Pelvic asymmetry as a risk factor for nonspecific chronic low back pain

Qiuhua Yu
Sun Yat-sen University First Affiliated Hospital
Huanjie Huang
Sun Yat-sen University First Affiliated Hospital
Zhou Zhang
Sun Yat-sen University First Affiliated Hospital
Xiaoqian Hu
University of Hong Kong
Wenfeng Li
Sun Yat-sen University First Affiliated Hospital
Le Li
Sun Yat-sen University First Affiliated Hospital
Min Chen
Sun Yat-sen University First Affiliated Hospital
Zhenwen Liang
Jinan University First Affiliated Hospital
Wai Leung Ambrose Lo (ambroselo0726@outlook.com)
The First Affiliated Hospital, Sun Yat-sen University https://orcid.org/0000-0001-7350-2157
Chuhuai Wang
Sun Yat-sen University First Affiliated Hospital

Research article

Keywords: pelvic asymmetry, low back pain, photographic assessment, pelvic posture

Posted Date: February 28th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-15467/v1

Version of Record: A version of this preprint was published on September 5th, 2020. See the published version at https://doi.org/10.1186/s12891-020-03617-3.

Abstract

Background Empirical evidence that identifies the pelvic asymmetry in which movement plane that contribute to non-specific chronic low back pain (NCLBP) is currently lacking.

Objective To establish the reliability of the Global Postural System (GPS) in assessing pelvic asymmetry and identify the association between pelvic asymmetry parameters and the occurrence of NCLBP in young adults.

Design A cross-sectional, regression study.

Methods People who aged between 18 and 30 and were diagnosed with NCLBP were recruited. Healthy individuals who were matched for age, gender, and education level were recruited as controls and for the reliability analysis. Reliability was assessed by the ICC (3, k), standard error and minimal detectable difference. Bivariate correlation analysis and logistic regression analysis were used to determine the risk factors.

Results Twenty-eight healthy participants and 28 people with NCLBP were recruited. Moderate to excellent ICCs were observed for the inter-rater and intra-rater reliability of most postural parameters. The bivariate correlation analysis indicated that age, body mass index and pelvic asymmetry parameters were related to the occurrence of NCLBP. Pelvic angle asymmetry (odd ratio=1.17), and asymmetry of the distance between the posterior superior iliac spine and the floor (odd ratio=1.21) were significant risk factors of NCLBP.

Limitation This study did not explore the causal relationship between pelvic asymmetry in the sagittal plane/pelvic asymmetry in the transverse plane and the occurrence of NCLBP. The interpretation of the results may not be generalized beyond the sample population.

Conclusions The GPS is a reliable method to assess pelvic asymmetry in a clinical setting. The pelvic asymmetry parameters obtained from the GPS are likely to assist in the early identification of the potential occurrence of NCLBP.

1. Introduction

Low back pain (LBP) creates a substantial socioeconomic burden for individuals worldwide (1). The occurrence of LBP is approximately 14% and is increasing in the young adult population (1). Most people who experience LBP do not have an identifiable pathology or radiographic evidence of arthrogenic or discogenic changes in the spinal column. Thus, this pathological condition is often referred to as nonspecific LBP (2, 3). Pelvic asymmetry has been reported to be a potential contributor to the development of LBP and a primary source of pain (4, 5). To date, there is a lack of empirical evidence that identifies the movement plane in which pelvic asymmetry is a risk factor of LBP in the young adult population. Identification of the risk factors for LBP may assist in the early identification and prevention of chronic LBP.

Pelvic asymmetry refers to the asymmetrical alignment of the pelvic bone in the frontal plane (lateral pelvic tilt), sagittal plane (iliac anterior/posterior rotation asymmetry) (6), or transverse plane (pelvic axial rotation) (7, 8) relative to the vertical axis. The classic overload principle suggests that plastic changes in biological tissues occur when tissues are stressed beyond the normal stress level during tasks of daily living (9). A large number of studies have demonstrated asymmetrical tissue adaptations in bone and muscle girth in people who participate in sports that are predominantly unilateral (10–12). Therefore, directional asymmetry can be interpreted as the biological plastic changes that occur in response to biomechanical loading (13). Healthy individuals who have pelvic asymmetry may not always be symptomatic (6). However, it has been suggested that pelvic asymmetry may be related to the development of nonspecific chronic LBP (NCLBP), since lateral pelvic tilt is highly related to asymmetrical lumbar movement and places abnormal mechanical stresses on the body (2), which increases the strain on the soft tissues in the lumbar region (14). The abnormal stresses on the soft tissues subsequently contribute to the development of LBP (15).

In the last decade, several methods have been developed to perform accurate postural evaluations during standing. Technological advancements have enabled the use of highly reliable and easy-to-operate tools, such as X-ray scanners (16, 17) and computerized photographic systems (18), to assess postural asymmetry. X-ray imaging is the standard method of assessing spinal alignment because it provides clear images of anatomical landmarks. However, X-ray imaging is not preferred in clinical and research settings for routine procedures because X-ray imaging is associated with radiation emission. The use of computerized photographic systems that assess posture by the positions of anatomical landmarks is the recommended approach (18) because they are simple, noninvasive, affordable and free of radiation (18, 19).

Acceptable levels of reliability (18, 20) and validity (21) of the photographic assessment systems have been reported in previous studies. To date, there is a wide variety of systems that are available for assessments with different levels of reported reliability. Published studies assessing pelvic and lower extremity alignments mostly investigated intra-rater reliability but not interrater reliability (19, 22, 23). The Global Postural System (GPS) is a recently developed computerized photographic postural assessment system. The GPS hardware that comprises a digital camera, a frame with a ruler and a fixed platform that enables consistent landmark identification is advantageous compared to a traditional photographic system that comprises a single camera placed in front of the person being assessed. The reliability of the GPS to assess pelvic asymmetry is not available, and it is essential to establish its reliability before it is recommended for clinical use.

The present study first established the reliability of the GPS to assess pelvic asymmetry in healthy young adults in a clinical setting. The second aim of the study was to explore the association between pelvic asymmetry parameters and NCLBP occurrences using a binary logistic regression model to identify potential risk factors for NCLBP in young adults. The findings of the present study may assist with the early identification and subsequent prevention of NCLBP. It is hypothesized that the GPS is sufficiently reliable to assess pelvic postural asymmetry and that pelvic postural asymmetry is related to the occurrence of NCLBP.

2. Methods

2.1 Sample population

Participants were recruited from the staff and student populations of Sun Yat-sen University. The inclusion criteria for the NCLBP group were as follows: 1) age between 18 and 30; 2) diagnosis of NCLBP lasting more than 3 months; 3) pain score of 2 or greater on the numerical rating scale (NRS) in both static (i.e., lying, sitting, or standing) and dynamic situations (i.e., moving or walking); 4) no nerve root compression symptoms; and 5) no radiographic evidence of congenital anomalies of the lumbosacral region. The exclusion criteria for the NCLBP group were as follows: 1) scoliosis; 2) history of fracture or surgery in the pelvic or spinal area; 3) history of a neurological disorder, a mental disorder or regular medications; and 4) pregnancy. Healthy individuals who were matched for age, gender, and education level were recruited as controls.

2.2 Ethics

Ethical approval of this study was obtained from the First Affiliated Hospital at Sun Yat-sen University (ETHICS No. [2019]206). An information sheet was provided to all participants prior to enrolment of the study. Written informed consent was obtained from all of the participants.

2.3 Study settings and instruments

The present study was conducted in the postural examination room in the Rehabilitation Outpatient Department of the First Affiliated Hospital of Sun Yat-sen University. The bespoke GPS 5.0 software was adopted for photo acquisition and postural analysis. The GPS hardware comprised of two aluminium, vertical bars with rulers on the sides, a plumb line for postural reference, and an adjustable mirror on the top that was attached to a stable platform (Figure 1). Two reference lines and four footprints facing different directions were used to calibrate the platform and enable consistent positioning of the feet. To set the scale of the lines, the horizontal distance between two vertical lines on the frame with rulers was recorded as 40 cm. A 1-m-tall digital camera with 2 megapixels (Logitech Pro C920; Logitech, China) was positioned 2.5 m away from the participant. The participant stood barefoot on the platform in undergarments while his or her posture was captured by the digital camera.

2.4 Data collection procedure

Prior to commencing postural assessment, participants' characteristics, of age, gender, education level, medication status, history of NCLBP in the past year and time spent on general physical exercise per week, were recorded. The centres of the anatomical landmarks were first marked by the assessors using red stickers. The selected anatomical landmarks were the bilateral anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanter, tuberositas tibiae and midpoint of the patella. Postures were captured from the anterior, posterior and left/right lateral views (Figure 1). During the postural examination, participants were asked to keep their usual body posture with their eyes looking straight ahead.

Reliability

For within-day inter-rater reliability of the GPS, healthy participants received a postural assessment by two different testers separately (tester A and tester B) during the first visit. Each tester was required to identify the anatomical landmarks and apply the red sticker at the centre of each landmark. The sequence of assessments by the two testers was randomized. Tester A then repeated the postural assessment procedure one week later to establish the intra-rater reliability. The two testers were trained by an experienced therapist who was not directly involved in the study.

Insert Figure 1 Around Here

Pelvic postural assessment for the NCLBP group

Participants in the NCLBP group received the GPS assessment by tester A on one occasion. The pelvic postural parameters that were included in the data analysis were: 1) the left/right anterior pelvic tilt angle; 2) the left/right distance between the ASIS and the midline; 3) the left/right height of the ASIS from the platform; and 4) the left/right Q angle (see Figure 1). All of these parameters were calculated by the photo analyser module of GPS 5.0 software. Similar to the methods used by Gnat and Bialy (8), the pelvic asymmetry ratios of each parameter were calculated first by dividing the parameter of the left side by the parameter of the right side to obtain a relative ratio between the two sides. Then, 1 was subtracted from this ratio to normalize the ratio. The equation that was used to quantify pelvic asymmetry is as follows:

Asymmetry ratio (%)=| *(left pelvic postural parameter / right pelvic postural parameter) – 1* | x 100.

The pelvic asymmetry ratios that were calculated are: 1) the Q angle asymmetry ratio (QAR); 2) the height of the PSIS from the platform asymmetry ratio (PHAR); 3) the height of the PSIS from the platform asymmetry ratio (PDAR); 4) the height of the ASIS from the platform asymmetry ratio (AHAR); 5) the distance between the ASIS and the midline asymmetry ratio (ADAR); and 6) the pelvic tilt angle asymmetry ratio in the sagittal plane (PTAR).

2.5 Data analysis

All statistical analyses were conducted in SPSS ver 20.0 software (IBM SPSS Inc. Chicago, IL, USA). Statistical significance was set at $p < 0.050$. The sample characteristics were analysed by descriptive statistics. For the reliability analysis, relative reliability was determined by the intraclass correlation coefficient (ICC). This study employed the $ICC_{(3, k)}$ model and interpreted ICC levels as follows: Excellent: > 0.75; Good to Fair: 0.74 – 0.40; and Poor: < 0.40 (24). Absolute reliability was determined by the standard error of measurement (SEM) and minimal detectable difference (MDD_{90}) (25). The MDD_{90} used in the present study corresponds to the upper bound of the random variation that 90% of stable patients generate when tested on multiple occasions (26). The formula for MDD_{90} is MDD=1.65*SEM* (26, 27). The pelvic asymmetry ratios are the ratio of pelvic postural parameters between left and right sides, which are affected by the measured values of the pelvic postural parameters.

For NCLBP risk factor identification, the differences in the demographic variables (including age, height, weight, BMI, duration of exercise per week), pelvic postural parameters and pelvic asymmetry parameters between groups were tested using an independent t-test. A stepwise logistic regression analysis with a forward conditional method was employed to explore the risk factors of NCLBP. Before testing this model, a bivariate Pearson correlation was performed to test the relationships between age, BMI, height, weight and the pelvic asymmetry parameters. The relationships between the occurrence of NCLBP and the other variables (including the BMI, height, weight and pelvic asymmetry parameters) were explored by Spearman correlation with the occurrences of NCLBP as ordinal data (the participants with NCLBP were marked as 1, and the controls were marked as 0). Adapting the methods used in the previous study (28), the age, BMI, height, weight, and pelvic asymmetry parameters were used as the independent variables in the logistic regression analysis.

3. Results

3.1 Participants

A total of fifty-six participants were recruited. Twenty-eight healthy participants (13 females and 15 males) who never experienced low back pain were recruited for the reliability analysis and as controls. Twenty-eight (14 females and 14 males) participants who reported experiencing chronic low back pain were included in the NCLBP group. The sample characteristics of both cohorts are presented in Table 1. Both groups were matched for age, height, weight and education levels with normal or corrected-to-normal visual acuity. No participants had a history of a neurological disorder, mental disorder or regular medication. Participants in the NCLBP group had a statistically higher BMI than those in the control group ($p = 0.03$).

Insert Table 1 Around Here

____

3.2 Reliability

Moderate to excellent ICCs were observed for within-day inter-rater and between-day intra-rater reliability of all parameters. Among all the parameters, the lowest ICC values were observed for the distance between the PSIS and the midline for both inter- and intra-rater reliability. Eight parameters were observed to have a lower bound of the confidence interval less than the acceptable lower bound of 0.75 for inter-rater reliability (29). For intra-rater reliability, lower bound of the confidence interval six parameters had a less than 0.75; the ICC values, SEM and MDD_{90} for intra-rater reliability were higher than those for inter-rater reliability across all parameters. The SEM for all pelvic postural assessments ranged from 0.38 to 2.28 for inter-rater reliability and from 0.32 to 2.02 for intra-rater reliability. The MDD_{90} for all pelvic postural assessments ranged from 0.90 to 5.31 for inter-rater reliability and from 0.74 to 4.71 for intra-rater reliability. Table 2 presents the results of all reliability indices for inter- and intra-rater reliability of all the pelvic postural parameters.

____

Insert Table 2 Around Here

____

3.3 Pelvic postural parameters

The results of the descriptive statistics of the pelvic postural parameters for both groups are presented in Table 3. Independent t-tests revealed that between-group differences were not statistically significant in all pelvic postural parameters (p>0.05), except for the distance from the left PSIS to the midline (p=0.04). The between-group differences for the asymmetry ratios of the pelvic tilt angle in the sagittal plane (PTAR), the Q angle (QAR), the distance between the ASIS and the midline (ADAR), and the distance between the PSIS and the midline (PDAR) were significant (p<0.05). The asymmetry ratios of the height of the ASIS from the midline (AHAR) and between the PSIS and the midline (PHAR) were not significant (p>0.05).

____

Insert Table 3 Around Here

____

3.4 Logistic regression

The binary correlations between age, BMI, height, weight, pelvic asymmetry parameters and occurrence of low back pain are shown in Table 4. The results of the bivariate correlation indicated that age, BMI and several pelvic asymmetry parameters were related to the occurrence of NCLBP. In the regression model, only BMI (B=0.48, p=0.05, odds ratio

(OR)=1.62), PTAR (B=0.15, p=0.02, OR=1.17), and PDAR (B=0.19, p=0.02, OR=1.21) were found to be significant factors for NCLBP (Table 5). Other factors including age, height, weight, QAR, AHAR, ADAR, and PHAR were not significant factors.

———————————————

Insert Table 4 and 5 Around Here

———————————————

4. Discussion

The current study investigated if the GPS was a reliable method for pelvic postural assessment when used in the clinical setting. It also explored the associations between pelvic asymmetry and the occurrence of NCLBP in the young adult population. The results of this study indicated that GPS was a reliable method for postural assessment. PTAR and PDAR were strong risk factors for NCLBP.

4.1 Reliability

The results of the present study indicated moderate to excellent inter- and intra-rater reliability for distance variables surrounding the pelvis assessed by the GPS, except for the distance between the PSIS and the midline. These results were consistent with those reported in published studies (19, 22, 23). A common issue related to the reliability of photographic pelvic posture assessments is the repositioning of markers between measurement sessions. The repositioning of markers at the centre of the ASIS and PSIS is particularly problematic due to the anatomical characteristics of these two points (19). This study observed that the horizontal distances (distance between the ASIS and the midline; distance between the PSIS and the midline) had lower ICC values than the vertical distances (distance between the ASIS and the platform; distance between the PSIS and the platform). A potential reason for this observation is that the ICC values tend to be affected by the spread of the data (30). The distances between the ASIS/PSIS to the midline are shorter than the distances between the ASIS/PSIS and the platform. Thus, the small range of the data may contribute to low ICC values. Parameters that involved the ASIS and PSIS also have higher MDD_{90} and SME values for inter-rater reliability than for intra-rater reliability, suggesting more measurement errors occur in assessments between individuals than in assessments within individuals. Muscle contractions and excessive soft tissue surrounding the pelvis made it difficult to locate the PSIS and ASIS landmarks (19, 23). This issue did not appear to be improved by thorough training prior to the data collections, which in theory should reduce the landmark repositioning error. The anatomical angle assessed by the GPS showed good to excellent inter- and intra-rater reliability. A previous study on intra-rater reliability reported an ICC of 0.84 and an SEM of 2.48 degrees and an ICC of 0.89 and an SEM of 2.16 degrees for pelvic tilt angle and Q angle, respectively (19). For inter-rater reliability, a previous study reported an ICC of 0.43 and an SME of 3.99 on the right and an ICC of 0.49 and an SEM of 4.24 degrees on the left for the pelvic tilt angle. An ICC of 0.84 and an SEM of 2.83 degrees on the right and an ICC of 0.89 and an SEM of 2.16 degrees on the left was reported for the Q angle (23). The smaller SEM values observed in the present study compared with previous studies indicates that the GPS has less measurement error that previous methods when measuring angle parameters.

4.2 LBP risk factors

Significant between-group differences in PTAR, QAR, ADAR and PDAR were observed, which may suggest that asymmetry parameters relate to the occurrence of NCLBP in young adults. The present study did not observe a significant difference in pelvic asymmetry parameters in the frontal plane (AHAR and PHAR) between the two cohorts.

This result suggests that asymmetry in the frontal plane is unlikely to contribute to the occurrence of NCLBP. These findings are supported by Levangie (4), who also reported pelvic asymmetry in the frontal plane was not positively related to the occurrence of NCLBP.

The logistic regression model suggested that BMI was a significant determinant of NCLBP, which was consistent with the findings of previous studies (31–33) that suggested overweight and high BMI increase tissue stress around the lumbar spine (31). Several studies have reported that anatomical variations of the lumbosacral and sacroiliac joints may also contribute to pelvic asymmetries (34, 35). The results of logistic regression analysis also reported that PTAR and PDAR were significant factors for NCLBP. The asymmetrical biomechanics of the articular surface of the lumbosacral and sacroiliac joints may increase one-sided muscle activity and subsequently lead to the occurrence of CLBP (36). Previous studies showed that anterior pelvic tilt angle was associated with LBP because an increased anterior pelvic tilt could increase the strain of soft tissue in the lumbar region (33, 37, 38). Existing studies that investigated the impact of unilateral and bilateral dominant sports on pelvic torsion (pelvic rotation in the sagittal plane) reported that people who participated in unilateral dominant sports had a greater prevalence of pelvic asymmetry than those who participated in bilateral dominant sports and non-athlete groups. Bussey (12) found that athletes who engaged in bilateral dominant activities (e.g., running and cycling) showed decreased pelvic asymmetry (including lateral pelvic tilt and pelvic torsion) and lower rates of low back pain than those who engaged in unilateral dominant activities (e.g., hockey). Early literature proposed that pelvic torsion caused positional changes to one or both innominate bones of the sacroiliac joint (4). The alteration of an innominate position may increase the stress to surrounding soft tissues because it is less efficient to dissipate the force from caudal or cephalad directions (4). The results of the logistic regression analysis indicated that only PTAR and PDAR were significant factors for the occurrence of NCLBP and that AHAR and PHAR were not significant factors. This finding is a novel finding of the present study since the existing study mostly focused on assessing pelvic asymmetry in predominantly lateral pelvic tilt or pelvic torsion calculated by both the height and the width of the ASIS and PSIS. Previous studies showed that the pelvic asymmetry ratio would increase when the participant experienced not only pelvic torsion but also lateral pelvic tilt(39). These findings indicated that the ratio or difference in the height between the left and right ASIS and PSIS could not specifically detect the predominant type of pelvic asymmetry (lateral pelvic tilt or pelvic torsion) for mixed pelvic asymmetry. Therefore, pelvic asymmetry may better be assessed by methods, such as the one proposed by Gnat and Bialy (8), that take into consideration the angular measurement and the ratio of the pelvis size to detect pelvic asymmetry in the sagittal plane.

4.3 Limitations

The study adopted a cross-sectional design that did not give indication of causality of whether asymmetry led to back pain or back pain led to asymmetry. However, the findings of the results may suggest that PTAR (pelvic asymmetry in the sagittal plane) and PDAR (pelvic asymmetry in the transverse plane) were more related to the occurrence of NCLBP than PHAD and AHAD (pelvic asymmetry in the frontal plane). Future prospective cohort studies should be conducted to clarify the uncertainty of causality. The interpretation of the results may not be generalized beyond the sample population age of 20 to 27. The camera used in the present study only had a 2 megapixel lens, which was likely to increase the measurement errors. Future studies could utilize higher resolution lenses to assess body posture.

5. Conclusion

The study demonstrated an acceptable level of reliability of the GPS to assess pelvic posture asymmetry. However, not all pelvic asymmetry variables demonstrated the same level of reliability. It is currently unclear whether the observed reliability may be sufficient to identify intervention-induced changes in the symmetry ratio. The pelvic tilt angle asymmetry ratio in the sagittal plane and the distance between the PSIS and the midline in the frontal plane were significant risk factors for NCLBP. Routine screening programmes may consider using those parameters to identify and minimize potential occurrences of NCLBP.

Declarations

Ethics approval and consent to participate

Ethical approval of this study was obtained from the First Affiliated Hospital at Sun Yat-sen University (ETHICS No. [2019]206). Written informed consent was obtained from all of the participants.

Consent to publish

Written informed consent for patient information and images to be published was provided by the participants.

Competing interests

The authors declared no conflict of interest associated with the work presented in this manuscript.

Funding

This research project was supported by Guangdong Province Medical Science Technology Research Grant (grant number A2019452); the National Natural Science Foundation of China (grant number 81772434, 81971224); and the Special Fund for Science and Technology of the Industry-University-Research Cooperative Innovation of Guangzhou, China (grant number 201704020122).

Authors' contribution

All authors have read and approved the final manuscript. All authors meet the four primary ICMJE criteria for authorship. In addition, all authors have been actively involved in the study in different capacities: QY and HH designed the study and conducted all stages of the study including data collection, analysis, interpretation, and drafting of the manuscript. ZZ, XH, WL, LL, MC, ZL participated in the design of research protocol, recruitment and data analysis. WLAL and CW revised the manuscript, interpreted the data and managed the trial.

Availability of data and materials

The dataset supporting the conclusions of this article is available from the authors upon request.

Data statement

The dataset supporting the conclusions of this article is available from the authors upon request.

References

1. Manchikanti L, Singh V, Datta S, Cohen SP, Hirsch JA, American Society of Interventional Pain P. Comprehensive review of epidemiology, scope, and impact of spinal pain. Pain Physician. 2009;12(4):E35-70.
2. Al-Eisa E, Egan D, Deluzio K, Wassersug R. Effects of pelvic skeletal asymmetry on trunk movement: three-dimensional analysis in healthy individuals versus patients with mechanical low back pain. Spine (Phila Pa 1976). 2006;31(3):E71-9.
3. Cuenca-Martinez F, Cortes-Amador S, Espi-Lopez GV. Effectiveness of classic physical therapy proposals for chronic non-specific low back pain: a literature review. Phys Ther Res. 2018;21(1):16-22.

4. Levangie PK. The association between static pelvic asymmetry and low back pain. Spine (Phila Pa 1976). 1999;24(12):1234-42.
5. Fann AV. The prevalence of postural asymmetry in people with and without chronic low back pain. Arch Phys Med Rehabil. 2002;83(12):1736-8.
6. Al-Eisa E, Egan D, Deluzio K, Wassersug R. Effects of pelvic asymmetry and low back pain on trunk kinematics during sitting: a comparison with standing. Spine (Phila Pa 1976). 2006;31(5):E135-43.
7. Juhl JH, Ippolito Cremin TM, Russell G. Prevalence of frontal plane pelvic postural asymmetry--part 1. J Am Osteopath Assoc. 2004;104(10):411-21.
8. Gnat R, Bialy M. A new approach to the measurement of pelvic asymmetry: proposed methods and reliability. J Manipulative Physiol Ther. 2015;38(4):295-301.
9. Hellebrandt FA, Houtz SJ. Mechanisms of muscle training in man: experimental demonstration of the overload principle. The Physical therapy review. 1956;36(6):371-83.
10. Krahl H, Michaelis U, Pieper HG, Quack G, Montag M. Stimulation of bone growth through sports. A radiologic investigation of the upper extremities in professional tennis players. American Journal of Sports Medicine. 1994;22(6):751.
11. Peters M. Footedness: asymmetries in foot preference and skill and neuropsychological assessment of foot movement. Psychological Bulletin. 1988;103(2):179.
12. Bussey MD. Does the demand for asymmetric functional lower body postures in lateral sports relate to structural asymmetry of the pelvis? Journal of science and medicine in sport. 2010;13(3):360-4.
13. Kurki HK. Bilateral Asymmetry in the Human Pelvis. Anatomical record (Hoboken, NJ : 2007). 2017;300(4):653-65.
14. Riegger-Krugh C, Keysor JJ. Skeletal malalignments of the lower quarter: correlated and compensatory motions and postures. J Orthop Sports Phys Ther. 1996;23(2):164-70.
15. Sorensen CJ, Johnson MB, Norton BJ, Callaghan JP, Van Dillen LR. Asymmetry of lumbopelvic movement patterns during active hip abduction is a risk factor for low back pain development during standing. Hum Mov Sci. 2016;50:38-46.
16. Wunderlich M, Ruther T, Essfeld D, Erren TC, Piekarski C, Leyk D. A new approach to assess movements and isometric postures of spine and trunk at the workplace. Eur Spine J. 2011;20(8):1393-402.
17. Brink Y, Louw Q, Grimmer-Somers K. The quality of evidence of psychometric properties of three-dimensional spinal posture-measuring instruments. BMC Musculoskelet Disord. 2011;12:93.
18. Hazar Z, Karabicak GO, Tiftikci U. Reliability of photographic posture analysis of adolescents. J Phys Ther Sci. 2015;27(10):3123-6.
19. Ashnagar Z, Hadian MR, Olyaei G, Talebian Moghadam S, Rezasoltani A, Saeedi H, et al. Reliability of digital photography for assessing lower extremity alignment in individuals with flatfeet and normal feet types. J Bodyw Mov Ther. 2017;21(3):704-10.
20. Ruivo RM, Pezarat-Correia P, Carita AI. Intrarater and interrater reliability of photographic measurement of upper-body standing posture of adolescents. J Manipulative Physiol Ther. 2015;38(1):74-80.
21. van Niekerk SM, Louw Q, Vaughan C, Grimmer-Somers K, Schreve K. Photographic measurement of upper-body sitting posture of high school students: a reliability and validity study. BMC Musculoskelet Disord. 2008;9:113.
22. Moncrieff MJ, Livingston LA. Reliability of a digital-photographic-goniometric method for coronal-plane lower limb measurements. Journal of sport rehabilitation. 2009;18(2):296-315.
23. Nguyen AD, Boling MC, Slye CA, Hartley EM, Parisi GL. Various methods for assessing static lower extremity alignment: implications for prospective risk-factor screenings. Journal of athletic training. 2013;48(2):248-57.

24. Portney L, Watkins M. Foundations of clinical research : applications to practice. Third ed. Pearson Prentice Hall2009.
25. Hu X, Lei D, Li L, Leng Y, Yu Q, Wei X, et al. Quantifying paraspinal muscle tone and stiffness in young adults with chronic low back pain: a reliability study. Sci Rep. 2018;8(1):14343.
26. Portney L, Watkins M. Foundations of clinical research: applications to practice. . Norwalk: Appleton & Lange; 2000.
27. Milner CE, Brindle RA. Reliability and minimal detectable difference in multisegment foot kinematics during shod walking and running. Gait Posture. 2016;43:192-7.
28. Masaki M, Aoyama T, Murakami T, Yanase K, Ji X, Tateuchi H, et al. Association of low back pain with muscle stiffness and muscle mass of the lumbar back muscles, and sagittal spinal alignment in young and middle-aged medical workers. Clinical biomechanics (Bristol, Avon). 2017;49:128-33.
29. Lee J, Koh D, Ong CN. Statistical evaluation of agreement between two methods for measuring a quantitative variable. Computers in biology and medicine. 1989;19(1):61-70.
30. Rankin G, Stokes M. Reliability of assessment tools in rehabilitation: an illustration of appropriate statistical analyses. Clin Rehabil. 1998;12(3):187-99.
31. Heuch I, Heuch I, Hagen K, Zwart JA. Body mass index as a risk factor for developing chronic low back pain: a follow-up in the Nord-Trondelag Health Study. Spine (Phila Pa 1976). 2013;38(2):133-9.
32. Shiri R, Karppinen J, Leino-Arjas P, Solovieva S, Viikari-Juntura E. The association between obesity and low back pain: a meta-analysis. American journal of epidemiology. 2010;171(2):135-54.
33. Krol A, Polak M, Szczygiel E, Wojcik P, Gleb K. Relationship between mechanical factors and pelvic tilt in adults with and without low back pain. Journal of back and musculoskeletal rehabilitation. 2017;30(4):699-705.
34. Jancuska JM, Spivak JM, Bendo JA. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. International journal of spine surgery. 2015;9:42.
35. Mahato NK. Asymmetric sacroiliac joint anatomy in partial lumbosacral transitional variations: Potential impact on clinical testing in sacral dysfunctions. Medical hypotheses. 2019;124:110-3.
36. Mahato NK. Lumbosacral transitional vertebrae: variations in low back structure, biomechanics, and stress patterns. Journal of chiropractic medicine. 2012;11(2):134-5.
37. Taniguchi M, Tateuchi H, Ibuki S, Ichihashi N. Relative mobility of the pelvis and spine during trunk axial rotation in chronic low back pain patients: A case-control study. PLoS One. 2017;12(10):e0186369.
38. Laird RA, Gilbert J, Kent P, Keating JL. Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. BMC Musculoskelet Disord. 2014;15:229.
39. Egan DA, Cole J, Twomey L. An Alternative Method for the Measurement of Pelvic Skeletal Asymmetry (PSA) Using an Asymmetry Ratio (AR). Journal of Manual & Manipulative Therapy. 1999;7(1):11-9.

Tables

	NCLBP（n=28） Mean (SD)	Control（n=28） Mean (SD)	t, *p value*
Age (years, Mean (SD))	22.21 (2.53)	22.61 (1.85)	t=0.663, *p*=0.51
Height (cm, Mean (SD))	166.82 (7.98)	168.32 (8.46)	t=0.682, *p*=0.50
Weight (kg, Mean (SD))	59.22 (9.35)	56.36 (10.51)	t=-1.076, *p*=0.29
BMI (kg/m^2, Mean (SD))	21.15 (2.16)	19.77 (2.51)	t=-2.219, *p*=0.03
General exercise duration per week (hour, Mean (SD))	0.56 (0.52)	0.47 (0.49)	t=-0.662, *p*=0.51
NRS (static, Mean (SD))	2.85 (0.76)	−	−
NRS (dynamic, Mean (SD))	3.82 (1.16)	−	−

Table 1: The characteristics of the two groups of participants. Keys: BMI: body mass index; NRS: numerical rating scale

		Inter-rater reliability			Intra-rater reliability		
		ICC (95% CI)	SEM	MDD_{90}	ICC (95% CI)	SEM	MDD_{90}
Anterior pelvis tilt angle	Left	0.76 (0.46,0.89)	2.28	5.31	0.83 (0.64,0.92)	2.02	4.71
	Right	0.77 (0.50,0.90)	2.15	5.01	0.79 (0.54,0.90)	1.98	4.62
Q angle	Left	0.78 (0.52,0.90)	1.83	4.26	0.90 (0.77,0.95)	1.44	3.37
	Right	0.74 (0.44,0.88)	1.82	4.24	0.79 (0.54,0.90)	1.80	4.19
The height of the ASIS from the platform	Left	0.96 (0.92,0.98)	1.35	3.15	0.99 (0.97,0.99)	0.79	1.85
	Right	0.97 (0.92,0.98)	1.27	2.96	0.98 (0.97,0.99)	0.85	1.99
The distance between the ASIS and the midline	Left	0.77 (0.50,0.89)	0.59	1.37	0.87 (0.72,0.94)	0.48	1.12
	Right	0.77 (0.24,0.91)	0.63	1.48	0.95 (0.89,0.98)	0.32	0.74
The height of the PSIS from the platform	Left	0.94 (0.88,0.97)	1.71	3.99	0.99 (0.98,0.99)	0.67	1.56
	Right	0.94 (0.87,0.97)	1.70	3.97	0.99 (0.98,0.99)	0.69	1.60
The distance between the PSIS and the midline	Left	0.72 (0.40,0.87)	0.38	0.90	0.74 (0.43,0.88)	0.45	1.05
	Right	0.68 (0.33,0.85)	0.46	1.06	0.70 (0.37,0.86)	0.41	0.96

Table 2: ICCs and absolute reliability for inter-rater and intra-rater reliability of all the pelvic postural variables

		Mean (SD)				
		Control Group			NCLBP Group	t, *p value*
		Tester A	Tester B: first time	Tester B: second time	Tester A	
Anterior pelvis tilt angle (º)	Left	21.04 (4.48)	21.04 (4.80)	21.36 (5.10)	22.29 (6.83)	t=-0.809, *p*=0.42
	Right	21.07 (4.99)	21.25 (4.00)	20.75 (4.53)	22.43 (7.06)	t=-0.831, *p*=0.41
Q angle (º)	Left	20.00 (3.45)	21.00 (4.24)	21.21 (4.67)	19.64 (7.99)	t=0.217, *p*=0.83
	Right	19.93 (3.24)	20.57 (3.87)	21.25 (3.89)	19.50 (7.97)	t=0.263, *p*=0.79
The height of the ASIS from the platform (cm)	Left	103.16 (6.92)	102.76 (6.91)	102.70 (7.00)	100.11 (18.27)	t=0.826, *p*=0.41
	Right	103.25 (6.81)	103.00 (6.76)	102.76 (6.75)	100.30 (17.96)	t=0.812, *p*=0.42
The distance between the ASIS and the midline (cm)	Left	14.44 (1.09)	14.45 (1.35)	14.46 (1.33)	14.43 (1.55)	t=0.030, *p*=0.98
	Right	14.73 (1.25)	15.54 (1.42)	15.45 (1.37)	14.76 (1.74)	t=-0.71, *p*=0.94
The height of the PSIS from the platform (cm)	Left	110.41 (7.51)	109.46 (6.96)	109.65 (6.41)	110.68 (6.88)	t=-0.141, *p*=0.89
	Right	110.56 (7.40)	109.41 (6.86)	109.43 (6.21)	110.66 (6.87)	t=-0.049, *p*=0.96
The distance between the PSIS and the midline (cm)	Left	5.52 (0.73)	5.68 (0.72)	5.79 (1.03)	6.28 (1.67)	t=-2.194, *p*=0.04
	Right	5.48 (0.83)	5.69 (0.79)	5.53 (0.72)	6.04 (1.29)	t=-1.948, *p*=0.06
PTAR (%)		8.3 (7.7)			19.9 (19.1)	t=-2.989, *p*=0.01
QAR (%)		10.3 (7.6)			51.6 (67.6)	t=-3.206, *p*<0.001
AHAR (%)		0.7 (0.5)			1.1 (1.4)_	t=-1.416, *p*=0.17
ADAR (%)		3.7 (3.8)			7.5 (3.7)_	t=-3.825, *p*<0.001
PHAR (%)		0.4 (0.3)			0.4 (0.4)	t=0.679, *p*=0.50
PDAR (%)		6.3 (4.0)			21.8 (17.5)	t=-4.570, *p*<0.001

Table 3: Means and standard deviations (SDs) of all pelvic postural variables and pelvic asymmetry pa
Keys: ASIS – anterior superior iliac spine; PSIS - posterior superior iliac spine; PTAR - pelvic asymmetry ratio in the sagittal plane; QAR - Q angle asymmetry ratio; AHAR - height of the ASIS platform asymmetry ratio; ADAR - distance between the ASIS and the midline asymmetry ratio; PHAR - the PSIS from the platform asymmetry ratio; PDAR – distance between the PSIS and the platform as ratio.

		Age	Height	Weight	BMI	PTAR	QAR	AHAR	ADAR	PHAR	PDAR	Group
Age	Pearson	—										
Height	Pearson	.045	—									
Weight	Pearson	-.015	.745**	—								
BMI	Pearson	-.051	.271*	.840**	—							
PTAR	Pearson	.108	-.070	.011	.044	—						
QAR	Pearson	.074	.040	.246	.330*	.191	—					
AHAR	Pearson	-.211	.309*	.154	-.040	.300*	-.046	—				
ADAR	Pearson	-.022	.148	.271*	.271*	.284*	.238	.146	—			
PHAR	Pearson	-.026	-.287*	-.196	-.067	.196	-.037	-.073	.195	—		
PDAR	Pearson	-.081	-.033	.017	.051	.156	.137	.078	.353**	-.052	—	
Occurrence of NCLBP	Spearman [a]	-.286*	-.091	.114	.276*	.447**	.623**	-.001	.495**	-.125	.535**	—

Table 4: The binary correlations between age, BMI, pelvic asymmetry parameters and the occurrence of low back pain. *denotes p<0.05; ** denotes p<0.01; a denotes the relationships between the occurrence of NCLBP and other variables as explored by Spearman correlation

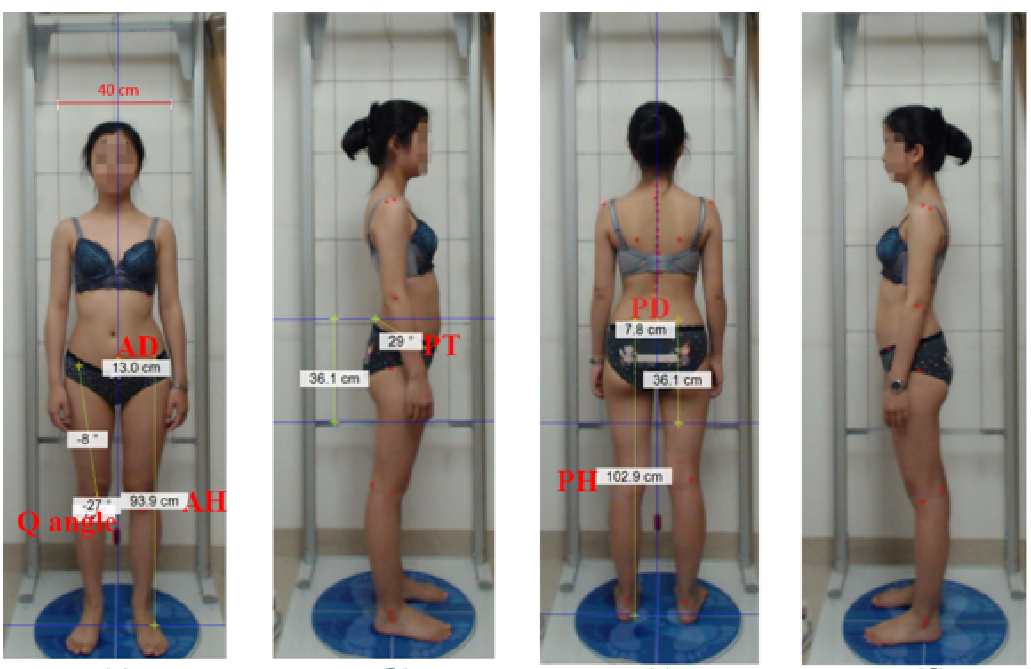
Dependent variables	Independent variables	Non-stand partial regression coefficient	p value	OR	95% confidence interval for odds ratio	
					lower	upper
	BMI	0.48	0.05[a]	1.62	1.00	2.63
	PTAR	0.16	0.02	1.21	1.02	1.34
	PDAR	0.19	0.02	1.17	1.04	1.42

Table 5: Results of the stepwise logistic regression analysis with a forward selection method. *a* denotes that p is equal to *0.052*, which is marginally significant

Abbreviations

ADAR	The distance between the ASIS and the midline asymmetry ratio
AHAR	The height of the ASIS from the platform asymmetry ratio
ASIS	Anterior superior iliac spine
BMI	Body mass index
GPS	Global Postural System
ICC	Intraclass correlation coefficient
LBP	Low back pain
MDD_{90}	Minimal detectable difference
NCLBP	Non-specific chronic low back pain
NRS	Numerical rating scale
OR	Odd ratio
PDAR	The height of the PSIS from the platform asymmetry ratio
PHAR	The height of the PSIS from the platform asymmetry ratio
PSIS	Posterior superior iliac spine
PTAR	The pelvic tilt angle asymmetry ratio in the sagittal plane
QAR	Q angle asymmetry ratio
SEM	Standard error of measurement

Figures



(a) (b) (c) (d)

Figure 1

Photos with different views taken by the GPS. 1a front view; 1b right lateral view; 1c back view; 1d left lateral view. Keys: AD - the distance between ASIS and the midline; AH - the height of the ASIS from the platform; PT- anterior pelvic tilt angle.