Acta of Bioengineering and Biomechanics
Vol. 21, No. 3, 2019

Original paper
DOI: 10.5277/ABB-01362-2019-02

A prospective longitudinal comparison of the sacral inclination angle in women between their early and advanced pregnancy and 6-month postpartum follow-up

AGNIESZKA OPALA-BERDZIK[1]*, JOANNA CIEŚLIŃSKA-ŚWIDER[1], RAFAŁ GNAT[2]

[1] Institute of Physiotherapy and Health Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.
[2] Motion Analysis Laboratory, Department of Physiotherapy, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.

Purpose: The impact of pregnancy on the anterior-posterior sacral orientation and its relation to lumbopelvic pain and weight gain has not been fully recognized. This longitudinal study aimed to compare the sacral inclination angle in women between their early and advanced pregnancy and at 6 months postpartum. The authors also searched for a correlation between the sacral inclination and lumbopelvic pain, BMI and change in body mass. *Methods*: Thirteen healthy women participated in the study. Data were collected at 8–16 and 35–38 weeks of gestation, and at 27–31.5 postpartum weeks. At each session, the women's sacral inclination angles were measured using the Saunders digital inclinometer. Data were also collected on lumbopelvic pain, BMI and body mass gain/loss. *Results*: There was no effect of the evaluation period on the sacral inclination ($p > 0.05$); however, various individual values of the sacral inclination in pregnancy and postpartum were noted. In advanced pregnancy, 61.5% of the women had recurrent pain in the lumbopelvic region. The sacral inclination did not correlate with the lumbopelvic pain, BMI and body mass change ($p > 0.05$) in the pregnancy and postpartum periods. *Conclusions*: Advanced pregnancy did not influence sacral inclination. However, individuals varied in their responses. Therefore, we suggest that an individually-based physical therapy approach concerning proper posture during and after pregnancy should be emphasized. The sacral inclination had no impact on the occurrence of recurrent lumbopelvic pain. BMI and changes in body mass did not influence the sacral inclination in advanced pregnancy and at 6 months postpartum.

Key words: *sacral inclination, lumbopelvic pain, BMI, gestational weight gain, pregnancy, postpartum*

1. Introduction

A woman's body has the ability to adapt to many changes taking place during her pregnancy. One of them is the adjustment of her posture to the increasing uterine load. From a biomechanical perspective, while standing a slight posterior tilt of the pregnant woman's body is necessary to withstand the increased mass located in the anterior trunk area. Such postural adaptation should reassure the proper location of the body's center of gravity in order to maintain optimal static stability and prevent the body from excessive energy expenditure [18], [22], [23], [32]. It is commonly assumed that the adjustment of the pregnant woman's spinal alignment takes place mainly at the level of the trunk by tilting her upper body backwards and increasing her lumbar lordosis and anterior pelvic tilt. This assumption was confirmed by Franklin and Conner-Kerr [6], Kouhkan et al. [12] and Whitcome et al. [32], however, other studies reported no alterations in the anterior-posterior lumbar and pelvic position in advanced pregnancy [2], [3]. A tendency for the flattening of the lumbar spine [18], [21] and a large inter-individual variability in pregnant women's spinal inclinations were also noted [3], [18], [21]. Because of the lack of coherence in the results of the above-mentioned studies, the problem of women's postural adaptation to pregnancy needs further investigation.

* Corresponding author: Department of Physiotherapy in Internal Diseases, Academy of Physical Education in Katowice, ul. Mikołowska 72, 40-065 Katowice, Poland. Phone: 322075301, e-mail: a.opala-berdzik@awf.katowice.pl
Received: April 12th, 2019
Accepted for publication: July 29th, 2019

A review of the literature has shown that less attention was given to explore the influence of pregnancy on the inclination of the sacral bone in the sagittal plane. The sacral inclination is related to pelvic tilt and lumbar lordosis; however, it is an independent measure [8], [29]. The increasing size and mass of the uterus located in the pelvic (and later also in the abdominal) cavity may have an impact on the inclination of the sacrum. We have found only one study on the sacral inclination in pregnant women. The study used the Spinal Mouse device for the measurement and showed non-significant differences between pregnant and non-pregnant women with regard to this variable [21]. Although the most accurate measurements of the spinal column curvatures are made from radiographs, during pregnancy the exposure to x-rays is contraindicated. One of the reliable indirect methods to measure the sacral inclination which can be safely performed in pregnant women is the use of the Saunders digital inclinometer [5], [10], [13]. To our knowledge, this method has not been utilized in research concerning the population of pregnant women so far.

The undertaken direction of research also relates to the problem of lumbopelvic pain, which is a very common complaint during pregnancy. It has been estimated that up to 70% of pregnant women may suffer from lumbopelvic pain [17], [31]. Depending on the pain intensity they may experience difficulty or limitations in performing daily activities [19], [31] and deal with feelings of frustration, guilt, irritability and upset at being unable to carry out their normal roles [14]. Lumbopelvic pain may affect the women's ability to care for their children and cause frequent absences from work, secondarily resulting in a socioeconomic burden [1], [14]. It has been documented that an increased BMI before and during pregnancy, multiparity, history of hypermobility, physically demanding occupations, low back pain or pelvic girdle pain before pregnancy and during a previous pregnancy may be related to the occurrence of lumbar and pelvic pain in pregnancy [17], [30]. However, until now, it is unclear whether changes in posture related to pregnancy may trigger the lumbopelvic pain as well. Some studies reported no relation between the pelvic or lumbar inclinations and lower back pain [2], [6], while one study demonstrated a positive correlation between pelvic inclination and the subjective sensation of pain in the lumbopelvic region in pregnant women [28]. Because the sacral bone forms the dorsal part of the pelvic girdle and is directly connected both to the pelvic bones and lumbar spine by soft tissue junctions, it is important to seek out the relationship of the sacral inclination with lumbopelvic pain in pregnant and postpartum women. Theoretically, the anterior-posterior orientation of the sacrum may also be related to gestational weight gain and BMI. In pregnancy, the lower trunk mass increase is the greatest, compared to other body segments [11]. To our knowledge, the influence of pregnancy on the sacral inclination in relation to lumbopelvic pain, BMI and pregnancy-related changes in body mass has not been investigated.

The primary aim of the study was to determine whether women in advanced pregnancy demonstrated an increased sacral inclination angle compared to that in early pregnancy and at 6 months postpartum. The secondary aim was to verify whether the sacral inclination angle in the advanced pregnancy and postpartum periods might have been related to the subjective sensation of lumbopelvic pain, BMI and changes in body mass.

2. Materials and methods

This study is a part of a project related to the longitudinal investigation of postural characteristics of women during and after pregnancy, which was conducted following the approval of the local Ethics Committee.

Participants and procedure

The women were recruited for the study by obstetricians from antenatal clinics in the region of Upper Silesia, Poland. For the purposes of the present study, twenty healthy volunteers by their 16th week of unifetal pregnancies (17 primigravida and 3 multigravida) were enrolled. Exclusion criteria consisted of any conditions considered by an obstetrician to indicate a high risk pregnancy, as well as any musculoskeletal disabilities, e.g., spinal or lower extremity pain/pathology (lumbopelvic pain only at the first appointment), neurologic abnormalities and obesity. Multigravida subjects were also excluded if they had a previous delivery within one year before enrollment. The eligibility criteria were confirmed by a physical examination and medical interview.

The women enrolled in the study reported for testing at the Biomechanics Laboratory at the Department of Human Motor Behavior at the Academy of Physical Education in Katowice. The aim of the study and the experimental procedures were explained to all subjects, and a written informed consent was obtained. The women were scheduled for three evalua-

Table 1. Characteristics of 13 women during their early (P1) and advanced (P2) pregnancy and at 6 months postpartum (PP)*

	Evaluation period [weeks]	Body mass [kg]	Body height [cm]
P1	13.9 ± 2.1 (8–16)	60.9 ± 11.0 (44–79)	166.0 ± 7.5 (150–177)
P2	36.3 ± 0.9 (35–38)	72.5 ± 10.4 (55–88)	
PP	27.3 ± 1.2 (27–31.5)	61.9 ± 11.3 (44–77)	

* Data are shown as the means ± standard deviations (ranges denoted in parentheses).

tion sessions: early pregnancy (by the 16th gestational week), advanced pregnancy (between 5 and 2 weeks before the due date) and 6 months postpartum. Six women were unable to participate in the advanced pregnancy session and one in the postpartum session. The reasons for their absences were the following: complications related to pregnancy (n = 4), delivery prior to the scheduled visit (n = 2), and relocation (n = 1). Therefore, only the data for the thirteen women (11 primigravida and 2 multigravida) who completed the study protocol were analyzed. At the first data collection session, the mean ± SD (range) age of the women was 27.9 ± 2.9 (23–33) years. The characteristics of the subjects at the three sessions are presented in Table 1.

Measurements

The sacral inclination angle was measured using the Saunders digital inclinometer (Baseline Digital Inclinometer, The Saunders Group Inc, Chaska, MN, USA). This method showed good and high intra-rater reliability in healthy individuals and in women diagnosed with osteoporosis of the spine [5], [13]. According to our pilot study performed on 12 healthy non-pregnant women, the $ICC_{3,3}$ was 0.91. The standard error of measurement was 0.92 degrees and the smallest detectable difference was 2.55 degrees. All measurements at each session were performed according to the manufacturer's instructions by the same licensed physical therapist (10 years of experience). For the measurements, clothing covering the back was removed to ensure accurate identification of bony landmarks and each woman was asked to stand erect barefoot with her feet hip-width apart, knees straight, arms by her sides, and with her hands facing inwards. The sacral midpoint (laying on the median sacral crest in the midline between the lower aspects of the posterior superior iliac spines) was palpated and marked. After landmarking, the inclinometer (its longer surface) was placed on a flat horizontal surface and the digital reading was set to zero degrees. Then, the inclinometer (its shorter surface) was placed at the sacral midpoint and the angle was read and recorded (Fig. 1). The measurement procedure was repeated three times and the mean values of the three measurements were used for the analysis. The measurement stayed in agreement with the studies of anterior-posterior human spine radiography defining the sacral inclination as the angle between the vertical plane and the tangential line to the sacral dorsum [8], [20] (Fig. 1).

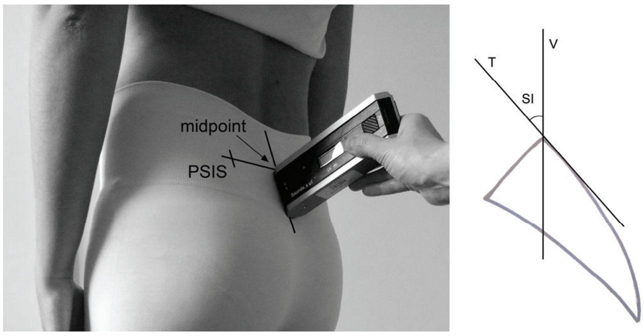

Fig. 1. Left: measurement of the sacral inclination: The Saunders digital inclinometer was placed at the sacral midpoint in the midline between the lower aspects of the posterior superior iliac spines (PSIS); the measurement was performed without clothing covering the sacral bone area (not shown in the photo). Right: a sacral bone sketched from a lateral perspective and a schematic representation of the sacral inclination (SI) – the angle between the vertical line (V) and the tangential line to the sacral dorsum (T)

At the second and third visits the women were asked about the occurrence of pain in the lumbopelvic region within the previous 4 weeks. The location of the subjective uni- or bilateral pain sensation in the lower back area (between the levels of L1 and ischial tuberosities) was verified by the physical therapist. The women reporting pain were asked whether they experienced it sometimes (recurrent pain) or constantly (persistent pain). The occurrence of lumbopelvic pain was calculated in percentages; however, to quantify the pain, an ordinal scale was used: 0 – no pain, 1 – recurrent pain and 2 – persistent pain. The intensity of the persistent pain was recorded based on the 1 to 10 scale (1 – minimal, very light and 10 – maximal, difficult to bear the pain).

Body height was measured at the initial visit and body mass was measured at each visit in order to calculate BMI. Gains in body mass were calculated by subtracting the early pregnancy body mass from the advanced pregnancy body mass, and losses in body mass were determined by subtracting the postpartum body mass from the advanced pregnancy body mass. Additionally, the gestational weight gain was calculated by subtracting the pre-pregnancy body mass from the advanced pregnancy body mass (the participants reported their pre-pregnancy body mass at the initial visit).

Statistical analysis

Friedman repeated measures analysis of variance (ANOVA) by ranks was performed to determine the effects of the three sessions (early and advanced pregnancy and 6 months postpartum) on the sacral inclination angle and BMI. When the results of the Friedman ANOVA were significant, a Wilcoxon signed-rank test was applied to compare the measures from the particular sessions. The Wilcoxon test was also used to compare the gain in body mass from early to advanced pregnancy with the loss in body mass from advanced pregnancy to 6 months postpartum. Spearman's rank correlation coefficient test was used to determine whether the sacral inclination correlated with lumbopelvic pain, BMI and changes in body mass in the advanced pregnancy and 6 months postpartum periods. The level of significance was set at $P < 0.05$. Analyses were performed using the Statistica 13.1 software (StatSoft, Inc., Tulsa, OK USA).

3. Results

The Friedman ANOVA showed the non-significant effect of the evaluation period on the sacral inclination angle ($p = 0.75$). The analysis showed the significant effect of the evaluation period on the women's BMI ($p = 0.00009$). The Wilcoxon test demonstrated that the BMI significantly increased from early to advanced pregnancy ($p = 0.001$) and decreased from advanced pregnancy to 6 months postpartum ($p = 0.002$). There was a non-significant difference between early pregnancy and 6 months postpartum BMI ($p = 0.17$). The Wilcoxon test also showed a non-significant difference between the gain in body mass from early to advanced pregnancy and loss in body mass from advanced pregnancy to 6 months postpartum period ($p = 0.23$; Table 2).

To verify what percentage of women experienced either no change, a decrease or an increase of the sacral inclination angle between the evaluation sessions, we took into account the smallest detectable difference of 2.55° found in our pilot study. Therefore, the 3° or less between-session difference in the magnitude of the angle was considered as no change. Of the 13 women in the advanced pregnancy period, 8 (61.5%) had an unchanged, 3°(23.1%) increased and 2 (15.4%) decreased sacral inclination angle compared to that in the early pregnancy period. At the 6-month postpartum follow-up, 6 women (46%) demonstrated no change, 4 (30.8%) a decrease and 3 (23.1%) an increase in the sacral inclination angle compared to that in the advanced pregnancy period. At 6 months

Table 2. The sacral inclination angle, lumbopelvic pain occurrence and body mass index (BMI) in 13 women in their early (P1) and advanced (P2) pregnancy and at 6 months postpartum (PP) as well as the women's body mass change (gain from P1 to P2 and loss from P2 to PP) and gestational weight gain (from pre-pregnancy to P2)*

Measure	P1	P2	PP
Sacral inclination [°]	16.3 ± 5.5 (7–27)	16.8 ± 3.8 (10–22)	16.5 ± 4.6 (10–27)
Lumbopelvic pain	0%	61.5%	38.5%
BMI**	21.9 ± 2.4 (18.6–26)	26.2 ± 1.9 (23.2–29.1)	22.3 ± 2.6 (18.6–26.6)
Body mass change [kg]		P2 – P1 = 11.6 ± 3.2 (7–18)	P2 – PP = 10.6 ± 4.0 (–1–15)
Gestational weight gain [kg]		P2 – pre-pregnancy = 12.7 ± 3.5 (6–20)	

* Data are shown as the means±standard deviations (ranges denoted in parentheses), except for the occurrence of lumbopelvic pain which is shown as a percentage.

** Significant increase from P1 to P2 ($p = 0.001$) and decrease from P2 to PP ($p = 0.002$); Wilcoxon signed-rank tests; Friedman ANOVA: $p = 0.00009$).

postpartum, 5 women (38.5%) demonstrated no change, 4 (30.8%) a decrease and 4 (30.8%) an increase in the sacral inclination compared to that in the early pregnancy period (Fig. 2).

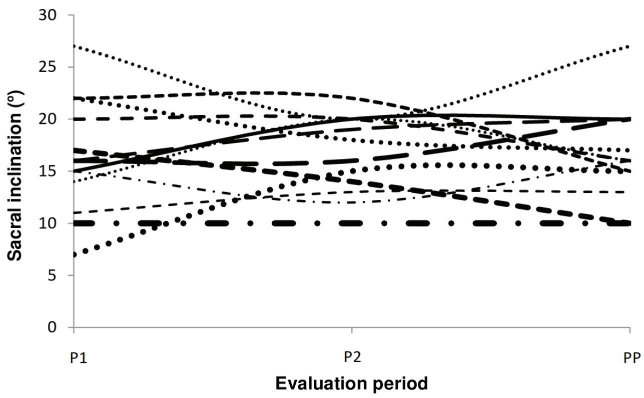

Fig. 2. Individual values of the sacral inclination angles in degrees for 13 women at three test sessions: P1: early pregnancy, P2: advanced pregnancy, PP: 6 months postpartum (each line is drawn between the three points representing the three angular values for the particular subject)

Of the 13 women, 8 (61.5%) reported recurrent and none (0%) persistent lumbopelvic pain in the advanced pregnancy period. At 6 months postpartum, 4 women (30.8%) complained of recurrent and 1 (7.7%) of persistent pain in the lumbopelvic region (Table 2). Spearman's test showed the non-significant correlation of the sacral inclination with lumbopelvic pain in the advanced pregnancy and at 6 months postpartum. Because only one woman complained of persistent lumbopelvic pain (with an intensity described as 3), the pain intensity could not be used as a measure to be analyzed in this study.

Spearman's test showed the non-significant correlation of BMI values with the sacral inclination angle values in the advanced pregnancy and 6-month postpartum periods ($p > 0.05$). Gains in body mass from early to advanced pregnancy did not correlate with the advanced pregnancy sacral inclination as well as losses in body mass from the advanced pregnancy to 6-month postpartum period did not correlate with the postpartum sacral inclination ($p > 0.05$).

4. Discussion

The primary objective of the present study was to compare the magnitude of the sacral inclination angle measured with the Saunders digital inclinometer in women between their early and advanced pregnancy periods and their 6-month postpartum follow-up. We hypothesized that the women would demonstrate an increased sacral inclination angle in advanced pregnancy compared to that in early pregnancy and the postpartum periods. However, this study suggests no effect of advanced pregnancy on the sacral inclination. Concomitantly, individual values of the sacral inclination in women during their three test sessions indicate various postural responses. These results may suggest that a posterior body tilt in reaction to the increased load in the anterior abdominal area in some pregnant women does not take place in the lumbosacral region. An observational case study conducted many years ago indicated that the major counterbalancing postural adjustments accompanying the progression of pregnancy concerned the elevation of the head, extension of the cervical spine, stabilization of the knee joints and increase in ankle extension [7]. It is possible that a woman's individual pre-pregnancy sagittal plane body alignment determines her individual postural adaptation to pregnancy.

The observed non-significant effect of advanced pregnancy on the sacral inclination in the present sample is in accordance with two recent studies reporting no alterations in the anterior-posterior lumbar and pelvic positions between early and advanced pregnancy and the postpartum period [2], [3]. In contrast, other studies suggested a tendency for the flattening of the lumbar spine [18], [21] or a significant increase in the depth of lumbar lordosis and anterior pelvic tilt in pregnancy [6], [12], [32]. A thorough comparison of the present results to the other studies is difficult because different parameters were assessed as well as different measurement tools and protocols were employed. To our knowledge, the study by Okanishi et al. [21] was the only one to evaluate sacral inclination in pregnancy. In that study, a group of 15 pregnant women between 17–34 weeks of gestation was compared to 10 non-pregnant controls. The study showed a tendency for sacral posterior inclination in the pregnant women, compared to that of the controls, and it reported that from among 15 pregnant women, 11 demonstrated a sacral posterior inclination. However, the authors correctly pointed out that the postural characteristics of the pregnant women might have been influenced by their individual anterior-posterior spinal alignment before pregnancy and that the difference in their sacral inclination, compared to that of the non-pregnant women, could have been not only an effect of pregnancy. Indeed, the results of the case-control studies comparing a small number of pregnant and non-pregnant women may be more questionable because of the large inter-individual spinal alignment differences in healthy subjects [8], [16]. In this light, we may emphasize the important advantages of the present study: its longitudinal character starting from the early stage of pregnancy and reaching as far as 6 months postpartum.

The between-session comparison of individual values of the sacral inclination angle in the present study indicates that in about half of the participants, the sacral inclination did not change and in the remaining it either increased or decreased from early to the advanced pregnancy. This may suggest various ways of adaptation for the sacral orientation in the sagittal plane to pregnancy. Similar observations were made by others, based on the assessment of women's sagittal plane lumbar spine and pelvic position in deferent stages of pregnancy and postpartum [3], [18]. Such findings indicate that a physical therapy approach concerning proper posture in pregnancy should be specific to women's individual postural behavior. General posture-correcting exercise regimens aiming to decrease lumbar lordosis and anterior pelvic tilt may, therefore, not be appropriate for some of pregnant women.

Interestingly, in the present study, about half of the women at 6 months postpartum also demonstrated a different (increased or decreased) sacral inclination angle compared to that in their early pregnancy. It is possible that the changed sacral orientation in some women after delivery is predisposed by persisting pregnancy-related soft tissue laxity [24] and abdominal muscle weakness [4]. Therefore, even a few months postpartum women may benefit from a posture evaluation and require individually-based instructions and therapeutic exercises to improve their posture.

Of the 13 women in the present study, 8 (61.5%) complained of lumbopelvic pain in advanced pregnancy and 5 (38.5%) postpartum. The reported pain was recurrent, except for one woman who had persistent pain of a low intensity postpartum. The study results indicate that lumbopelvic pain was not related to the magnitude of the sacral inclination neither in the advanced pregnancy stage nor at 6 months postpartum. This may suggest that the pain in the lumbopelvic region could have rather been related to other factors not assessed in the present study, such as increased erector spinae activation in pregnancy [3], the low endurance of the back flexors [9] or the increased motion of the pelvic girdle joints in the perinatal period [15]. The presented results are in accordance with some studies reporting that the lumbar curvatures or sagittal pelvic tilt were not related to back pain in pregnant women [2], [6]. However, Tlapakova et al. [28] demonstrated a positive relationship between the pelvic inclination of pregnant women and lower back pain. The present study and the above-mentioned studies engaged a relatively small sample of subjects. However, Ostgaard et al. [25] searched for the influence of some biomechanical factors on the occurrence of low back pain in 855 pregnant women. The authors reported a weak correlation of the depth of the lumbar lordosis with back pain and they concluded that the occurrence of back pain during pregnancy could not be explained primarily by biomechanical factors.

In pregnancy, the rate of segment mass increase is the greatest at the lower trunk level, and it is expected to influence posture [11], therefore, in the present study we hypothesized that BMI and the change of body mass in the perinatal period might have an impact on the sacral inclination. However, no correlation of the sacral inclination with BMI in the advanced pregnancy stage and at 6 moths postpartum were observed. Furthermore, the change in body mass did not correlate with the sagittal plane sacral orientation. When recruiting women to the present study in their early pregnancy period, obesity was an exclusion criterion because it could have been an additional factor influencing posture. The gestational weight gain in most cases (except for two women) did not exceed the values of the recommended weight gain in pregnancy [26]. Additionally, the women demonstrated a similar loss in body mass after pregnancy, compared to their body mass increase during pregnancy. We suppose that because of the relatively small inter-individual differences in the body mass change and the advanced pregnancy and postpartum BMI in the present study sample, the relationship between these factors and the sacral inclination was not detected. Concomitantly, it should also be considered that an increased body mass in pregnancy is not fully related to an increased uterine load. During pregnancy, the increased body mass also consists of the increased size of the breasts, blood volume or amount of fat tissue located in other parts of the body. However, this study suggests that the perinatal body mass change of non-obese women did not have an impact on their sacral inclination. Similarly, no correlation was found between the lumbar lordosis angle and body mass in the pregnancy and postpartum periods [27].

The findings herein should be considered with caution because of the relatively small sample size of the study. Another weakness of this investigation may be the fact that the first test session concerned women up to 16 weeks of gestation. To consider the first measurement of the sacral inclination as a control for the following sessions, it would be more appropriate to enroll women in the very early stages of pregnancy, such as up to 8 weeks. However, it is very difficult to recruit women for this kind of study in their first weeks of pregnancy. Our results may only refer to non-obese women with uncomplicated pregnancies and recurrent lumbopelvic pain.

5. Conclusions

There was no effect of advanced pregnancy on sacral inclination; however, individual values of the sacral inclination in pregnancy and at 6 months postpartum indicate various postural responses to pregnancy. Based on the present findings, we suggest that the physical therapy approach concerning proper posture in the pregnancy and postpartum periods should be specific to a woman's individual postural behavior. The sacral inclination had no impact on the occurrence of recurrent lumbopelvic pain in the advanced pregnancy stage and at 6 months postpartum. BMI and the change in body mass did not influence the sacral inclination of the women in their perinatal period.

Acknowledgements

This study is a part of a project regarding the longitudinal investigation of postural characteristics of women during and after pregnancy, which was funded by the Polish Ministry of Science and Higher Education grant 2 P05D 05227. The study was supported by statutory funds from the Jerzy Kukuczka Academy of Physical Education in Katowice. The authors gratefully acknowledge Professor Andrzej Markiewicz for contributing to the general conception of the study.

References

[1] BACKHAUSEN M., DAMM P., BENDIX J., TABOR A., HEGAARD H., *The prevalence of sick leave: Reasons and associated predictors – A survey among employed pregnant women*, Sex Reprod. Healthc., 2018, 15, 54–61.

[2] BETSCH M., WEHRLE R., DOR L., RAPP W., JUNGBLUTH P., HAKIMI M., WILD M., *Spinal posture and pelvic position during pregnancy: A prospective rasterstereographic pilot study*, Eur. Spine J., 2015, 24, 1282–1288.

[3] BIVIÁ-ROIG G., LISÓN J.F., SÁNCHEZ-ZURIAGA D., *Changes in trunk posture and muscle responses in standing during pregnancy and postpartum*, PLoS ONE, 2018, 13 (3), e0194853.

[4] COLDRON Y., STOKES M.J., NEWHAM D.J., COOK K., *Postpartum characteristics of rectus abdominis on ultrasound imaging*, Man. Ther., 2008, 13, 112–121.

[5] CZAPROWSKI D., PAWŁOWSKA P., GĘBICKA A., SITARSKI D., KOTWICKI T., *Intra- and interobserver repeatability and reliability of the assessment of the anterio-posterior curvatures of the spine using Sanders digital inclinometer*, Ortop. Traumatol. Rehabil., 2012, 14, 145–154.

[6] FRANKLIN M.E., CONNER-KERR T., *An Analysis of Posture and Back Pain in the First and Third Trimesters of Pregnancy*, J. Orthop. Sports Phys. Ther., 1998, 28, 133–138.

[7] FRIES E.C., HELLEBRANDT F.A., *The influence of pregnancy on the location of the center of gravity, postural stability, and body alignment*, Am. J. Obstet. Gynecol., 1943, 46, 374–380.

[8] GEIGER E.V., MÜLLER O., NIEMEYER T., KLUBA T., *Adjustment of pelvispinal parameters preserves the constant gravity line position*, Int. Orthop., 2007, 31, 253–258.

[9] GUTKE A., OSTGAARD H.C., OBERG B., *Predicting persistent pregnancy-related low back pain*, Spine, 2008, 20, 386–393.

[10] HAWRYLAK A., CHROMIK K., RATAJCZAK B., BARCZYK-PAWELEC K., DEMCZUK-WŁODARCZYK E., *Spinal range of motion and plantar pressure in sport climbers*, Acta Bioeng. Biomech., 2017, 19, 169–173.

[11] JENSEN R.K., DOUCET S., TREITZ T., *Changes in segment mass and mass distribution during pregnancy*, J. Biomech., 1996, 29, 251–256.

[12] KOUHKAN S., RAHIMI A., GHASEMI M., NAIMI S.S., AKBARZADEH BAGHBAN A., *Postural changes during first pregnancy*, Br. J. Med. Med. Res., 2015, 7, 744–753.

[13] MACINTYRE N.J., BENNETT L., BONNYMAN A.M., STRATFORD P.W., *Optimizing reliability of digital inclinometer and flexicurve ruler measures of spine curvatures in postmenopausal women with osteoporosis of the spine: An illustration of the use of generalizability theory*, ISRN Rheumatol., 2011, ID 571698, 8 pp., DOI:10.5402/2011/571698.

[14] MACKENZIE J., MURRAY E., LUSHER J., *Women's experiences of pregnancy related pelvic girdle pain: A systematic review*, Midwifery, 2018, 56, 102–111.

[15] MENS J.M., POOL-GOUDZWAARD A., STAM H.J., *Mobility of the pelvic joints in pregnancy-related lumbopelvic pain: a systematic review*, Obstet. Gynecol. Surv., 2009, 64, 200–208.

[16] MIESZAŁA W., DEMCZUK-WŁODARCZYK E., CHROMIK K., HAWRYLAK A., MAŁACHOWSKA-SOBIESKA M., *Examining relationships of the anterior pelvic tilt angle with the anterior-posterior curvatures and elongation of the spine*, Acta Bioeng. Biomech. 2019, 21, 37–44.

[17] MOGREN I.M., *Low back pain and pelvic pain during pregnancy: Prevalence and risk factors*, Spine, 2005, 30, 983–991.

[18] MOORE K., DUMAS G.A., REID J.G., *Postural changes associated with pregnancy and their relationship with low-back pain*, Clin. Biomech., 1990, 5, 169–174.

[19] MORINO S., ISHIHARA M., UMEZAKI F., HATANAKA H., IIJIMA H., YAMASHITA M., AOYAMA T., TAKAHASHI M., *Low back pain and causative movements in pregnancy: a prospective cohort study*, BMC Musculoskelet. Disord., 2017, 18, 416.

[20] NAKIPOGLU G.F., KARAGÖZ A., ÖZGIRGIN N., *The Biomechanics of the Lumbosacral Region In Acute And Chronic Low Back Pain Patients*, Pain Physician, 2008, 11, 505–511.

[21] OKANISHI N., KITO N., AKIYAMA M., YAMAMOTO M., *Spinal curvature and characteristics of postural change in pregnant women*, Acta Obstet. Gynecol. Scand., 2012, 91, 856–861.

[22] OPALA-BERDZIK A., BACIK B., CIEŚLIŃSKA-ŚWIDER J., PLEWA M., GAJEWSKA M., *The influence of pregnancy on the location of the center of gravity in standing position*, J. Hum. Kinet., 2010, 26, 5–11.

[23] OPALA-BERDZIK A., BŁASZCZYK J.W., BACIK B., CIEŚLIŃSKA-ŚWIDER J., ŚWIDER D., SOBOTA G., MARKIEWICZ A., *Static Postural Stability in Women during and after Pregnancy: A Prospective Longitudinal Study*, PLoS ONE, 2015, 10 (6), e0124207.

[24] OPALA-BERDZIK A., BŁASZCZYK J.W., ŚWIDER D., CIEŚLIŃSKA-ŚWIDER J., *Trunk forward flexion mobility in reference to postural sway in women after delivery: A prospective longitudinal comparison between early pregnancy and 2- and 6-month postpartum follow-ups*, Clin. Biomech., 2018, 56, 70–74.

[25] OSTGAARD H.C., ANDERSSON G.B., SCHULTZ A.B., MILLER J.A., *Influence of some biomechanical factors on low-back pain in pregnancy*, Spine, 1993, 18, 61–65.

[26] RASMUSSEN K.M., CATALANO P.M., YAKTINE A.L., *New guidelines for weight gain during pregnancy: what obstetrician/gynecologists should know*, Curr. Opin. Obstet. Gynecol., 2009, 21, 521–526.

[27] SCHRÖDER G., KUNDT G., OTTE M., WENDIG D., SCHOBER H.C., *Impact of pregnancy on back pain and body posture in women*, J. Phys. Ther. Sci., 2016, 28, 1199–1207.

[28] TLAPAKOVA E., JELEN K., MINARIKOVA M., *The relationship between pelvis inclination, exercise and low back pain (LBP) during pregnancy*, Acta Univ. Palacki. Olomuc., Gymn., 2011, 41, 15–21.

[29] VAZ G., ROUSSOULY P., BERTHONNAUD E., DIMNET J., *Sagittal morphology and equilibrium of pelvis and spine*, Eur. Spine J., 2002, 11, 80–87.

[30] VERMANI E., MITTAL R., WEEKS A., *Pelvic girdle pain and low back pain in pregnancy: A review*, Pain Pract., 2010, 10, 60–71.

[31] WANG S.M., DEZINNO P., MARANETS I., BERMAN M.R., CALDWELL-ANDREWS A.A., KAIN Z.N., *Low back pain during pregnancy: Prevalence, risk factors and outcomes*, Obstet. Gynecol., 2004, 104, 65–70.

[32] WHITCOME K.K., SHAPIRO L.J., LIEBERMAN D.E., *Fetal load and the evolution of lumbar lordosis in bipedal hominis*, Nature, 2007, 450, 1075–1078.