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# Gait analysis of pregnant patients with lumbopelvic pain using inertial sensor

Ayumi Tanigawa[a], Saori Morino[a], Tomoki Aoyama[b], Masaki Takahashi[c,*]

[a] School of Science for Open and Environmental Systems, Graduate School of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan

[b] Department of Physical Therapy, Human Health Sciences, Kyoto University Graduate School of Medicine, 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan

[c] Department of System Design Engineering, Faculty of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan

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ABSTRACT

*Background:* Lumbopelvic pain (LPP) is one of the most common discomforts during pregnancy. However, few studies have evaluated relation between LPP and gait in pregnancy quantitatively.

*Research question:* This study aimed to investigate the relation between the LPP and gait characteristics such as symmetry, stability, and the degree of motion during pregnancy.

*Methods:* Gait data were collected for fifty-two pregnant women between the third and tenth month of pregnancy on smooth, horizontal walkway by using inertial measurement sensor units attached to the participants' lumbar. The degrees of trunk movement, movement symmetry, gait variability, and symmetry of rotation were expressed as the root mean square (RMS), autocorrelation peak (AC), coefficient of variance (CV), and the degree of asymmetry at the approximate amount of angular variation (DA) respectively, which were calculated from measured acceleration data and angular velocity data. An independent *t*-test was performed to investigate differences in these gait parameters between LPP group and pain free group classified according to the presence or absence of the pain, which is evaluated by using a questionnaire. In addition, LPP group was divided into 5 subgroups based on the types of pain, and the differences between the groups were also investigated by using a one way ANOVA.

*Results:* Rotational asymmetry was observed in movement of the roll direction of the LPP patients. The DA of the roll angle of the LPP group was significantly greater than that in the pain free group (0.140 ± 0.093 vs. 0.077 ± 0.053, respectively; $p = 0.004$). In the analysis of pain complications, the significant difference in DA of roll angle, and CV of yaw angle were observed.

*Significance:* The results indicated that motion asymmetry of both rotation and translation increased significantly in LPP patients' gait.

## 1. Introduction

Lumbopelvic pain (LPP) is one of the most common discomforts during pregnancy, experienced by 45% of pregnant women and 25% of women postpartum [1]. LPP affects activity of daily life [2] and decreases its quality [3]. Two changes are suggested as the main factors of LPP. One is the postural change occurring with the growth of the fetus [1–4]. Moreover, lumbar lordosis and pelvic anteversion are observed in pregnancy posture accompanied by abdominal swelling and increased weight [4]. It has been suggested that these postural changes are related to low back pain [5]. The other factor is the joint relaxation due to pregnancy-related hormones [3,4,6], which causes pelvic malalignment and provokes LPP. Additionally, there are some reports on the relation between pelvic asymmetry in static posture and LPP, such as, for example, the difference in the degree of pelvic anteversion on the right and left side [4] and asymmetric laxity of the sacroiliac joints [7]. These physical and physiological changes affect motion patterns and loads on muscles [8], which appear to provoke LPP.

Regarding the changes of motion patterns related to pregnancy, many studies have focused on walking [9–13] as a component of daily life activities, such as housework, exercise, and working [14]. The walking strategy for stabilization [9], which is observed as a decrease of the step length [10,11], increase of the step width [11], and decrease of the horizontal trunk rotation [11], has been reported as the characteristic of the gait of pregnant women. Pregnant women with LPP have lower walking speed [12] and decreased horizontal trunk rotation

* Corresponding author.
*E-mail address:* takahashi@sd.keio.ac.jp (M. Takahashi).

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range of motion [12,13] than healthy pregnant women. Moreover, motion asymmetry is observed in trunk rotation and lateral bending of LPP patients [15–17]. Therefore, a specific strategy would be expected in the gait of pregnant women with LPP. However, few studies have evaluated relation between LPP and gait in pregnancy in quantitative terms. For measuring walking in pregnancy, a simple method, which would consider physical load or measurement place and cost, is required. For example, the inertial measurement unit (IMU), which is composed of accelerometer and gyro sensor, is considered to be suitable. Recently, IMU has been analyzed with a growing demand for a quantitative gait evaluation method and its improved performance [18]. Accelerometer can evaluate translation, while the gyro sensor can evaluate rotation during walking. Furthermore, IMU can also evaluate cyclic patterns and variability of the gait.

Thus, in our study we aimed to investigate the relation between the LPP and gait characteristics, such as symmetry, stability, and the degree of motion during pregnancy by using the IMU.

## 2. Methods

### 2.1. Study design

This study used a cross-sectional design to investigate the relation between the LPP and gait characteristics.

### 2.2. Subjects

Pregnant women who attended an event for mothers and expecting mothers held in Aichi Prefecture, Japan, in March 2013 were recruited for the purpose of this study. Among the attendees, 52 pregnant women without any history of lower back, foot, ankle, knee, musculoskeletal, or neuromuscular trauma or disease, were included in this study (mean age 29.9 ± 3.8 years (range; 21.0–39.0), mean gestational age 6.8 ± 1.7 months (range; 3.0–10.0)). The inclusion criterion was pregnancy without serious orthopedic disorders or neurological diseases, whereas a high-risk pregnancy was an exclusion criterion.

### 2.3. Ethical considerations

Written informed consent was obtained from each participant, in accordance with the guidelines approved by the Research Ethics Committee of Kio University and the Declaration of Human Rights, Helsinki, 1975. The study's protocol was approved by the Research Ethics Committee of Kio University (Approval No. H25-47).

### 2.4. Questionnaire

Personal characteristics (age, height, and mass), gestational age, and the presence or absence of LPP were obtained from questionnaire responses. In this study, we collectively treat low back pain (LBP), sacroiliac joint pain (SJP), and pubic symphysis pain (PSP) as LPP. Participants were asked whether they have ever experienced these pains during pregnancy using a picture of the human body, which is shown in Fig. 1(a).

### 2.5. Gait measurement

All subjects were evaluated by a test walking performed on a smooth, horizontal, 14 m walkway. Gait was measured in a 10 m long middle section of the walkway, which was created by applying 2 lines (2 m from each end of the walkway) to allow acceleration and deceleration. Each Subject performed the tests at their preferred speed wearing the same type of soft thin-soled shoes that did not influence their gait. The sensor units (MVP-RF-8, MicroStone Co., Nagano, Japan) that contained a triaxial angular rate gyroscope and a linear accelerometer were attached to a fixed belt at the level of the L3 spinous process, which is close to the site where the body's center of mass is supposed to be located during quiet standing, based on the method used by Moe-Nilssen and Helbostad [19]. To prevent the potential measurement error such as the effects of gravitational acceleration, we put the IMU on the flat floor and calibrated the accelerometer before each gait trial. To identify the walk cycle, a pressure sensor (FlexiForce, Nitta Co., Osaka, Japan) was attached to the subject's heel. Each sensor was synchronized with the accelerometer. The signals were sampled at a frequency of 200 Hz and were wirelessly and simultaneously transferred to a personal computer via a Bluetooth personal area network. The subjects were timed as they walked over the 10 m portion of the walkway, and their gait velocity was expressed in meters per second.

### 2.6. Data analysis

Signal processing was performed by using MATLAB (The MathWorks Co., Release 2013b, Tokyo, Japan). In order to reduce individual differences for accurate analysis, stable 10 steps data were used, which were extracted by using a cyclic pattern of acceleration. Fig. 1(b) shows the coordinate system used in this study. Synthesized acceleration was calculated by composing measurements of each directional acceleration data. Each directional angular velocity data was integrated for the purpose of calculating the rotation angle. It has been emphasized that the major problem of integration of angular velocity data from gyro sensors is drift. In this study, we examined the effect to measurement data by drift using turntable equipped with a motor and an encoder. The IMU was mounted on the turntable so that each axis of the sensor coordinate could be coaxial to that of the turntable in each trial. Then the motor was rotated by position control in order to the time history of rotation angle become sine wave and the IMU measurement data was compared to encoder data. The experiments are performed in various conditions for each axis; amplitude is set to 2.5° or 5°and the frequency is set to 0.6 Hz, 0.8 Hz, 1.0 Hz or 1.2 Hz, which is determined from assumption of trunk rotation during walking. Based on these results, we compensated for drift by estimating it as a linear equation using least squares method. The experimental setting and the measurement data and correction result of a trial is shown in Fig. 2. Synthesized acceleration was used for evaluating translation and each directional rotation angle was used for evaluating rotation.

### 2.7. Evaluation index

Based on the method used by Nishiguchi et al. [18], the root mean square (RMS), the autocorrelation peak (AC), and the coefficient of variance of the acceleration peak intervals (CV) were calculated by using synthesized acceleration and each directional rotation angle.

RMS represents the degree of the trunk movement whose higher value indicates greater movement of the trunk. RMS is affected by gait velocity and it is proportional to the square of gait velocity. Therefore, we adjusted the RMS by dividing it by the square of the gait velocity [20].

AC is defined as peak value around the lag related to gait cycle of autocorrelation function, which is calculated from measured cyclic data. Autocorrelation is useful for finding repeating patterns in a signal, and symmetry is a fundamental property of autocorrelation. When it comes to gait, the AC value indicates the degree of gait balance, and therefore, a higher AC value indicates a greater degree of symmetry during movement.

CV was calculated from the mean and standard deviation of the time intervals between the neighboring positive peaks of measured data. To derive the effects of high frequency noise, acceleration data was smoothed by using a low-pass filter whose cutoff frequency is set to 5 Hz. The CV indicates the degree of gait variability, which was defined as the variability in the time that elapsed between the heel contacts for two consecutive footfalls. A higher CV value indicates more instable gait [21].

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