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The influence of body mass on foot dimensions during pregnancy

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ABSTRACT

In this study, a time-series approach was used to measure women's feet to accurately analyze changes in foot size and body mass during pregnancy. One-hundred women who were pregnant for the first time were asked to respond to questions on subjective complaints of foot discomfort listed in a questionnaire. Among these 100 women, a sample of 30 was obtained and used to measure the women's feet from the twentieth week of the gestation period until labor. The data (from 5 of the 30 women) were used to establish a prediction model for the influence of body mass on changes in foot size during pregnancy. The results indicate that the women subjectively complained that their shoes were too tight, resulting in foot discomfort. From the twentieth to the thirty-eighth week of pregnancy, the average increase in foot length, width, and back foot surface was 0.86 cm (3.6%), 0.25 cm (2.6%), and 18.36 cm^2 (11.9%), respectively. The height of the arch decreased by an average of 0.52 cm (−24.2%). Body mass accounted for more than 90% of the variation (R^2) in foot dimensions during pregnancy and, thus indicated satisfactory predictive ability. The prediction model developed in this study can serve as a reference for clinical applications and shoe design to prevent women from experiencing extreme discomfort in their feet during pregnancy.

1. Introduction

During pregnancy, because of the normal accumulation of fluid and fat, a woman's body mass increases by an average of 10–16 kg (Alvarez et al., 1988; Hytten and Chamberlain, 1991; Wetz et al., 2006; Ochsenbein-Kplble et al., 2007; Gaymer et al., 2009). Increased body mass enlarges the contact area between the arches of the feet and the ground (Fabris et al., 2006). This enlargement consequently increases plantar pressure (Hills et al., 2001; Drerup et al., 2003; Fabris et al., 2006; Karadag-Saygi et al., 2010) and results in foot discomfort and other foot symptoms (Robinson et al., 2010). From a physiological perspective, increased body mass during pregnancy may cause an increase in foot volume, which is closely related to foot length, foot width, and height of the arch (Nyska et al., 1997; Bird et al., 1999; Foti et al., 2000; Wetz et al., 2006; Gaymer et al., 2009). The enlarged contact area between arches and the ground may also change the foot structure and decrease the arch height (Nyska et al., 1997). From the perspective of foot orthopedics, an accumulation of soft tissues is responsible for the increased foot swelling and foot volume that occurs during pregnancy (Alvarez et al., 1988). The negative effect of ill-fitting shoes on muscles and bones was reported to overburden the toes, forefeet, arches, and ankles, and can lead to foot conditions and foot pain (Xiong et al., 2009).

Although previous research has suggested that pregnancy changes foot dimensions, accurate measurements of these dimensions are lacking. In general, the dimensions and shape of pregnant women's feet exhibit swelling that becomes evident after 13–35 weeks of pregnancy (Alvarez et al., 1988; Gabriel et al., 2013). In a previous study, the feet of pregnant women were measured once every 3 months and a significant increase in foot length, width, and volume was observed. However, long intervals between measurements render the accurate assessment of changes problematic (Wetz et al., 2006).

Foot swelling, particularly at the later stages of pregnancy, causes a poor fit between a pregnant woman's feet and her shoes, and results in foot discomfort. Furthermore, pregnant women are susceptible to foot diseases (Gilbert, 2002) and may experience it difficulty in choosing suitable shoes, which may hinder their ability to walk and conduct daily activities (Fabris et al., 2006; Ribeiro et al., 2011). Because foot comfort depends on the fit between a person's feet and shoes, several researchers have attempted to design shoes that reduce the burden and impact on feet to enhance foot comfort (Light et al., 1980; Chen et al., 1994; Hodge et al., 1999).

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The impact of shoes on the feet of pregnant women is a factor that may be easily overlooked (Cernekova and Hlavacek, 2005). Shoes are not currently designed to prevent or reduce foot discomfort experienced by pregnant women; in other words, most pregnant women wear shoes that do not fit properly, resulting in foot discomfort (Bamigboye and Hofmeyr, 2006). Therefore, foot pain may be correlated with shoe design (Broch et al., 2004). As previously mentioned, previous research has indicated that an increase in foot length, width, and volume occurs during pregnancy, and that the measurement of these changes is complicated by the lengthy interval between measurements. In the current study, a time-series approach was used to measure these changes, assess the relationship between foot shape and body mass during pregnancy accurately, and explore how changes in foot dimensions lead to foot discomfort.

2. Methods

The condition of women's feet during pregnancy was investigated using a subjective self-report questionnaire and objective foot dimension measurement. Gestational age was divided into Gestation period I (GI, weeks 12–19), Gestation period II (GII, weeks 20–28), and Gestation period III (GIII, weeks 29–38). The defined gestation stages were also adopted by Hirst et al. (2012). Generally, pregnant women do not notice changes in their feet until GII, and foot discomfort becomes most evident during GIII (Kline and Stein, 1984). Therefore, we surveyed women's subjective symptoms and measured their feet once every 2 weeks during GII and GIII.

2.1. Samples identification

We used a 2-stage design for sample identification (Fig. 1). At Stage 1, 100 women who were pregnant for the first time were asked to respond to questions on complaints of foot discomfort listed in a questionnaire. At Stage 2, the foot dimensions of 30 of these women were monitored from the twentieth week of the gestation period until labor. A 3-D foot scanner was used to measure the foot dimensions. Repeated measurements were highly difficult to obtain because the pregnant participants were not always available for every measurement; therefore, we collected complete data on the foot dimensions of 5 of the 30 pregnant women biweekly, from the twentieth to the thirty-eighth week of pregnancy.

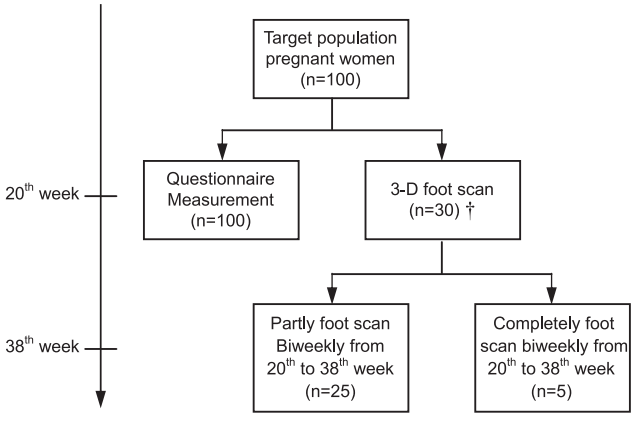

Fig. 1. Samples identification process for foot dimensions measurement during pregnancy. A total of 5 of the 30 participants involved fortnightly complete photographic experiments with a total of nine times biweekly for 18 weeks (20th to 38th week). This study therefore used the data of 5 participants to develop regression models to predict foot size dimensions using body mass during pregnancy. Eventually, the measured foot sizes of the 25 women were used to validate the regression models.

2.2. Participants

The women recruited for this study were from the Department of Obstetrics and Gynecology at Chang Gung Memorial Hospital in Taoyuan, Taiwan. All the participants were Chinese residents of Taiwan. The selection criteria included being in GI, being 20–40 years of age, having no history of foot disease, being pregnant for the first time, and not being at a gestation stage where disease and addictive substances could easily cause problems (i.e., cigarette smoking, alcohol intake, and illicit or abused drugs). The mean and standard deviation (SD) for age, height, and body mass of the 30 participants at the start of the study were 28.9 (4.8) years, 159.4 (4.5) cm, and 50.4 (6.8) kg, respectively. The study was approved by the Ethics Committee of Chang Gung Memorial Hospital in Taiwan (No: 97–2538B).

2.3. Available samples for foot scanning and model development

We used a 3-D scanner to capture images of the participants' feet, which were monitored until postpartum. Most of the participants did not receive foot scan at regular intervals (once every 2 weeks). The average rate of women who were measured during GII and GIII was 65.3%. Among the 30 participants, only 5 women received regular foot scan. The mean (SD) age, height, and body mass of the 5 participants at the start of the study were 28.5 (4.3) years, 159.2 (3.8) cm, and 50.3 (6.5) kg, respectively. The foot measurements of the participants were calculated using the root mean square error. The errors in foot length, foot width, and arch height for the two participant groups ranged from 0.018 cm to 0.082 cm (0.35%–0.82%), which were within ±1 mm, and complied with the International Organization for Standardization (ISO) 20685:2010 standards (ISO, 2010; i.e., the maximum error in foot dimensions was less than 2 mm). The error in back foot surface area measurements was 1.632 cm^2 (1.08%).

2.4. Questionnaire

The weeks in which we collected the questionnaires data for the 3 stages were week 16 (GI, weeks 12–19), week 25 (GII, weeks 20–28) and week 35 (GIII, weeks 29–38). We used a structured questionnaire to assess the fit between pregnant women's feet and their shoes. The questionnaire included 3 parts: (1) basic information: height, body mass, age, and gestational age; (2) foot disease history: foot discomfort, location of discomfort, and change in shoe size; foot measurements were divided into forefoot, midfoot, and rearfoot (Au and Goonetilleke, 2007); and (3) shifts in the location of discomfort during pregnancy. The questionnaire was developed by the Department of Obstetrics and Gynecology at Chang Gung Memorial Hospital in Taoyuan, Taiwan.

2.5. Foot measurements

A Gemini 3-D foot scanner (Industrial Technology Research Institute of Taiwan) automatically scanned, analyzed, and calculated the foot dimensions. The entire image capture process took less than 1 s. The scanner recorded each participant's right foot dimensions using a 3-D camera with a spatial distribution of 1 mm. A typical sample of a foot scan in this study is shown in Fig. 2. The accuracy of the foot measurements were all within 1%, which were assessed by Yu and Tu (2009). The 4 measurements were foot length, foot width, height of the arch, and back foot surface area (Fig. 3), which have been used in previous studies (Burnfield et al., 2004; Yu and Tu, 2009).

One hundred pregnant women participated in the questionnaire survey. The feet of thirty of these women were subsequently