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Estimation of inertial parameters of the lower trunk in pregnant Japanese women: A longitudinal comparative study and application to motion analysis

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ABSTRACT

We aimed to quantify the inertial parameters of the lower trunk segment in pregnant Japanese women and compare kinetic data during tasks calculated with parameters estimated in this study to data calculated with standard parameters. Eight pregnant women and seven nulliparous women participated. Twenty-four infrared reflective markers were attached to the lower trunk, and the standing position was captured by eight infrared cameras. The lower trunk was divided into parts, and inertial parameters were calculated. Pregnant women performed a movement task that involved standing from a chair, picking up plates, and walking forward after turning to the right. Kinetic analysis was performed using standard inertial parameters and the newly calculated parameters. There were more significant differences between methods in the kinetic data at the latter stages of pregnancy. The inertial parameters calculated in this study should be used to ensure the validity of biomechanical studies of pregnant Japanese women.

1. Introduction

The abdomen increases in mass and volume during pregnancy, causing changes in physical function. The center of mass (COM) location shifts and the alignment of the spine exhibits compensatory changes (Franklin and Conner-Kerr, 1998; Gaymer et al., 2009; Ostgaard et al., 1993). These changes in alignment differ between individuals (Gilleard et al., 2002) and can affect the musculoskeletal and postural control systems (Nagai et al., 2009; Ponnapula and Boberg, 2010), cause low back pain (Bastiaanssen et al., 2005; Cheng et al., 2009; Gutke et al., 2010; Lisi, 2006) and make it difficult for pregnant women to perform some activities of daily living (Garshasbi and Faghih Zadeh, 2005).

Previous biomechanical studies involving pregnant women have assessed changes in postural control during pregnancy. We reported that movement patterns of pregnant women during rising from a chair and walking forward were different from those of nulliparous women and varied with the number of days since conception (Sunaga et al., 2013). Difficulties performing a trunk flexion movement caused pregnant women to rise from a chair with insufficient forward displacement of their COM, meaning that they transitioned to walking and enhanced their forward propulsion after the transition to walking to compensate for insufficient forward displacement of the COM. Insufficient lower extremity lift and enhanced forward propulsion caused uncertain toe clearance and postural unsteadiness at the initiation of walking, increasing the risk of falling (Sunaga et al., 2013).

In the United States, accidental falls cause 10–25% of traumas during pregnancy (Connolly et al., 1997). Dunning et al. (2003) reported that the prevalence of falls in employed pregnant women was 26.6%, and that in non-employed pregnant women was 27.2%,

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with the most common contributing factors to falls being slippery floors and carrying an object or a child. McCrory et al. (2011) demonstrated that pregnant women walked slower than non-pregnant women, and pregnant women who had fallen during pregnancy walked slower than pregnant women who had not fallen during pregnancy. Falls during pregnancy cause trauma for the mother and, at worst, intrauterine fetal death (Connolly et al., 1997; Dunning et al., 2003; El-Kady et al., 2004; Murao et al., 2000). Knowledge of postural control and movement patterns of pregnant women is necessary to develop safety guidelines to prevent falls.

Body segment inertial parameters (BSPs) are essential to understand human biomechanics. These include the ratio of segment mass to whole body mass, the distance of the segment COM from the edge of the body segment, and the radius of gyration of the segment. BSPs are required for kinetic analysis of movements, to calculate variables such as the COM location, joint moments, and joint powers. BSPs of Caucasian men (Chandler et al., 1975; Clauser et al., 1969; Dempster, 1955), young Japanese individuals (Ae et al., 1992), elderly Japanese individuals (Okada et al., 1996), and Japanese children (Yokoi et al., 1986) have been reported. Lee et al. (2009) reported the effects of BSP estimates on joint kinetics of the lower extremity during gait and highlighted the necessity of accurate BSP estimates. However, the available BSP estimates are not applicable to pregnant women, who have a distinctively different body shape to non-pregnant women (Yokoi et al., 2002). Furthermore, we believe that the BSPs of pregnant Japanese women will differ from those of pregnant Caucasian women, as, for example, the mean body mass gain of Japanese women during pregnancy is 9.8 kg (Tsukamoto et al., 2007), whereas that of Canadian women is 14.1 kg (Hui et al., 2006). A regression expression to estimate the BSPs of pregnant Canadian women has been presented (Jensen et al., 1996), but the BSPs of pregnant Japanese women have not been reported. As such, biomechanical studies have thus far used standard BSPs that are not applicable to pregnant women.

The aim of this study was to estimate the BSPs of pregnant Japanese women and quantify the changes in BSPs over time. These data will be useful for future motion analysis studies especially in analyzing motions in pregnant women. In addition, we compared BSPs between pregnant and nulliparous Japanese women. Jensen et al. (1996) reported that the lower trunk mass of pregnant Canadian women increased significantly in the second and third trimesters of pregnancy, but there were no significant changes in the mass of other body segments. Therefore, in this study, we focused only on the lower trunk segment.

Several methods have been used to estimate BSPs, including cadaver measurements (Chandler et al., 1975; Clauser et al., 1969; Dempster, 1955), mathematical modeling (Jensen, 1993; Jensen et al., 1996; Nikolva and Toshev, 2007), and X-ray scanning (Lee et al., 2009). Ideally, BSPs should be estimated in three dimensions, but methods involving radiation, such as X-ray scanning, are contraindicated for pregnant women. Ferrigno et al. (1994) calculated the volume of the trunk using a three-dimensional (3D) motion capture system, a method that was further validated by comparing inspired and expired lung volumes to volumes determined by spirometry (Cala et al., 1996). 3D motion capture has been widely used to analyze chest wall motion during breathing (Aliverti et al., 2001; Kenyon et al., 1997; Wang et al., 2009); however, to our knowledge, this method has not been previously used to estimate BSPs. In the present study, we used a 3D motion capture system, which has no undesirable effects on both the mother and fetus, to estimate BSPs of pregnant Japanese women. The estimated BSPs were used to perform kinetic analyses of pregnant women performing a movement task that involved rising from a chair, picking up square plates, turning to the right, and walking a few steps. In many cases, the motion of rising from a chair and walking also included turns to head toward a destination and perform some aimed motion. For these reasons, and in accordance with the increased risk of falling when carrying an object, we studied rising from a chair and turning while carrying an object, which seems to be routinely performed even during pregnancy.

2. Methods

2.1. Participants and measurements

Eight pregnant women (maternal group) with a mean age of 34.4 (SD 5.9) years, a mean body height of 160.3 (SD 4.1) cm, and a mean pre-pregnancy body mass of 55.4 (SD 6.6) kg volunteered for this study. Seven nulliparous women with a mean age of 29.3 (SD 2.4) years, a mean height of 156.5 (SD 5.6) cm, and a mean body mass of 52.4 (SD 7.6) kg also volunteered for this study and formed the control group. The maternal group was examined on the following three occasions: between the 16th and 18th weeks of gestation (Exam 1), between the 24th and 25th weeks of gestation (Exam 2), and between the 32nd and 33rd weeks of gestation (Exam 3), as per previous studies (Gilleard et al., 2008; Jang et al., 2008; Sunaga et al., 2013) and taking into consideration possible risks to the mother and fetus. The control group was examined on one occasion. Examinations of BSPs and motion were performed on the same day. The Ethics Committee of Saitama Prefectural University approved this study (Approval Number 24007), and the study was conducted in accordance with the Declaration of Helsinki. All participants provided their written, informed consent prior to enrollment.

2.2. Examination to estimate BSPs and motion analysis

Twenty-four infrared reflective markers were attached to the lower trunk and lower extremities of the subjects (Fig. 1), who were dressed in tight, non-reflective clothes. The lower edge of the 10th rib defined the top edge of the lower trunk segment, and the greater trochanter defined the bottom edge of the lower trunk segment. This segment division was based on previous studies involving Japanese individuals (Ae et al., 1992; Jensen, 1993; Nikolva and Toshev, 2007; Yokoi et al., 1986) and was chosen to enable comparisons across studies.

Standing posture was captured using eight infrared cameras (Vicon Motion Systems, Oxford, UK) while the subjects were standing comfortably and looking straight ahead. The coordinates of the markers were identified using a motion analysis software Vicon NEXUS 1.7.1. (Vicon Motion Systems, Oxford, UK). The center of the bottom edge of the posterior surface of the lower trunk segment was defined as the origin of the coordinate system, and the left-right, antero-posterior, and vertical axes of the lower trunk segment were defined as the x, y, and z axes, respectively. The coordinate system was orientated so that the right was positive and the left was negative.

For subjects in the maternal group, body mass, height of the uterine fundus, and abdominal girth were obtained at each examination using the most recent obstetric check-up record. Abdominal girth was measured at the level of the most projecting point around the navel. For subjects in the control group, body mass was measured on the day of the experiment.

For the maternal subjects, the markers were replaced after the examination of BSPs to enable measurement of the movement task. Thirty-five markers were attached to the subject at the following locations, according to the Plug-in-Gait Full Body Model (Vicon Motion Systems, 2010): right and left foreheads and back of the