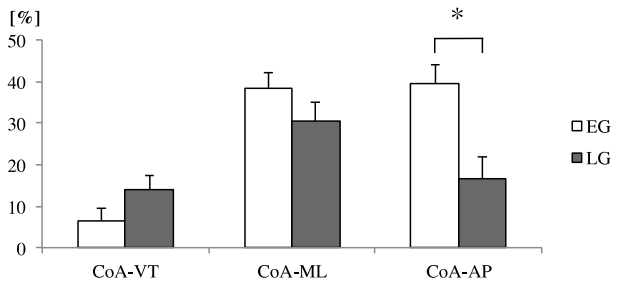

Fig 2. Comparisons of CoA values in three directions between groups. Comparisons of CoA values representing mean ± SE in three directions between groups (EG and LG). Error bars represent SE. CoA-AP was significantly different between groups (P < .01). EG, early pregnancy group; LG, late pregnancy group; CoA, coefficient of attenuation; VT, vertical; ML, mediolateral; AP, anteroposterior.
Significant P–values are < 0.05. *: $P < 0.05$.

We assessed gait variability by using stride-time CV and ACs; these measurements of gait variability did not differ between the groups, suggesting that gait variability would not change during pregnancy. Stride-time CV is one of the measurements of stride consistency for lower-limb movement and represents temporal stride variability during gait; a low value of it reflects rhythmic gait. Meanwhile, the trunk moves in three directions during walking, so we examined trunk movement in all directions (VT, ML, and AP) by using AC to represent the variability in stride-to-stride trunk movement. Gait variability has been explored in other populations to examine gait instability or fall risk by assessing lower-limb and/or trunk movement [18,19], and the increase in gait variability is associated with aging, and poor physical and cognitive functions. Some studies have found an association between gait variability and executive functions, one of the domains of cognitive function [20,21], in elderly populations. The influence of hormones such as estrogens on executive functions has been widely reported in studies on the application of estrogen replacement therapy to women after natural menopause [22]. The levels of these hormones change dramatically during pregnancy, so previous studies investigated the changes in executive functions associated with pregnancy [23,24]. However, consistent results regarding the association between hormones and executive functions have yet to be obtained from studies involving pregnant women. This might suggest that executive functions are only slightly influenced by pregnancy-related changes in hormones. Additionally, considering that our subjects were healthy young pregnant women, gait variability would not deteriorate in healthy pregnant women, although approximately 30% of women fall ill while pregnant [25].

RMS, the amplitude of acceleration, of the upper trunk did not differ in all directions between groups, while pregnant women in the third trimester showed significantly smaller lower-trunk RMS in the AP direction than those before the third trimester. The movement of the center of pressure (COP) during gait moved significantly less anteriorly at the end of the stance phase in late pregnancy than after birth [22]. Our results extend these previous findings. The trunk is the main constituent of "passenger" (head, neck, trunk, and arms) and, for successful locomotion, plays an important role in attenuating the mechanical

perturbations transmitted from the hips, through the pelvis and the spinal column, up to the head. CoA of acceleration is a parameter showing this functional ability of the trunk [13]. In our study, the functional ability in the ML direction did not differ between the groups. Recently, McCrory et al. reported that the frontal plane range of motion of the thorax during a gait cycle did not differ between the second and third trimesters of pregnancy [26], suggesting that pregnancy-related changes around the trunk would not affect the frontal plane movement of the trunk during gait. On the other hand, the attenuation rate in the AP direction was reduced in pregnant women during the third trimester compared with that before the third trimester. Other studies reported a decrease in the sagittal plane range of motion of the thorax during gait in women in the third trimester of pregnancy compared with those in the second trimester and with non-pregnant controls [6, 26]. It is thus likely that the range of motion in the sagittal plane is limited by pregnancy-related changes that occur in the third trimester [10]. This would suggest that the trunk becomes stiff in late pregnancy [4], as shown by the results of our study. The trunk includes 60% of the total body mass and gains mass as the fetus develops over the course of pregnancy. The fact that stiffness of the trunk occurs in late pregnancy suggests that the inertial force caused by propulsion during gait becomes a greater load on the muscles of the lower trunk at this stage. A relationship between the stiffness of the trunk and lower back pain has been reported in other populations [9,27], so pregnancy-related lower back pain may be associated with stiffness of the trunk, particularly in the AP direction. However, we did not measure the muscle activity of the lower trunk during gait and also did not determine how many of our subjects had lower back pain, so further studies are required to clarify these issues.

Marked physical changes occur in the third trimester of pregnancy, particularly around the trunk associated with the development of the fetus. This study may indicate the influence of pregnancy-related physical changes on gait, but it has some limitations. Firstly, it has a cross-sectional design, so we only show the differences of trunk control during gait between during and before the third trimester. Additionally, the number of samples in each group in our study is relatively small. Further studies should undertake longitudinal approaches with larger sample sizes than in this study.

In conclusion, the present cross-sectional study suggests the possibility that the ability to control trunk equilibrium declines in late pregnancy. Further studies will be needed to confirm the current results longitudinally in order to clarify one of the causes of pregnancy-related lower back pain from a kinematic perspective.

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Conflict of interest

The authors report no conflict of interest.

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