Spine
SPINE Volume 44, Number 2, pp E67–E73

ANATOMY

主論文

The Association of Variations in Hip and Pelvic Geometry With Pregnancy-Related Sacroiliac Joint Pain Based on a Longitudinal Analysis

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Study Design. Cross-sectional study using radiological measurements and longitudinal data analysis.

Objective. We aim to explore hip/pelvic geometry on anteroposterior radiographs and examine if such parameters are associated with clinical symptoms.

Summary of Background Data. Pregnancy-related sacroiliac joint pain is a common disease and is responsible to the disability of daily activities. The etiology is likely to be correlated with the biomechanical factors which are determined by trunk load and hip/pelvic geometry. Previous studies have already found the association between symptoms and weight increase during pregnancy. However, the relationship between bony anatomy and pregnancy-related sacroiliac joint pain remains unknown.

Methods. In total, 72 women were included in the final analysis. In pregnant women with self-reported sacroiliac joint pain, pain scores at 12, 24, 30, and 36 weeks of pregnancy were recorded and included in a mixed-effect linear regression model as dependent variables. The radiological measurements were included as independent variables. Furthermore, to investigate the relationship between hip/pelvic geometry and the activity-specific nociceptive phenomenon, the radiological measurements between patients with and without activity-induced pain were compared using a binominal logistic regression model.

Results. The relative bilateral is chial tuberosity distance (betta coefficient: 0.078; $P=0.015$) and the relative bilateral femoral head length (betta coefficient: 0.011; $P=0.028$) showed significant interactions with the slope of pain scores. Moreover, women whose pain exacerbate during prolonged walking had a higher odds in hip/pelvic geometry of the bilateral ischial tuberosity distance (odds ratio [OR]: 1.12; $P=0.050$) and the bilateral femoral head length (OR: 1.16; $P=0.076$) with approximately significant *P*-value.

Conclusion. These data indicate hip/pelvic anatomical variations are associated with the degree of pain increasing and the activity-specific pain during pregnancy, which may help to have further understanding on the biomechanical factor in developing pregnancy-related sacroiliac joint pain.

Key words: biomechanics, mixed-effects models, pelvic geometry, pelvic girdle pain, radiographic measurements, sacroiliac joint.

Level of Evidence: 3

Spine 2019;44:E67–E73

Pregnancy-related pelvic girdle pain (PGP) has been reported to be a common disorder with a prevalence that varies from 4% to 76%.[1] PGP is likely to emerge during the first trimester of pregnancy and may attain peak values between 24 and 36 weeks of gestation.[2–4] PGP often contributes to disabilities and limitations in daily activities, such as the ability to arise from a seated position, turning over on a bed, prolonged walking, and sitting or standing.[5–8] Furthermore, it can lead to restrictions in lumbar spine movement.[9] The exact definition of PGP has yet to be definitively determined, and terminologies, such as "back pain,"[10] "pelvic pain,"[11] "lumbopelvic pain,"[12] "low back pain and pelvic pain,"[13] "pelvic girdle relaxation,"[14] and "posterior pelvic pain,"[15] have all been interchangeably used in relevant studies from the 1990s to the 2010s. According to the latest European guidelines,[1] the occurrence

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Acknowledgment date: March 14, 2018. First revision date: June 7, 2018. Acceptance date: June 11, 2018.

The manuscript submitted does not contain information about medical device(s)/drug(s).

No funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000002774

of PGP has been related to two main symptom profiles: (1) pain radiating into the posterior iliac crest or gluteal fold, and (2) pain occurring in conjunction with pain at the symphysis pubis. Therefore, there has been a tendency to investigate sacroiliac joint (SIJ) pain and pubic symphysis pain separately in recent studies.

The etiology of pregnancy-related SIJ pain remains unknown. Plausible explanations have been focused on hormonal and biomechanical factors, which are responsible for the laxity of the ligaments of the SIJ. However, the reported effects of relaxin on the development of SIJ pain is still controversial,[14,16–18] which made us question whether the biomechanical factors is the major determinants of this condition. The SIJ complex is composed of a strong, bony, interlocking ligamentous system, and compressive corset muscle groups that provide stability against SIJ shear forces. A dysfunction in any of these components could lead to abnormal SIJ motion,[19] which might result in passive strain on the surrounding viscoelastic ligaments, ultimately leading to a triggering of the nociceptive elements.[20–22]

An increase in the SIJ shear forces is another risk factor for PGP. Clinically, both pre-pregnancy obesity[23] and an increase in the body mass index (BMI) during the peripartum period[13,24–26] have been closely linked to the development of SIJ symptoms. A previous study[27] proposed a biomechanical assumption that owing to the force of gravity and that of the hip joint braced force do not act along the same vector, resulting in a shear forcing acting on the SIJ. From an anteroposterior view, the larger lever arm generated by the supportive forces acting on the pelvis was considered to be associated with a greater shear force, and therefore may be a factor in the development of SIJ pain. However, the relationship between the hip/pelvic bony anatomy and pregnancy-related SIJ pain has, to our knowledge, never been evaluated in any clinical study.

The geometry of the hip and pelvis as determined using radiography was confirmed to be an ancient, but effective method in evaluating anatomical bony characteristics. This method has already been widely used for predicting the potential risk factors for lateral tibiofemoral osteoarthritis.[28,29] We aim to examine these radiological measurements in a similar way to assess the hip and pelvis anatomy, and their association with the development of SIJ pain.

METHODS

Ethical Approval

The ethics committee of Kyoto University approved the study (approval number E2076 2014/03/06), and written informed consent was acquired from all participants prior to recruitment.

Enrollment of Participants

Patients were enrolled from two community obstetrical clinics located in the ward of Midori and Moriyama, Nagoya, Japan. All participants in the current study met the following inclusion criteria: (1) self-reported SIJ pain from the 12th to the 36th week of pregnancy, (2) radiographic examination performed immediately postpartum (within 12 h). Patients were excluded from the study if had: (1) a history of lasting lumbopelvic dysfunction before pregnancy; (2) treatment in any pharmaceutical or physiotherapy prescription to ease symptoms during the study period; (3) any visceral disorder which could interfere with the evaluation of the pain. A flow chart (Figure 1) shows the enrollment process of participants.

Outcome Measurements

Procedures

All participants attended the initial clinical examination in the first trimester, and three follow-up examinations at 24, 30, and 36 weeks of gestation. Data on ages and heights were self-reported by the participants at the first visit. Weight, degree of pain, and the pelvic belt-use hours per

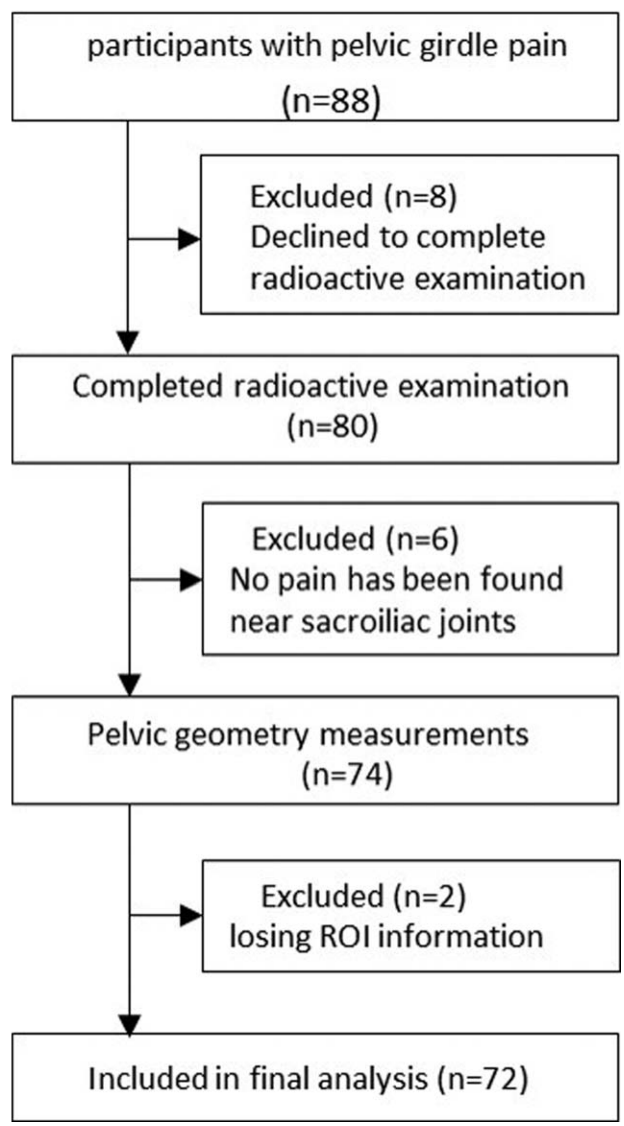

Figure 1. Study population flow chart. ROI indicates region of interest.

week, were evaluated at each of the examination. For the participants who had pelvic girdle pain during pregnancy and consented to the x-ray examination, pelvic radiographs were taken immediately after delivery. All measurements were obtained by trained obstetricians or maternity assistants with abundant clinical experience.

Pain Evaluation

For all participants, pain in the bilateral sacroiliac joints was assessed using an 11-point (0–10, natural numbers) numeric rating scale (NRS) score, mean value of both sides was recorded in representative of the comprehensive degree of the SIJ pain. To acquire more detailed information about the pain experienced in daily living circumstances, the NRS score questionnaire addressed each of the specific activities that exacerbated pain most frequently in the participants. The level of pain experienced during the four activities including: rising from a seated position, prolonged sitting, prolonged standing, and prolonged ambulation, were recorded at every clinical interview, and were introduced in the subsequent subgroup analysis. The participants that reported positive symptoms at one or more time-points were categorized as the subjects with "task-specific SIJ pain exacerbation."

Radiological Evaluation

Anteroposterior pelvic radiographs were taken in the standing position within 12 hours of delivery. Participants were required to maintain an upright position while the x-ray were obtained. The specific parameters of each x-ray process included the passage of an irradiating beam, perpendicular to the frontal plane of the body and parallel to the floor, with a distance to the x-ray film being fixed at 0.3 m. The anatomical characteristics of the hip and pelvic radiographs were measured using methods described in previous research.[28] The measurements included the pelvic width (PW), the femoral head to femoral head length (FH–FH), and the distance between the bilateral ischial tuberosities (IT–IT) (Figure 2). FH–FH and IT–IT distances represented the body weight lever arm in the standing and sitting positions, respectively, and the PW was used for normalization by transforming each of these measurements into percentages. All radiographs were assessed by one examiner, who was blinded to each subject's pain information. The intra-class correlation coefficient (ICC) for intra-observer variability was calculated based on the re-measured value of 30 randomly selected radiographs 3 months after the first evaluation. Each parameter illustrated excellent reliability with ICC > 0.9 (Supplementary Table 1, http://links.lww.com/BRS/B370).

Statistical Analysis

Data analysis was performed using SPSS (version 22.0; IBM Corporation, Armonk, NY). To evaluate the differences in time-dependent changes of the NRS scores during pregnancy among individuals with different anatomical characteristics, a longitudinal data analysis was performed using mixed-effect regression models with random intercepts and slopes. We checked the interaction between the hip/pelvic geometry and the time variables to assess the effects on the slope of ongoing SIJ pain in pregnancy. For the hip/pelvic geometry, the ratios of FH–FH/PW, IT–IT/PW, and IT–IT/FH–FH were used as the independent variables; for the time variables, the NRS scores at 12, 24, 30, and 36 weeks were included in the model.

Figure 2. Radiological assessment of hip/pelvic geometry. FH–FH indicates femoral head to femoral head length; IT–IT, length between bilateral ischial tuberosities; the mid line was drawn through the L5 spinous process to the pubic symphysis; PW, pelvic width, the distance between the bilateral edges of iliac crests.

For the pain assessments, subject variations could be generated by diversity in psychological status, pain threshold, or cognitive differences among participants,[26,30,31] which could lead to subjectively biased pain scores. The mixed-effect regression model can remove the effects generated by subject variations, and will allow the analysis to be focused on the within-subject variations by modeling individuality, instead of only comparing pain scores at a certain point during the pregnancy.

Binomial logistic regression was used to examine the association between hip/pelvic geometry and the pain experienced during daily activities. We included Yes/No pain exacerbating answers regarding the four daily activities as the outcome (0 = no 1 = yes), and continuous parameters of FH−FH/PW, IT−IT/PW, and IT−IT/FH−FH as the independent variables. The associations of radiological assessments with activity-specific pain were expressed using ORs with 95% CIs.

Covariates for adjustments were chosen *a priori* based on clinical experiences and previous studies. For both the mixed-effect regression and the binomial logistic regression analyses, the variables of age,[32] BMI,[13,24,25] and pelvic belt equipping hours,[19,33,34] were included in the models. *P*-values <0.05 were considered to be statistically significant.

RESULTS

A total of 72 women (aged 24−41 yr) were included in the data analysis. Table 1 summarized the demographic characteristics for each outcome measurement.

Table 2 demonstrates the results of the mixed linear regression model. The differences in the regression slope of the NRS scores among individuals with different hip/pelvic geometries were calculated by checking the interaction between the measurements and the time variables. The positive beta (β) coefficient represented the average increment in the slope per one unit (%) increase in the pelvic measurements. The ratio parameters of FH−FH/PW (β coefficient: 0.011, 95% CI: [0.0012−0.020]; $P = 0.028$) showed a significantly interactive effect on the slope of the NRS scores from the 12th to the 36th week of gestation, and the higher percentages in the IT-IT/PW (β coefficient: 0.078, 95% CI: [0.0015−0.014]; $P = 0.015$) were also significantly associated with a greater slope. All analyses were conducted after adjustments for age, BMI, and pelvic belt equipping hours were made.

The correlations between task-specific pain and the pelvic anatomical measurements were analyzed using binominal logistic regression (Table 3). Although there were no statistically significant results, the percentage indicators of FH−FH/PW (OR: 1.16, 95% CI: 0.99−1.36; $P = 0.076$) and IT-IT/PW (OR: 1.12, 95% CI: 0.99−1.26; $P = 0.050$) were associated with a higher odds ratio with an approximately significant *P*-values in patients who had exacerbations of pain during periods of prolonged walking after adjusting for all covariates. In addition, participants who had pain exacerbations when rising from a seated position had a lower odds ratio in both the IT-IT/PW (OR: 0.92, 95% CI: 0.83−1.01; $P = 0.091$) and the IT−IT/FH−FH (OR: 0.92, 95% CI: 0.84−1.01; $P = 0.079$) groups. However, there was no even

TABLE 1. Demographic Variables for Each of the Outcome Measurements (n = 72)

Variables	Value (95% CI)
Age, yr	32.0 (30.9, 33.1)
Height, m	1.58 (1.57, 1.60)
Fetus weight, kg	3.08 (2.99, 3.16)
Pelvic belt, no [%]*	25 [34.7]
Pelvic belt, h/wk	11.5 (4.90, 18.1)
Pelvic width (PW), mm	320.0 (314.9, 325.2)
FH−FH, mm	209.1 (206.5, 211.8)
IT−IT, mm	129.1 (126.0, 132.1)
FH/PW ratio, %	65.5 (64.7, 66.3)
IT/PW ratio, %	40.5 (39.3, 41.8)
FH/IT ratio, %	61.8 (60.4, 63.2)

	12 Weeks	24 Weeks	30 Weeks	36 Weeks
Weight, kg	53.4 (51.5, 55.4)	57.1 (55.2, 59.0)	59.7 (57.8, 61.6)	62.3 (60.3, 64.1)
Body mass index (BMI), kg/m^2**	21.4 (20.6, 22.1)	22.8 (22.1, 23.5)	23.9 (23.2, 24.6)	24.9 (24.2, 25.6)
NRS score, points	1.97 (1.38, 2.55)	3.10 (2.47, 3.73)	3.60 (2.91, 4.29)	3.91 (3.18, 4.64)

The number and percentage of pelvic belt equipping participants.

**Maximum values of BMI have been confirmed at 36 weeks gestation for every participant, hence, the BMIs at 36 weeks were included in the statistical analysis as covariates.*

BMI indicates body mass index; FH−FH, length between bilateral femoral heads; IT−IT, length between bilateral ischial tuberosity; NRS, numeric rating scale; PW, pelvic width; 95% CI, 95% confidence interval.

TABLE 2. Results of the Mixed-Effect Linear Regression Model Showing an Interaction Between Radiological Measurements and Slopes of NRS Scores (n = 72)

Variables	Beta Coefficient (95% CI)*	*P*-Value
FH–FH/PW, %	**0.011 (0.0012, 0.020)**	**0.028**
IT–IT/PW, %	**0.078 (0.0015, 0.014)**	**0.015**
IT–IT/FH–FH, %	0.0053 (−0.000015, 0.011)	0.051

The interaction between the radiological measurements and the slopes of the NRS scores was calculated. Longitudinal time variables of NRS scores at the 12, 24, 30, and 36 weeks gestation were included as the dependent variables. Hip/pelvic geometry and other confounders including age, body mass index, and pelvic belt equipping hours, were transformed into longitudinal data first, and then included as the independent variables.

*Beta coefficient indicates the average increment on the slope of the NRS scores per unit (mm or %) increase in the variables of hip/pelvic geometry.

FH–FH indicates length between bilateral femoral heads; IT–IT, length between bilateral ischial tuberosity; NRS, numeric rating scale; PW, pelvic width; 95% CI, 95% confidence interval.

Variables in boldface indicating the significance of P-value < 0.05.

approximately significant relationship to pelvic geometry was found in the prolonged sitting or standing tasks.

DISCUSSION

The plausible explanation for joint instability due to the laxity of the ligamentous system is based on a combination of factors comprising accumulated mechanical stress and insufficient self-bracing effects provided by the lumbar corset muscles. Meanwhile, the mechanical stress provided by shear forces could be caused solely by overweight, or it could have some connections with hip/pelvic anatomy. The current research focused on the prospects of latter and found by indirect but supportive results. The variables of FH–FH/PW were positively associated with the slopes of the NRS regression lines during pregnancy, which indicated that women with relatively wider femoral head to femoral head lengths were more susceptible to developing SIJ pain. Similar to the simplified loading mode of the pelvis raised by Snijders,[27] body weight transduced through the vertebrate to the sacrum can be allocated to the bilateral lower limbs, and the shear force around the SIJ was closely associated with the lever arm generated by the supportive force at the hip joint. Although it was impossible to spot the joint center accurately on the anteroposterior x-ray plain, based on our results, we concluded that a larger value of FH–FH/PW suggested a larger lever arm that could generate higher shear forces in the vicinity of SIJ.

Interestingly, we also found that the width between the bilateral ischial tuberosities exhibited a positive correlation with the slope of time-varying NRS. We present two possible explanations with regard to these results: first, the amount of time spent in sitting comprises a large proportion of one's daily life, especially among urban non-physical workers. While seated, the body weight is apt to be transduces through the ischial tuberosity rather than the hip joint. Therefore, the shear forces generated by the ischial tuberosity lever arm were considered to have an important role in the development of SIJ pain. For another possible explanation, we found the FH–FH/PW and IT–IT/PW displayed a positive correlation (supplementary Table 2, http://links.lww.com/BRS/B370). It is possible that the women with wider bilateral ischial tuberosity lengths also have the anatomical features of longer femoral heads distances.

Binominal regression was used to evaluate the association between pelvic anatomy and the nociceptive phenomenon, which is described as pain exacerbations experienced during weight-bearing activities.[35] Based on our results, higher odds ratios of FH–FH/PW and IT–IT/PW were demonstrated in women whose pain was exacerbated during prolonged periods of walking, but it was not statistically

TABLE 3. Results of Binominal Logistic Regression Showing the Relationships Between Radiological Measurements and Task-Specific SIJ Pain (n = 72)

Variables	Participant's Pain was Exacerbated When Rising from a Seated Position (Yes n = 31)		Participant's Pain was Exacerbated With Prolonged Sitting (Yes n = 20)		Participant's Pain was Exacerbated With Prolonged Standing (Yes n = 14)		Participant's Pain was Exacerbated With Prolonged Walking (Yes n = 19)	
	OR (95% CI)	*P*-Value	OR (95% CI)	*P*-Value	OR (95% CI)	*P*-Value	OR (95% CI)	*P*-Value
FH–FH/PW, %	0.93 (0.81, 1.08)	0.359	0.99 (0.84, 1.16)	0.860	0.96 (0.79, 1.17)	0.664	1.16 (0.99, 1.36)	0.076
IT–IT/PW, %	0.92 (0.83, 1.01)	0.091	1.03 (0.92, 1.15)	0.610	1.03 (0.91, 1.17)	0.624	1.12 (0.99, 1.26)	0.050
IT–IT/FH–FH, %	0.92 (0.84, 1.01)	0.079	1.04 (0.94, 1.15)	0.411	1.06 (0.94, 1.19)	0.368	1.09 (0.98, 1.20)	0.110

FH–FH indicates length between bilateral femoral heads; IT–IT, length between bilateral ischial tuberosities; OR, odds ratio; PW, pelvic width; SIJ, sacroiliac joint; 95% CI, 95% confidence interval OR (95% CI) for hip/pelvic geometry between individuals with or without a task-specific pain exacerbation was calculated using statistical software, the task-specific pain exacerbation was included as the binary outcome, and the continuous variables of radiological measurements were included as the predictors. Participants reporting nociceptive symptoms at least once during the clinical interview period is indicated above by a ''Yes'' response. Age, body mass index, and pelvic belt equipping time were also included for adjustment.

significant ($P = 0.076$ and 0.050). Furthermore, we assumed that the instantaneous increasing of the lever arm force (changes of force bearing point from IT to FH) should be associated with SIJ pain when rising from a seated position, and the results suggested that participants with nociceptive symptoms of aggravated pain had lower odds of IT–IT/FH–FH with an approximately significant *P*-value of 0.079. On the other hand, no significant or approximately significant differences between the groups were found during prolonged sitting or standing. The results of pain exacerbations associated with dynamic movements were a much better fit for our prediction than the results obtained in static positions. This indicated that the ligamentous laxity-induced hypermobility of the SIJ may be a concurrent trigger in the development of pain. In future studies, NRS scores in different activities should be divided into subcategories and be analyzed separately.

The current study has some limitations. First, as previous research described, both the angle and the friction of the articular contact area could affect the shear forces between the sacrum and the iliac.[36] We assumed these parameters would be similar among the participants because of the difficulty in assessing the real structures of the SIJ. Second, the diameters and circumferences of the pelvic outlet have been confirmed to exhibit slight changes from pre- to post-parturition, using several magnetic resonance imaging studies conducted for comparisons.[37,38] Thus, it is conceivable that pelvic geometry is subject to change during pregnancy and delivery. Therefore, the data we present may not be completely consistent with the real-time geometry of the corresponding period. Third, we only collected self-reported NRS without pain-triggering maneuver tests, which might elude some mild SIJ pain cases. Fourth, despite the fact that the intra-observer ICC was good, the radiological evaluations could be a potential source of bias, caused by uncontrollable factors such as slight pelvic rotations.[39] Fortunately, the bilateral symmetry of each of the measurements was confirmed, which implies that our outcomes should not be affected too much by the pelvic rotation. Fifth, the limited sample size restricted the numbers of concurrent covariates. According to the previous studies, a history of pregnancy-related pelvic pain,[5,9] primiparity,[23] transversely oriented muscle weakness,[40] and strenuous work or exercise,[41] could also be confounders of SIJ pain. In addition, considering the relatively small beta coefficients and OR in our results, recruitments in the future should include participants with a wider range of anatomical variations. Finally, due to the limitation of local health insurance, only the participants who were diagnosed with pelvic girdle pain underwent x-ray examinations, which led to an imbalance in the amount of radiographic information obtained among people with and without SIJ pain, because the majority of participants had multi-regional (groin or pubic symphysis) symptoms.

In conclusion, women with relatively wider bilateral femoral heads or ischial tuberosity lengths are likely to be predisposed to a higher degree of SIJ pain during pregnancy. Furthermore, the presence of nociceptive SIJ pain in the daily activities as prolonged walking or rising from seated position, was associated with hip/pelvic measurements with approximately significant *P*-values. These results indicated that the bony anatomy of the hips and pelvis may be correlated to the SIJ moment arm, which could help to explain the biomechanical factors involved in the development of SIJ pain.

➢ Key Points

- ❑ This study reviewed the relationship between the bony hip and pelvic geometry and pregnancy-related sacroiliac joint pain; by taking anatomical measurements of length on anteroposterior radiographs.
- ❑ We conducted an analysis of the longitudinal data of the sacroiliac joint pain scores during pregnancy using mixed model linear regression; and found that the slopes of pain scores in-patients are associated with hip/pelvic biomechanical factors.
- ❑ We also found that nociceptive sacroiliac joint pain experienced during dynamic activities is likely associated with hip/pelvic anatomical variations, with approximately significant *P*-value ($0.05 < P$-value < 0.10).

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References

1. Vleeming A, Albert HB, Ostgaard HC, et al. European guidelines for the diagnosis and treatment of pelvic girdle pain. *Eur Spine J* 2008;17:794–819.
2. Owens K, Pearson A, Mason G. Symphysis pubis dysfunction–a cause of significant obstetric morbidity. *Eur J Obstet Gynecol Reprod Biol* 2002;105:143–6.
3. Saugstad LF. Persistent pelvic pain and pelvic joint instability. *Eur J Obstet Gynecol Reprod Biol* 1991;41:197–201.
4. Depledge J, McNair PJ, Keal-Smith C, et al. Management of symphysis pubis dysfunction during pregnancy using exercise and pelvic support belts. *Phys Ther* 2005;85:1290–300.
5. Wu WH, Meijer OG, Uegaki K, et al. Pregnancy-related pelvic girdle pain (PPP), I: Terminology, clinical presentation, and prevalence. *Eur Spine J* 2004;13:575–89.
6. Larsen EC, Wilken-Jensen C, Hansen A, et al. Symptom-giving pelvic girdle relaxation in pregnancy. I: Prevalence and risk factors. *Acta Obstet Gynecol Scand* 1999;78:105–10.
7. Aslan E, Fynes M. Symphysial pelvic dysfunction. *Curr Opin Obstet Gynecol* 2007;19:133–9.
8. Glinkowski WM, Tomasik P, Walesiak K, et al. Posture and low back pain during pregnancy - 3D study. *Ginekol Pol* 2016;87: 575–80.
9. Ostgaard HC, Roos-Hansson E, Zetherstrom G. Regression of back and posterior pelvic pain after pregnancy. *Spine (Phila Pa 1976)* 1996;21:2777–80.
10. Kristiansson P, Svärdsudd K, von Schoultz B. Serum relaxin, symphyseal pain, and back pain during pregnancy. *Am J Obstet Gynecol* 1996;175 (1 pt 1):1342–7.

11. Damen L, Buyruk HM, Guler-Uysal F, et al. Pelvic pain during pregnancy is associated with asymmetric laxity of the sacroiliac joints. *Acta Obstet Gynecol Scand* 2001;80:1019–24.
12. Al-Sayegh NA, Salem M, Dashti LF, et al. Pregnancy-related lumbopelvic pain: prevalence, risk factors, and profile in Kuwait. *Pain Med* 2012;13:1081–7.
13. Mogren IM, Pohjanen AI. Low back pain and pelvic pain during pregnancy: prevalence and risk factors. *Spine (Phila Pa 1976)* 2005;30:983–91.
14. Hansen A, Jensen DV, Larsen E, et al. Relaxin is not related to symptom-giving pelvic girdle relaxation in pregnant women. *Acta Obstet Gynecol Scand* 1996;75:245–9.
15. Ostgaard HC, Andersson GB, Schultz AB, et al. Influence of some biomechanical factors on low-back pain in pregnancy. *Spine (Phila Pa 1976)* 1993;18:61–5.
16. Aldabe D, Ribeiro DC, Milosavljevic S, et al. Pregnancy-related pelvic girdle pain and its relationship with relaxin levels during pregnancy: a systematic review. *Eur Spine J* 2012;21:1769–76.
17. Hainline B. Low back pain. *Adv Neurol* 2002;90:9–23.
18. Borg-Stein J, Dugan SA. Musculoskeletal disorders of pregnancy, delivery and postpartum. *Phys Med Rehabil Clin N Am* 2007;18:459–76; ix.
19. Flack NA, Hay-Smith EJ, Stringer MD, et al. Adherence, tolerance and effectiveness of two different pelvic support belts as a treatment for pregnancy-related symphyseal pain - a pilot randomized trial. *BMC Pregnancy Childbirth* 2015;15:36.
20. Szadek KM, Hoogland PV, Zuurmond WW, et al. Nociceptive nerve fibers in the sacroiliac joint in humans. *Reg Anesth Pain Med* 2008;33:36–43.
21. Szadek KM, Hoogland PV, Zuurmond WW, et al. Possible nociceptive structures in the sacroiliac joint cartilage: an immunohistochemical study. *Clin Anat* 2010;23:192–8.
22. Fortin JD, Washington WJ, Falco FJ. Three pathways between the sacroiliac joint and neural structures. *AJNR Am J Neuroradiol* 1999;20:1429–34.
23. Biering K, Nohr EA, Olsen J, et al. Pregnancy-related pelvic pain is more frequent in women with increased body mass index. *Acta Obstet Gynecol Scand* 2011;90:1132–9.
24. Mogren IM. BMI, pain and hyper-mobility are determinants of long-term outcome for women with low back pain and pelvic pain during pregnancy. *Eur Spine J* 2006;15:1093–102.
25. Yosef A, Allaire C, Williams C, et al. Multifactorial contributors to the severity of chronic pelvic pain in women. *Am J Obstet Gynecol* 2016;215:760.e1–760.e14.
26. Kovacs FM, Garcia E, Royuela A, et al. Prevalence and factors associated with low back pain and pelvic girdle pain during pregnancy: a multicenter study conducted in the Spanish National Health Service. *Spine (Phila Pa 1976)* 2012;37:1516–33.
27. Snijders CJ, Vleeming A, Stoeckart R. Transfer of lumbosacral load to iliac bones and legs. Part 1: Biomechanics of self-bracing of the sacroiliac joints and its significance for treatment and exercise. *Clin Biomech (Bristol, Avon)* 1993;8:285–94.
28. Boissonneault A, Lynch JA, Wise BL, et al. Association of hip and pelvic geometry with tibiofemoral osteoarthritis: multicenter osteoarthritis study (MOST). *Osteoarthritis Cartilage* 2014;22: 1129–35.
29. Weidow J, Mars I, Karrholm J. Medial and lateral osteoarthritis of the knee is related to variations of hip and pelvic anatomy. *Osteoarthritis Cartilage* 2005;13:471–7.
30. Beales D, Lutz A, Thompson J, et al. Disturbed body perception, reduced sleep, and kinesiophobia in subjects with pregnancy-related persistent lumbopelvic pain and moderate levels of disability: an exploratory study. *Man Ther* 2016;21:69–75.
31. Chang HY, Jensen MP, Yang YL, et al. Risk factors of pregnancy-related lumbopelvic pain: a biopsychosocial approach. *J Clin Nursing* 2012;21:1274–83.
32. Gutke A, Ostgaard HC, Oberg B. Predicting persistent pregnancy-related low back pain. *Spine (Phila Pa 1976)* 2008;33: E386–93.
33. Sichting F, Rossol J, Soisson O, et al. Pelvic belt effects on sacroiliac joint ligaments: a computational approach to understand therapeutic effects of pelvic belts. *Pain Physician* 2014;17:43–51.
34. Mens JM, Damen L, Snijders CJ, et al. The mechanical effect of a pelvic belt in patients with pregnancy-related pelvic pain. *Clin Biomech (Bristol, Avon)* 2006;21:122–7.
35. Quadros AU, Pinto LG, Fonseca MM, et al. Dynamic weight bearing is an efficient and predictable method for evaluation of arthritic nociception and its pathophysiological mechanisms in mice. *Sci Rep* 2015;5:14648.
36. Pel JJ, Spoor CW, Pool-Goudzwaard AL, et al. Biomechanical analysis of reducing sacroiliac joint shear load by optimization of pelvic muscle and ligament forces. *Ann Biomed Eng* 2008;36:415–24.
37. Huerta-Enochian GS, Katz VL, Fox LK, et al. Magnetic resonance-based serial pelvimetry: do maternal pelvic dimensions change during pregnancy? *Am J Obstet Gynecol* 2006;194:1689–94; discussion 1694-5.
38. Michel SC, Rake A, Treiber K, et al. MR obstetric pelvimetry: effect of birthing position on pelvic bony dimensions. *AJR Am J Roentgenol* 2002;179:1063–7.
39. Bittersohl B, Freitas J, Zaps D, et al. EOS imaging of the human pelvis: reliability, validity, and controlled comparison with radiography. *J Bone Joint Surg Am* 2013;95:e58.
40. Gutke A, Ostgaard HC, Oberg B. Association between muscle function and low back pain in relation to pregnancy. *J Rehabil Med* 2008;40:304–11.
41. Juhl M, Andersen PK, Olsen J, et al. Psychosocial and physical work environment, and risk of pelvic pain in pregnancy. A study within the Danish national birth cohort. *J Epidemiol Community Health* 2005;59:580–5.