Research article

Evaluating pelvic rotator strength: Investigating asymmetry and its correlation with pelvic rotation angle during active straight leg raise

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Abstract

Background: Although lumbopelvic rotation control muscle is important to maintain pelvic neutral alignment during active straight leg raise (ASLR), pelvic rotator strength has not been evaluated. Thus, a novel method is needed to measure pelvic rotator strength and to determine whether pelvic rotator muscle asymmetry is related to side difference in transverse plane pelvic rotation angle (TrPRA) during ASLR.

Objective: To find average pelvic rotator strength, verify the reliability of pelvic rotator strength measurement method, and identify the correlation between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR.

Methods: Forty healthy participants were enrolled. Pelvic rotator strength was measured using a hand-held dynamometer. TrPRA was measured using a smart KEMA motion sensor. Reliability was analyzed using intraclass correlation coefficient (ICC). The correlation between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR was analyzed using Pearson's correlation coefficient.

Results: The average pelvic rotator strength was 120.3 N (72.9–202.2) for males and 94.4 N (58–125.8) for females. The reliability of pelvic rotator strength measurement demonstrated good to excellent intra- (ICC = 0.87–0.97) and inter-rater (ICC = 0.93–0.98) values. A significant moderate relationship existed between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR ($r = 0.39$, $p < 0.05$).

Conclusion: The pelvic rotator muscle strength measurement method can be clinically used with good to excellent intra- and inter-rater reliability. Pelvic rotator strength asymmetry should be considered to evaluate and manage the pelvic rotation control during ASLR.

Keywords
movement, muscle strength, pelvis, range of motion

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Introduction

The pelvis should be maintained in a neutral position to avoid uncontrolled pelvic motion (UPM), such as rotation, by engaging stabilizing muscles during active straight leg raise (ASLR).[1–5] In a previous study that confirmed abdominal electromyography (EMG) by rotating the pelvis with a fixed thorax in the sitting position, high electromyographic activity was found in the transversus abdominis (TrA) and internal oblique abdominis (IO) muscles of the lower abdominal region.[6] Hu et al. (2012) reported that pelvic rotators, such as the TrA and IO, are important for controlling pelvic rotation movement during ASLR.[7] Thus, many researchers have analyzed to evaluate the EMG of the

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abdominal muscles, including pelvic rotators, while performing ASLR.[2,3,7–9] People with low back pain showed asymmetric EMG activity of pelvic rotators during ASLR.[10] Nevertheless, using EMG in clinical settings is challenging, and despite pelvic rotators being recognized as crucial stabilizers for controlling the pelvis during ASLR, there is currently a lack of studies assessing pelvic rotator strength.

Pelvic asymmetry can produce asymmetric biomechanical loads on joints or tissues during weight bearing activities.[11] Pelvic asymmetry alignment is assessed by comparing the height of the anterior superior iliac spines (ASISs) on the left and right in the supine position.[12] However, since asymmetry or movement in the pelvis is relatively small, evaluation via palpation or observation is difficult.[5] A previous study measured movement such as transverse plane pelvic rotation angle (TrPRA) during ASLR using the smart KEMA motion sensor and identified a larger TrPRA value in participants with low back pain than in healthy participants.[5] When ASLR is performed, if excessive pelvic rotation occurs asymmetrically only on one side, continuous stress or load can be accumulated only on one side.[5,13] Comerford and Mottram (2012) defined the transverse plane lumbopelvic rotation toward lifting the leg during ASLR as uncontrolled lumbopelvic rotation (ULPR), and these ULPR may contribute to pain and asymmetrical symptoms of the lumbopelvic region.[1,4] However, there was no study to confirm whether pelvic rotator strength asymmetry is related to pelvic rotation control during ASLR.

Therefore, this study aimed to determine the average pelvic rotator strength among healthy college students; validate the reliability of a pelvic rotator strength measurement method developed by the authors; and investigate the correlation between pelvic rotator strength asymmetry and the side difference in TrPRA during ASLR.

Materials and methods

Participants

Forty healthy (22 males, 18 females) participants (age: 23.1 ± 2.0 years, body weight: 66.7 ± 12.3 kg, body height: 169.3 ± 7.7 cm, body mass index: 23.1 ± 3.2 kg/m^2, TrPRA in the supine position: $1.6 \pm 1.1°$) were recruited from the university community (Table 1). Exclusion criteria included the following: (1) a history of serious low back pain (ie, requiring medical treatment or time off work); (2) acute pain during ASLR; (3) leg cannot be raised due to weakness of hip flexors; (4) cardiovascular problems, metabolic or rheumatologic disease, osteoporosis, or other serious diseases.[5,14–16] The Yonsei University Mirae Campus Institutional Review Board approved the study method (approval number: 1041849-202306-BM-105-01), and all participants provided written informed consent.

Table 1. Demographic characteristics of the participants (n = 40).

	Total (n = 40)	Male (n = 22)	Female (n = 18)
Age (years)	23.1 ± 2.0	24.0 ± 2.1	22.1 ± 1.3
Body weight (kg)	66.7 ± 12.3	74.9 ± 6.8	56.6 ± 9.6
Body height (cm)	169.3 ± 7.7	174.7 ± 4.8	162.7 ± 4.9
Body mass index (kg/m^2)	23.1 ± 3.2	24.6 ± 2.0	21.4 ± 3.5
TrPRA in the supine position (°)	1.6 ± 1.1	1.4 ± 0.9	1.7 ± 1.2

Values are presented as mean ± standard deviation. °, degrees; TrPRA, Transverse plane pelvic rotation angle.

Instrumentation

For measuring pelvic rotator strength, we used a hand-held dynamometer (HHD) (VDFG-500, VPOER, China). It can be measured in units of Newton (N) and up to 500 N. Measurement could be measured in 0.1 N units. In "peak" mode, the maximum force shown during the measurement was displayed on the screen (Figure 1A). A smart KEMA motion sensor (Korea Tech Co., Ltd, Seoul, Korea) was used to obtain motion data for pelvic rotation. Motion data regarding pelvic rotation were sent to the tablet via Bluetooth with a smart KEMA software.[17] Previous studies have noted that TrPRA measurements during ASLR using the pelvic rotation measurement system (PRMS) with a smart KEMA motion sensor demonstrated high to very high intra-rater reliability (range, 0.87 [95% CI, 0.73–0.94] to 0.95 [95% CI, 0.89–0.98]) and suggested that it is a simple method.[5,18] A motion sensor and PRMS were combined to measure TrPRA, and a bubble bar was used to evaluate whether the PRMS maintained the transverse plane. The upright bar of the PRMS could be adjusted according to the distance between both ASISs (Figure 1B).

Procedures

Pelvic rotation angle measurement. Participants were placed in the supine position on a firm therapeutic table. The participants' ASIS was assessed and the upright bar of the PRMS was adjusted with the ASIS width. For measurement equipment calibration, upright bar of the PRMS was placed on the table surface and adjusted to zero degrees. Next, the upright bar was placed on both sides of the participants' ASIS, and the initial TrPRA was measured in the supine posture. Before performing ASLR, the examiner adjusted the initial TrPRA of the participants to zero degrees for the pelvic neutral position. This adjustment was performed at every measurement to eliminate the effects of the initial TrPRA. ASLR was performed twice for each leg, starting with the participant's dominant side leg. To prevent the participant from pressing the table with his or her arms, the

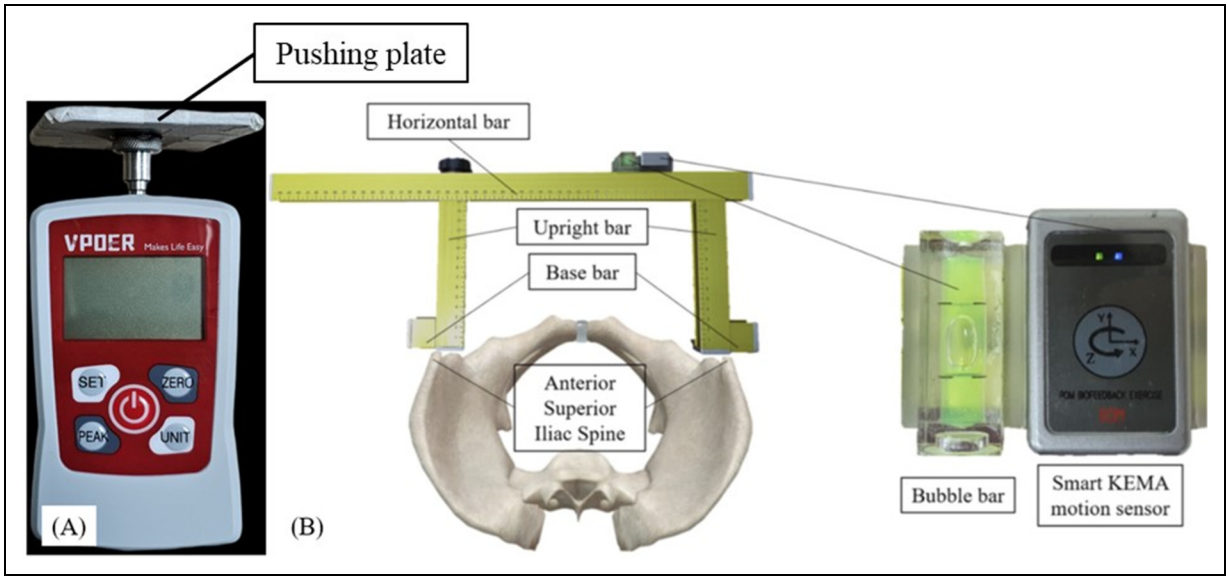


Figure 1. (A) Hand-held dynamometer, (B) PRMS with smart KEMA (Kinetic Ergocise based on Movement Analysis) motion sensor and bubble bar. PRMS, pelvic rotation measurement system.

arms were crossed in front of the chest. Next, participant's legs were raised up to the 20 cm high target bar on the table without any knee flexion, and a point 5 cm above the ankle joint remained in contact with the target bar for 5 s. During ASLR, the examiner maintained a contact state to ensure that the upright bar of the PRMS was not separated from both ASISs. Kinematic data were estimated as the mean of the values for the middle 3 s of the 5 s. The participant had a 2 min rest time between each attempt.[5] The side difference in TrPRA was calculated as the absolute value of the right side (Rt) minus the left side (Lt) (|Rt side − Lt side|) (Figure 2).

Pelvic rotator strength measurement. Participants took a side-lying position on the therapeutic table with a non-slip mat while facing the wall with the measurement side up. The participants took a 90° position with both hip and knee flexed, and their eyes looked straight ahead while maintaining a neutral position without trunk flexion or extension. A pillow was placed between the calves to keep the legs parallel. We created a wooden fixing equipment ($22 \times 30 \times 13$ cm) to fit the subject's knee level to fix the HHD and used a plastic plate to fit the HHD size to prevent the HHD from shaking on the fixing equipment (Figure 3A). In addition, the fixing equipment was firmly placed on the wall to prevent pushing. The HHD and the participant's knee were approximately 1 cm apart. The participant's knee was adjusted so that the pushing plate center of the HHD can be pressed. To measure pelvic rotator strength, the participants were asked to rotate their pelvis via pushing the knee toward the pushing plate of HHD to transfer pelvic rotator force to femur using the maximum strength for 5 s and obtained the maximum strength as a Newton (N) value (Figure 3B). Participants were instructed not to flex, extend, or abduct the hip joint while pushing the knee toward the pushing plate of HHD. Prior to measurement, the examiners practiced the procedure for several times to ensure consistent fixation of the participant's thorax and ribs, maintaining steady fixation point and force. During measurement, the examiner fixed firmly the participant's thorax and rib using constant force possible with the examiner's hand to prevent rotation motion in the thoracic spine. After explaining the measurement motion, practice was performed five times before pelvic rotator strength measurement for familiarization to strength test performance. For data collection, we measured three trials on each side and used the average value. There was a 30 s break time between each trial. For inter-rater reliability, the measurement was performed through the same measurement process by examiner A (JJY) and examiner B (HSY) on the same day (Day 1), with a 10 min break before the examiner was changed. Examiner was determined randomly for measurement. For intra-rater reliability, examiner A conducted the measurement once again using the same process on another day (Day 2) within 3 days after the first measurement date.[19] Pelvic rotator strength test was conducted using both legs and pelvic rotator strength asymmetry was calculated using the following formula: $\frac{|\text{Right} - \text{Left}|}{|\text{Right} + \text{Left}|} \times 100$

Statistical analysis

Statistical analysis was conducted using the SPSS for Windows ver. 29.0 software (IBM Corp., Armonk, NY, USA). For data

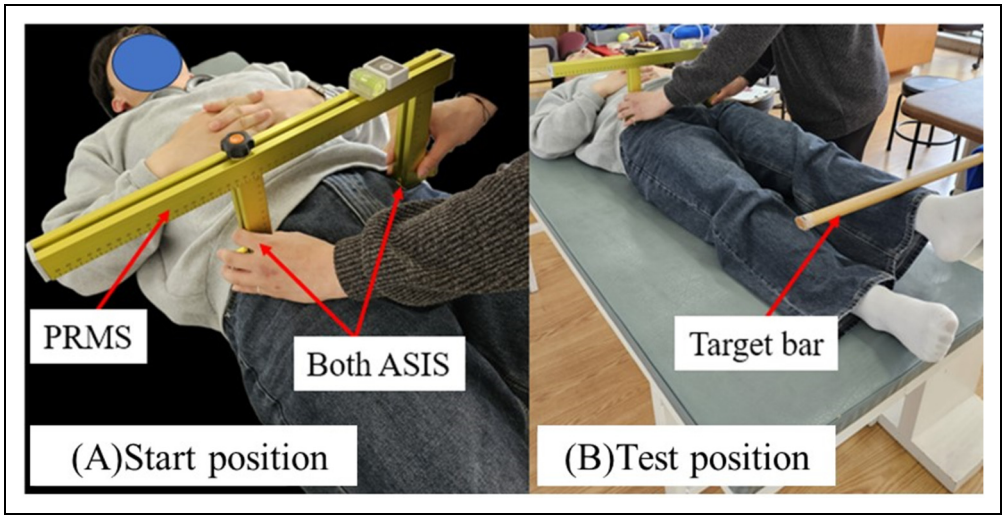


Figure 2. Pelvic rotation angle measurement during active straight leg raise. (A) Start position (0° degree of pelvic rotation). (B) Test position; PRMS, pelvic rotation measurement system; ASIS, anterior superior iliac spine.

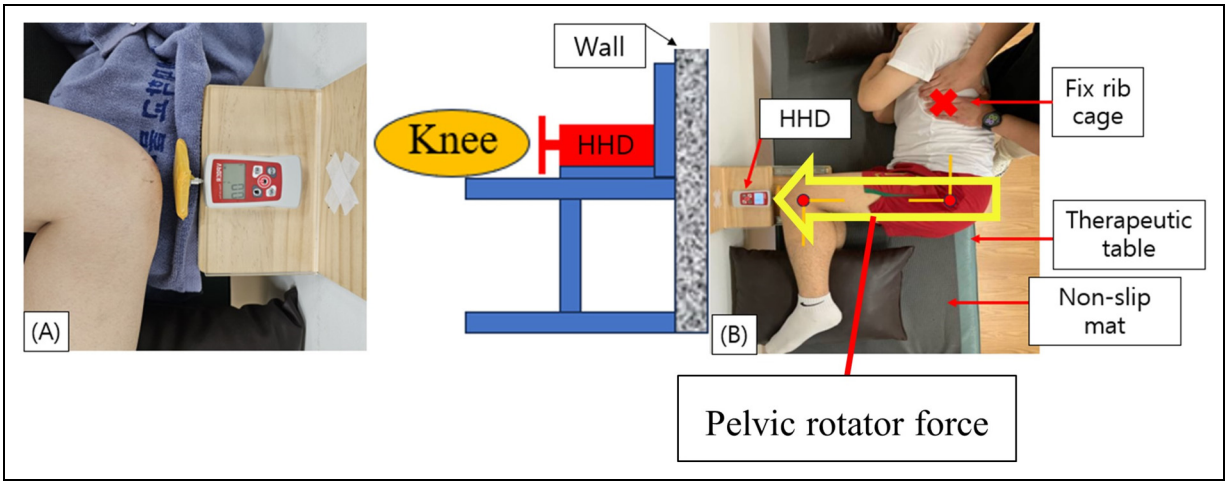


Figure 3. Pelvic rotator strength measurement. (A) Top and side view of setting position, (B) during measurement. HHD, hand-held dynamometer.

normality assessment, the Kolmogorov-Smirnov test was used. The pelvic rotator strength data from days 1 and 2 were used to analyze intra-rater reliability. Pelvic rotator strength data obtained by examiners A and B on day 1 were used to analyze inter-rater reliability. Intra-rater reliability was calculated using ICC 3,3 (two-way mixed model with absolute agreement for mean value of three measurement), inter-rater reliability calculated using ICC 2,2 (two-way random model with absolute agreement for two examiners).[20] The ICCs were explained as follows: ICC values less than 0.5 (poor), 0.50–0.75 (moderate), 0.75–0.90 (good), greater than 0.90 (excellent).[21] Pearson's correlation coefficient was used to verify correlation between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR. According to previous studies, the level of association was graded as follows: trivial (r = 0.0–0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), and extremely large (0.9–1.0).[22,23] The standard error of the mean (SEM) for each measurement was determined using the standard deviation (SD) and ICCs, as follows: $SEM = SD\sqrt{1 - ICC}$. By dividing the SEM by the average muscle strength, the SEM was also expressed as a SEM%.[24] The minimal detectable change (MDC) was calculated as $SEM \times 1.96 \times \sqrt{2}$.[25] MDC% was calculated by dividing the MDC by the average muscle strength.[24]

Results

Table 2 presents the average pelvic rotator strength of all, male, and female participants. The mean ± SD values of

the pelvic rotator strength for the three measurements and intra- and inter-rater reliability using the mean value of the pelvic rotator strength were presented in Table 3 with the ICC, SEM, SEM %, MDC, and MDC% values. Intra- and inter-rater reliability of the pelvic rotator strength measurement showed good to excellent reliability (ICC = 0.87–0.98). Moreover, a moderate relationship was observed between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR ($r = 0.39$, $p < 0.05$; Figure 4).

Table 2. Pelvic rotator strength of the participants measured using a hand-held dynamometer.

	Total (n = 40)	Male (n = 22)	Female (n = 18)
Left rotation (N)	109.5 ± 30.5 (58–202.2)	121.2 ± 34.7 (72.9–202.2)	95.3 ± 16.1 (58–123.9)
Right rotation (N)	107.7 ± 28.2 (60.6–190.9)	119.4 ± 29.0 (75.1–190.9)	93.5 ± 20.0 (60.6–125.8)

Values are presented as mean ± standard deviation and minimum and maximum. N, Newton unit.

Table 3. Reliability of the pelvic rotator strength measurement (n = 40).

			Pelvic rotator strength (N)	ICC (95% CI)	SEM	SEM %	MDC	MDC%
Intra-rater reliability (ICC 3,3)	Left rotation	Day 1	109.5 ± 30.5	0.94 (0.88–0.97)	8.1	7.3	22.4	20.4
		Day 2	113.9 ± 27.7		7.3	6.4	20.2	17.7
	Right rotation	Day 1	107.7 ± 28.2	0.93 (0.87–0.96)	7.5	6.9	20.7	19.2
		Day 2	110.7 ± 24.4		6.5	5.8	18.0	16.2
Inter-rater reliability (ICC 2,2)	Left rotation	Examiner A	109.5 ± 30.5	0.96 (0.93–0.98)	6.1	5.5	16.9	15.4
		Examiner B	106.3 ± 31.0		6.2	5.8	17.2	16.2
	Right rotation	Examiner A	107.7 ± 28.2	0.97 (0.94–0.98)	4.9	4.5	13.6	12.6
		Examiner B	105.7 ± 30.0		5.2	4.9	14.4	13.6

Values are presented as mean ± standard deviation. ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of the mean; N, Newton unit; MDC, minimal detectable change; %, percentage.

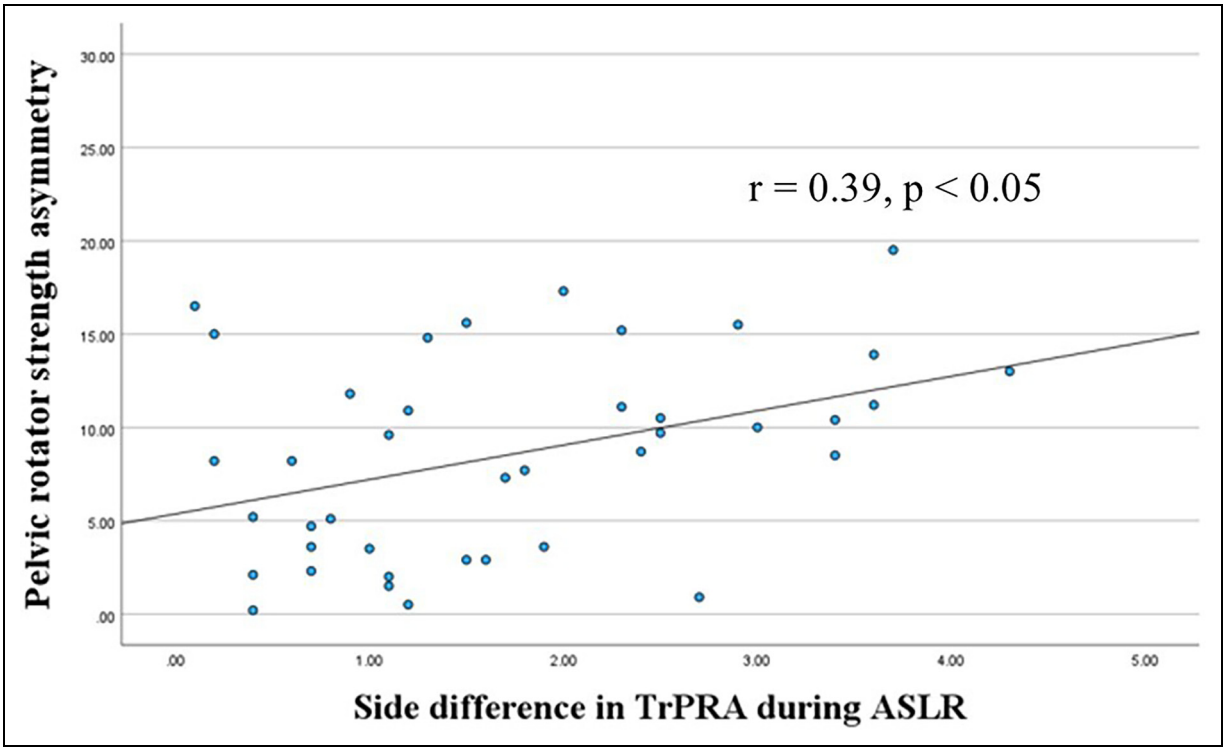


Figure 4. Pearson correlation coefficients between pelvic rotator strength asymmetry and the side difference in TrPRA during ASLR. TrPRA, transverse plane pelvic rotation angle; ASLR, active straight leg raise.

Discussion

This study was conducted to investigate the average pelvic rotator strength, verify the reliability of novel method to measure pelvic rotator strength, and determine the correlation between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR. In the present study, the average pelvic rotator strength was 120.3 N (72.9–202.2) for males and 94.4 N (58–125.8) for females. The intra- and inter-rater reliability of pelvic rotator strength measurement showed good to excellent reliability (ICC = 0.87–0.98). Also, this study showed a moderate positive correlation between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR.

To the best of our knowledge, this is the first study to measure pelvic rotator strength using HHD in side-lying position. In our study, the intra- and inter-rater reliability of the pelvic rotator strength measurement method using HHD was good to excellent (ICC = 0.87–0.98). A recent systematic review that examined the reliability of upper-limb muscle strength measurement using HHD demonstrated that only 48% of the studies showed good intra-rater reliability.[26] The rationale for the HHD showing such low reliability is that the pressure to press the HHD is not constant during the strength test by each examiner. Previous studies have measured muscle strength by fixing HHD, confirmed the high reliability of this method, and said that errors by examiner can be reduced and the reliability of HHD can be improved.[24,27] Although HHD was used in our study, the reason for the high reliability is that the measurement equipment instability was removed by fixing the HHD, and only the strength of the pure participant was measured because the pressure of the examiner was not involved. Methods of measuring muscle strength include the "break test" using the manual resistance of the examiner and "make test" using only the measuring equipment without the examiner's pressure.[28] When measuring hip abductor strength with the "break test" using HHD, the reliability was low due to fluctuation depending on the hip abduction angle, while the "make test" using the tensiometer maintained a certain measurement posture, resulting in high reliability.[28] Our study also conducted the "make test" without intervention or instability of the examiner by fixing HHD. So, as we have seen in previous studies and our studies, it is thought that measurement errors caused by the examiner can be reduced by fixing the HHD, which may vary depending on the pressure of the examiner. In the present study, the inter-rater reliability values were higher with smaller confidence intervals when compared with the intra-rater values. A possible reason for the higher inter-rater reliability is that inter-rater test was conducted on the same day with a 10-min break between measurements, which allowed the learning effect to potentially influence the subjects.

In our study, the average pelvic rotator strength for males and females was measured to be 120.3 N (72.9 N to 202.2 N) in males and 94.4 N (58 N to 125.8 N) in females. Until recently, methods for pelvic rotator strength measurement used by physical therapists in clinical settings were limited. Furthermore, despite the assertion emphasizing the importance of the pelvic rotator muscle in controlling pelvic rotation during ASLR, no research has specifically focused on pelvic rotator strength. In a previous study, the lumbar rotation strength was measured while sitting and fixing the pelvis, and the rotation strength was measured to be approximately 300 N.[29] Because of the spine structure, rotational movement occurs more easily in the thoracic spine than in the lumbar spine.[1,30] Therefore, how much muscle strength of the pelvic rotator comes out on average remains unknown. Previous study has measured the lumbar rotation strength, but there is a possibility that the thoracic spine is more involved than the lumbar spine in actual movement. Unlike previous study, our study measured pelvic rotator strength, including the lumbar spine, by moving the pelvis with the thorax and rib fixed in the side-lying position. Therefore, reducing the movement of the thoracic spine, which is easy to rotate, and measuring the pure pelvic rotator strength, including that of the lumbar spine, are possible.

This study revealed a moderate relationship ($r = 0.39$, $p < 0.05$) between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR. Hu et al. (2010) noted that bilateral co-contracting of the abdominal wall muscles is necessary for symmetrical stabilization of the pelvis during ASLR.[3] In particular, pelvic rotators such as TrA and IO are important to maintain neutral pelvic alignment against rotation of the pelvis toward the lifted leg during ASLR.[7] In a previous study, people with no low back pain symptoms but with difficulty in performing ASLR and those with low back pain showed greater EMG asymmetry in TrA and IO than those without symptoms and no difficulty during ASLR.[10] In another study, the low back pain group had less change in muscle thickness of the TrA and IO at ASLR than the healthy group.[31] UPM, such as rotation motion, is related to the efficiency of lumbopelvic rotational stability muscles, such as the abdominal oblique.[4] So, these differences in muscle thickness changes on ultrasound may also be related to changes in TrPRA during ASLR. Therefore, pelvic rotator strength asymmetry may be a factor to contributing the asymmetry of the actual pelvic rotation movement. So, selective interventions will be possible to improve the asymmetry of movement, which can contribute to low back pain by prior checking of the pelvic rotator strength asymmetry.

Our study was conducted to confirm the correlation between pelvic rotator strength asymmetry and side difference in TrPRA during ASLR, and a moderate correlation ($r = 0.39$, $p < 0.05$) was confirmed. There are some reasons why correlationship was moderate level. First, it is possible that the mobility of the lumbar spine influences

pelvic rotator strength. However, the lumbar rotation angle was not measured in this study. In future studies, investigating the correlation between the lumbar rotation angle and pelvic rotator strength is necessary. Second, when measuring pelvic rotator strength in the side-lying position, the hip adductors of the opposite side of tested side may have affected pelvic rotator strength. Hip adductors, such as the adductor longus, adductor brevis, adductor magnus, pectineus, and gracilis, attach to the pubic bone.[32] Thus, the involvement of the hip adductors during pelvic rotation may have influenced the actual pelvic rotator strength. Further study may need to confirm how much hip adductors contribute to pelvic rotator strength in side-lying. Also, pelvic rotation strength might not be the main factor in maintaining pelvic neutrality during ASLR. The motor control of core muscles, which includes muscle activation timing and recruitment patterns, along with the force and form closure in lumbopelvic region could be more crucial for stabilizing the pelvis during an ASLR than addressing the asymmetry of pelvic rotator muscle strength.

In this study, 50% of the participants demonstrated more TrPRA on the stronger side of the pelvic rotator, whereas the remaining 50% demonstrated more TrPRA on the weaker side. Although asymmetry in pelvic rotator strength does not correspond with the direction of increased pelvic rotation, measuring the strength of the pelvic rotator could be a useful tool for predicting asymmetry in pelvic rotation movement in the clinical setting.

This study had some limitations. First, the findings of this study cannot be generalized to participants with back pain or other diseases because only healthy participants were enrolled. Second, the results of this study cannot be generalized to participants of different ages because only young participants were included. Long-term studies are needed to evaluate the effects of improvement in pelvic rotator strength asymmetry in participants of various ages and with back pain. Third, standardized methods were not used while fixing rib and thoracic spine. Therefore, the fixing force may have been different depending on the examiner's fixing force. Further research requires fixing in a particular way. Fourth, the absolute value was used for calculating asymmetry, so it is hard to establish that a lot of pelvic rotation occurs when ASLR is performed using the leg where the pelvic rotation strength was weak. In future, checking the correlation by considering the direction would be necessary.

Conclusion

This new method for measuring pelvic rotator strength, designed to enhance clinical usability, demonstrated good to excellent intra-rater and inter-rater reliability. In addition, a positive correlation was observed between pelvic rotator strength asymmetry and the side difference in TrPRA during ASLR, suggesting that evaluating and managing lumbopelvic stability during ASLR should include consideration of pelvic rotator strength asymmetry.

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Statements and declarations

Ethical approval

The study was approved by the Yonsei University Mirae Campus Institutional Review Board (approval number: 1041849-202306-BM-105-01)

Informed consent

Every study subject gave their informed permission. The participants whose pictures are included in this article gave permission for their pictures to be used.

Author contributions

JYJ: Conceptualization, Methodology, Data Curation, Investigation, and Writing-Original data. CHY, SMH and JHK: Conceptualization and Methodology. SYH: Data Curation, Investigation. OYK: Conceptualization, Methodology, Writing-Reviewing, and Editing.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability

Data can be made available upon request, except for personal information, which will be excluded to ensure the privacy and confidentiality of individuals involved.

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