European Journal of Physical and Rehabilitation Medicine 2023 Jul 27
DOI: 10.23736/S1973-9087.23.07834-6

ORIGINAL ARTICLE

The role of an active muscular subsystem in prone instability test during rest and leg raise conditions

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ABSTRACT

BACKGROUND: Clinicians commonly used prone instability test (PIT) by assessing the posterior-to-anterior (PA) displacement to identify lumbar instability. Most studies focusing on passive subsystem found greater mobility in lower lumbar (L4-L5) than upper lumbar (L1-L3) spine. However, there is still a lack of evidence to demonstrate the role of active subsystem. Additionally, it is unclear whether sex affects PA displacements.

AIM: To determine differences in displacement among five lumbar segments, between two testing positions (rest and leg raise), and between male and female during PIT in individuals with chronic non-specific low back pain (CNLBP).

DESIGN: A cross-sectional study design.

SETTING: Spine biomechanics laboratory.

POPULATION: Individuals with CNLBP.

METHODS: An electromagnetic tracking system was used to measure PA displacement with sensors attached at T12, S2 and a hand-held dynamometer. Participants were asked to perform PIT, while a 100N force was applied to each lumbar segment during resting and leg raise positions.

RESULTS: Significantly less PA displacement ($P<0.05$) was seen in lower compared to upper lumbar spine and in leg raise compared to rest at L1 to L4. No significant interaction of sex with different lumbar levels and conditions ($P>0.05$) during PIT was found.

CONCLUSIONS: Although previous studies have reported that the lower lumbar spine had greater mobility, the lower amount of displacement during the rest position suggests the role of an active subsystem contributing to lumbar stability regardless of sex.

CLINICAL REHABILTATION IMPACT: A reduction in displacement during the leg raise position across L1 to L4 suggesting an interaction of stabilizing subsystems of the spine to provide lumbar stability.

(*Cite this article as:* Maharjan S, Thu KW, Kongoun S, Sornkaew K, Richards J, Wattananon P. The role of an active muscular subsystem in prone instability test during rest and leg raise conditions. Eur J Phys Rehabil Med 2023 Jul 27. DOI: 10.23736/S1973-9087.23.07834-6)

Key words: Low back pain; Joint instability; Hip dislocation.

Chronic non-specific low back pain (CNLBP) is one of the leading musculoskeletal conditions that can cause physical limitations, participation restriction, and financial burden to patients.[1] Prevalence of CNLBP has been reported to be as high as 85% of the low back pain population.[1, 2] Previous studies have also reported the incidence of lumbar instability in CNLBP ranging from 13 to 46%.[3, 4] Recent evidence suggests that patients with CNLBP have underlying neuromuscular control deficits.[5-7] This could cause a compromise in the stabilizing system (passive, active, and neural subsystems) leading to the inability to control segmental motion under normal physiological loads which in turn increases the risk of injury to the lumbar structure.[8-10]

Numerous clinical tests have been identified to diagnose clinical lumbar instability (CLI).[11, 12] The prone instability test (PIT) has been shown to have fair to moderate specificity and sensitivity[12, 13] and is frequently used in clinical settings to identify individuals with CNLBP who have suspected lumbar instability.[9, 13, 14] PIT comprises 2 conditions of testing (resting and leg raise). Resting condition requires patients to lie prone with the lower half of the body out of the treatment table, the clinician then applies a passive posterior-to-anterior (PA) compression force over the L1 to L5 spinous processes to provoke pain. If the patient complains of pain which is thought to be due to stress on surrounding structures, they were asked to raise both legs off the ground (leg raise condition). The provocative force is then reapplied to the painful level. Subsiding pain after the leg raises indicates a positive test,[13, 14] which is assumed to be the result of compensation by the active subsystem for the deficit in the passive subsystem.[13, 14] This is supported by Sung *et al.* (2019) who demonstrated muscle-enhanced stability during leg raises of PIT.[14] Furthermore, the amount of segmental displacement against an applied force has been reported to be important to determine spinal stability.[9] However, the amount of segmental displacement of the vertebrae during PIT is still unknown.

Previous studies evaluated the magnitude of segmental displacement of each lumbar vertebra in cadavers[15, 16] and showed increased displacement in the lower lumbar spine (L4 and L5).[16, 17] Although the results from cadaveric samples may give some understanding of the passive subsystem, it does not provide data on the contribution of the active subsystem to stability. This could limit the generalizability to clinical practice where passive, active, and neural subsystems interact to provide lumbar stability during static posture and movements.[8-10] Therefore, it is necessary to investigate PA displacement across the L1 to L5 lumbar spine during leg raise condition of PIT to better understand the contribution of the active subsystem in lumbar stability.

Evidence demonstrated abnormal segmental movement in individuals with LBP compared to asymptomatic individuals based on radiological findings[18] as well as passive segmental motion testing.[17, 19] Studies by Kulig *et al.* (2007) and Lundberg and Gerdle (2000) found abnormal segmental movement excursions during the manual application of PA compression force in individuals with CNLBP during prone lying compared to asymptomatic individuals.[17, 19] However, those studies evaluated the function of the passive subsystem alone. Therefore, assessing the PA displacement of lumbar spine during resting and leg raise conditions of PIT could provide a greater understanding regarding the role of both passive and active subsystems in spinal stability in individuals with CNLBP.

In addition to the contribution from passive and active subsystem, intrinsic factor such as sex could also affect the PA displacement of lumbar spine. Although lumbar lordosis and pelvic tilt were found to be greater while trunk muscle mass was found to be lesser in female compared to male,[20, 21] the activation of major lumbar stabilizer muscle; lumbar multifidus (LM) had demonstrated no significant difference between males and females in both healthy and CNLBP groups suggesting similar lumbar stability.[22] It is also supported by a study by Galbusera *et al.* (2021) in which they found no difference between males and females when assessing the segmental motion of each level using radiographs.[23] However, it has been shown that males and females with low back pain had different fatty infiltration patterns across L1 to S1.[24, 25] Accordingly, investigating the effect of sex in PA displacement during PIT is necessary to provide insight on the functional difference of passive and active subsystem to control PA displacement.

Hence, this study aimed to compare PA displacement across L1 to L5, between resting and leg raise positions, and between male and female during PIT in individuals with CLBP. We hypothesized that there would be a significant increase in PA displacement from L1 to L5 during resting, and significant reduction in PA displacement during leg raise position when the active subsystem (back muscles) helps to stabilize the lumbar spine regardless of sex.

Materials and methods

Study design

This study used a cross-sectional design to determine PA displacement across L1 to L5 and between resting and leg raised positions in male and female individuals with CNLBP.

Participants

The participants were recruited from the Faculty of Physical Therapy, Mahidol University and from the surrounding areas. The inclusion criteria for individuals with CNLBP were age between 18 and 40 years, having low back pain for more than 3 months (currently pain-free), or having recurrent back pain (during remission) for at least two episodes per year that interfered with activities of daily living which required treatment. The exclusion criteria were Body Mass Index greater than 30 kg/m^2 because presence of subcutaneous adipose tissue may not allow adequate vertebral displacement against externally applied PA force, presence of specific LBP conditions (*e.g.*, degenerative spine, spondylosis, or spinal stenosis, history of abdominal or back surgery), red flags (*e.g.*, infection, tumours, fracture, radicular syndrome, or inflammatory disease), previously diagnosed with neurological, musculoskeletal, or cardiac abnormalities (*e.g.*, scoliosis, myelopathy, atrial fibrillation), having menstruation, those who are pregnant or those receiving motor control training exercises, such as Pilates, stabilization exercises etc., for the past 6 months. This study was a part of intervention study with pre-specified sample size of 33 participants. However, we performed sample size calculation based on preliminary analysis comparing L5 displacement between resting (0.92±0.47 cm) and leg raise (0.76±0.30 cm), with a correlation between the 2 positions of 0.91. The alpha level was set to 0.05 (2-tailed) with an 80% power which yielded a total sample size of 20 participants. 33 participants were greater than required sample size; therefore, 33 participants should have sufficient statistical power for our study. All participants provided written informed consent before participating in the study, and the study was approved by the university institutional review board (COA No. 2021/184.0309) and complied with the declaration of Helsinki.

Instruments and measures

Electromagnetic motion tracking system (EMT; 3D Guidance trakSTAR, Ascension Technology Corp., Burlington, VT, USA) was used to collect PA displacement data at 100 Hz. EMT has been widely used in research to assess the segmental motion.[14, 26] Two EMT sensors (Model 800: 8×20 mm with 3.3 m cable) were attached over the thoracic (T12 spinous process) and pelvis (S2 spinous process), while another sensor was attached to a hand-held dynamometer (Model 01165, Lafayette Instrument, Lafayette, IN, USA) to apply the PA compression force (Figure 1A). PA displacement can be used to represent lumbar stability. Resolution reported by the manufacturer was 1.4 mm for positional data and 0.5 degrees for rotational data. Before the recent study, we analyzed the lumbar segmental displacement testing with the application of the study protocol in 15 individuals (4 healthy individuals and 11 individuals with CNLBP). This pilot phase demonstrated that test-retest reliability was good ($ICC_{3,1}$=0.67; CI=0.58-0.74). In addition, sensors were attached to the thoracic spine and pelvis which should be able to resist a compression force, and pilot work showed the displacement of the thoracic and pelvic sensors during the compression tests were negligible.

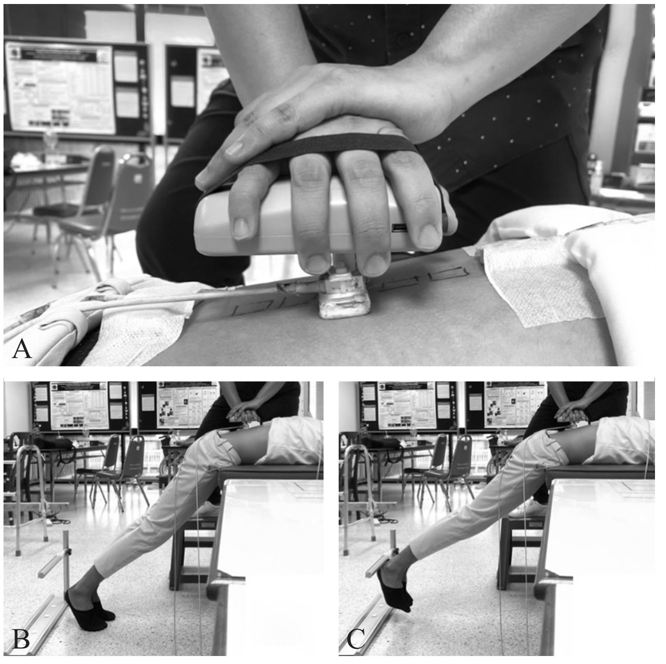

Figure 1.—Electromagnetic tracking sensors were attached over T12 spinous process, S2 spinous process, and a hand-held dynamometer (A) to provide compression force during resting (B) and leg raise (C) positions.

Procedure

To perform the PIT, participants were asked to lie in a prone position on a stable treatment table (Dimension: 50×50×132 inches) with both legs extended beyond the table and feet on the ground (Figure 1B). The assessor used a hand-held dynamometer with an EMT sensor to apply a 100N PA compression force over the L1 to L5 spinous process in a randomized order. The magnitude of 100 N force was selected based on a pilot study of 5 healthy participants, where 50N to 250N forces were used over the spinous processes and a PA compression force of 100N was found to be tolerated by the participants and showed a linear force-displacement curve. The force was applied for 10 seconds at the end of expiration to decrease the chance of raising the intra-abdominal pressure which may affect the PA displacement. Two trials were taken for each position with a 2-minute rest between measurements. Participants were then asked to raise both legs to an adjustable reference bar set to 10 inches above the ground (Figure 1C). The reference bar was adjusted depending on participant's limb length to maintain standard height of leg raises so that hip extension was approximately 10 degrees from resting position. A study by Wattananon *et al.* (2019) showed significant activity of LM when hip was extended to 10 degrees in prone position.[27] The assessor then applied the same 100N PA compression force over the L1 to L5 spinous processes with the same duration. The PA displacement data over the five spinous processes and two positions were used for further analysis.

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences (IBM SPSS statistics for windows, version 23). Descriptive statistics were used to describe demographic and clinical data. A three-way mixed ANOVA with 2 groups (male and female) and 2 repeated measures (5 levels; L1 to L5 and 2 conditions; resting and leg raise) was performed to determine differences in PA displacement. *Post-hoc* pairwise comparisons with a Bonferroni correction were performed if a main effect was seen, and the significance level was set at 0.05.

Data availability

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

Results

A total of 33 participants with CNLBP were recruited (mean age 27.2 years; 17 females; mean BMI 23.2 kg/m^2; mean height 1.68 meters; mean weight 66 kg) with a mean duration of low back pain of 3.42 years and mean recurrent episodes of 9.27 in the last 6 months. They were pain-free during the day of measurement. Demographic and clinical data are presented in Table I.

A three-way mixed ANOVA showed a significant interaction between the five spinous processes and two positions ($F_{4,108}$=11.72, P<0.01; partial η^2=0.30), main effect of level ($F_{4,108}$=13.34, P<0.01, partial η^2=0.33) and condition ($F_{1,27}$=37.04, P<0.01; partial η^2=0.58). However, results did not show significant interaction between level and sex (P>0.05), and condition and sex (P>0.05), as well as main effect of sex (P>0.05) on PA displacement. Therefore, further *post-hoc* pairwise comparisons for interaction effect between level and condition regardless of sex were performed (Figure 2). Results demonstrated a gradual decrease in PA displacement from L1 to L5 in the resting position, while no significant differences were seen between L1 to L5 in the leg raise position (P>0.05). Additionally, significant differences (P<0.05) in PA displacement were seen between the resting and leg raise positions at L1 to L4, but not at L5 (P>0.05).

Table I.—*Demographic characteristics.*

Demographic data	Mean (SD)
Age (years)	27.2 (6.6)
Number of females (%female)	17 (51.5%)
Height (in meters)	1.6 (0.09)
Weight (in kilograms)	66 (14.9)
Body Mass Index (kg/m^2)	23.2 (4.1)
Duration of low back pain (years)	3.4 (4)
Recurrent episodes within 6 months (episodes)	9.3 (8.2)

SD: standard deviation.

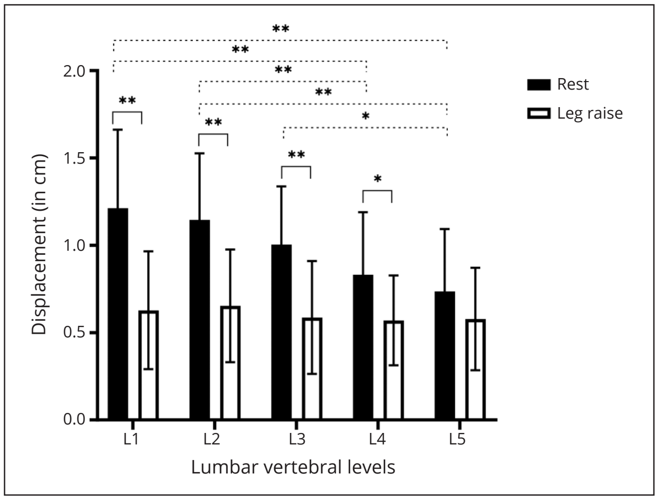

Figure 2.—*Post-hoc* multiple comparisons among 5 levels (L1 to L5) for each position, and between 2 positions (resting and leg raise) for each level.
*Level of significance P<0.05; **level of significance P<0.001.

Discussion

To the best of our knowledge, this is the first study that aimed to explore PA displacement for each lumbar vertebral level and the effect of sex during resting and leg raise positions of PIT in individuals with CNLBP. Our findings partially supported our hypothesis. We found that PA displacements in the upper lumbar spine (L1 to L3) were significantly greater than those in the lower lumbar spine (L4 and L5) contradicting our hypothesis. However, the comparison between the two positions did support our hypothesis with the PA displacement for L1 to L4 significantly decreasing during leg raise compared with the resting position. We also found that sex has no effect in PA displacement between 2 conditions of PIT across 5 lumbar levels.

Greater PA displacement was seen in the upper lumbar (L1 to L3) compared to the lower lumbar (L4 and L5) spine in the resting position. In contrast, several in-vitro studies have reported opposite findings of greater lower lumbar spine excursion.[15, 16] The disagreement could be because the above-noted studies measured the displacement of the lumbar spine in cadavers taking only the passive subsystem (disc, joint capsule, and ligaments) into account. Unlike the previous studies, the measurement on human participants in this study suggest the interaction of three stabilizing subsystems of the spine (active, passive, and neural subsystems) to control the spinal motion hence leading to different results.[10]

Particularly, lumbar multifidus muscle (LM) out of many muscles of the active subsystem is considered a major stabilizer which lies medial from the transverse process crossing 2-3 segments to the spinous process of the upper segments and has a greater cross-sectional area in the lower part of the lumbar spine.[28] Based on its anatomy, the LM can generate a large force over a small excursion, which in turn provides stability to the lower lumbar spine in both static and dynamic conditions.[28] Furthermore, passive mechanical properties of LM having high elastic modulus 45% greater than that of other back muscles suggested that LM could withstand high stress.[29] Therefore, in resting conditions of PIT, LM may be able to resist externally applied PA force causing lesser PA displacement in lower lumbar spine. However, abnormal changes in LM such as atrophy, fatty infiltration, reduced thickness, and muscle activation deficit have been reported in CLBP compared to healthy individuals by recent studies[7, 28] which may affect the ability to stabilize the spine during leg raise. Another explanation for the lower PA displacement in the lower lumbar spine in the resting position could be that the resting position during the PIT, with the hip already in a flexed position, might cause tension in the passive structures around the L4-L5 region.

Although we used a different approach to evaluate lumbar stability, our findings were consistent with previous studies that used magnetic resonance imaging (MRI) to assess lumbar segmental excursions during PA compression in a prone position.[17, 30] Both studies found a greater amount of lumbar excursion in the upper lumbar spine, with the least excursion being seen at L4-L5 in both healthy individuals and patients with low back pain. Interestingly, when compared between groups, they found that patients with low back pain had a greater lumbar excursion at L4-L5 than healthy individuals even though L4-L5 had the least excursion among the five lumbar segments.[17, 30] Further studies using our approach should include healthy individuals to determine whether individuals with CNLBP demonstrate greater instability in the lower lumbar spine.

The significant reduction in PA displacement in L1 to L4 during the leg raise compared to the resting position is consistent with the study by Sung *et al.* (2019).[14] This could be due to the contribution of the active subsystem to stabilize the lumbar spine during the leg raise, while there is minimal contribution of the active subsystem during the resting position.[10, 13] However, the study showed no significant difference between the resting position and leg raise at L5. The lack of a significant difference at L5 may suggest that participants with CNLBP cannot generate enough force to stabilize the lumbar spine which could be due to significant LM atrophy in L5.[31] One study demonstrated greater fatty infiltration in the LM and less in the psoas muscle in the L4-L5 region in females with CNLBP compared with females without LBP.[24] These findings suggest that patients might be using the psoas muscle to compensate for LM activation deficits. This could increase the risk of injury to the lumbar spine.

The findings of this study showed no significant difference in PA displacement among levels during the leg raise position. Although there were no previous studies to compare the findings, this study provides evidence to support the mechanism of PIT in which the activation of back muscles would stabilize the lumbar spine causing a reduction in PA displacement during the leg raise position. This finding is also in line with many studies that have highlighted the role of the active subsystem in spinal stability.[8, 10, 32]

Our findings demonstrated no interaction of sex with PA displacement between the different lumbar levels and the conditions of PIT. Our findings were consistent with studies that showed no difference in LM activation using ultrasound imaging and segmental motion of each lumbar level using radiographs between males and females.[22, 23] Although studies demonstrated that males and females with CNLBP had different fatty infiltration patterns in lumbopelvic region, those patterns were found in obese female patients (BMI>30 kg/m^2).[25] As our study excluded those participants with BMI greater than 30 kg/m^2, this would imply that both male and female participants in our study should have similar fatty infiltration patterns, thereby having similar effects on the LM activation. Accordingly, our finding suggests that PIT could demonstrate the integrity of passive and active subsystem in controlling the vertebral displacement regardless of sex.

Limitations of the study

There are some limitations in this study. Using a standardized protocol to minimize variability such as standard magnitude of PA compression force and reference bar to lift the leg, may not represent the clinical scenario. However, the testing procedure was designed to replicate assessments used in the clinical setting as much as possible. In this study, individuals with specific low back pain and older adults with an age greater than 40 were excluded. Hence, caution should be taken in generalizing the results of this study to those populations.

Conclusions

Our findings demonstrated that sex has no effect in PA displacement between the two conditions of PIT across the 5 lumbar levels. The lower lumbar spine (L4 and L5) had greater stability than the upper lumbar spine (L1 to L3) during the resting position. We also found a reduction in displacement during the leg raise position across L1 to L4 suggesting an interaction of stabilizing subsystems of the spine to provide lumbar stability. However, the lack of any significant difference between resting and leg raise positions at L5 may suggest an inadequate force to stabilize the lumbar spine at this level.

References

1. GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet 2020;396:1204–22.

2. Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, *et al.* A systematic review of the global prevalence of low back pain. Arthritis Rheum 2012;64:2028–37.

3. Areeudomwong P, Jirarattanaphochai K, Ruanjai T, Buttagat V. Clinical utility of a cluster of tests as a diagnostic support tool for clinical lumbar instability. Musculoskelet Sci Pract 2020;50:102224.

4. Puntumetakul R, Yodchaisarn W, Emasithi A, Keawduangdee P, Chatchawan U, Yamauchi J. Prevalence and individual risk factors associated with clinical lumbar instability in rice farmers with low back pain. Patient Prefer Adherence 2014;9:1–7.

5. Kong-Oun S, Prasertkul W, Fungkiatphaiboon P, Wattananon P. The inter-rater reliability of clinical observation of prone hip extension and association between aberrant movement and chronic low back pain. Musculoskelet Sci Pract 2022;57:102476.

6. Luomajoki H, Kool J, de Bruin ED, Airaksinen O. Movement control tests of the low back; evaluation of the difference between patients with low back pain and healthy controls. BMC Musculoskelet Disord 2008;9:170.

7. Sungnak P, Songjaroen S, Krityakiarana W, Wang HK, Richards J, Wattananon P. Individuals with impaired lumbopelvic control demonstrate lumbar multifidus muscle activation deficit using ultrasound imaging in conjunction with electrical stimulation: a cross-sectional Study. Arch Phys Med Rehabil 2022;103:1951–7.

8. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech (Bristol, Avon) 1996;11:1–15.

9. Fritz JM, Erhard RE, Hagen BF. Segmental instability of the lumbar spine. Phys Ther 1998;78:889–96.

10. Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. J Spinal Disord 1992;5:383–9, discussion 397.

11. Chatprem T, Puntumetakul R, Kanpittaya J, Selfe J, Yeowell G. A diagnostic tool for people with lumbar instability: a criterion-related validity study. BMC Musculoskelet Disord 2021;22:976.

12. Ferrari S, Manni T, Bonetti F, Villafañe JH, Vanti C. A literature review of clinical tests for lumbar instability in low back pain: validity and applicability in clinical practice. Chiropr Man Therap 2015;23:14.

13. Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. Arch Phys Med Rehabil 2005;86:1753–62.

14. Sung W, Hicks GE, Ebaugh D, Smith SS, Stackhouse S, Wattananon P, *et al.* Individuals with and without low back pain use different motor control strategies to achieve spinal stiffness during the prone instability test. J Orthop Sports Phys Ther 2019;49:899–907.

15. Cook DJ, Yeager MS, Cheng BC. Range of motion of the intact lumbar segment: a multivariate study of 42 lumbar spines. Int J Spine Surg 2015;9:5.

16. White AA 3rd, Panjabi MM. The basic kinematics of the human spine. A review of past and current knowledge. Spine 1978;3:12–20.

17. Kulig K, Powers CM, Landel RF, Chen H, Fredericson M, Guillet M, *et al.* Segmental lumbar mobility in individuals with low back pain: in vivo assessment during manual and self-imposed motion using dynamic MRI. BMC Musculoskelet Disord 2007;8:8.

18. McGregor A, Anderton L, Gedroyc W. The assessment of intersegmental motion and pelvic tilt in elite oarsmen. Med Sci Sports Exerc 2002;34:1143–9.

19. Lundberg G, Gerdle B. Correlations between joint and spinal mobility, spinal sagittal configuration, segmental mobility, segmental pain, symptoms and disabilities in female homecare personnel. Scand J Rehabil Med 2000;32:124–33.

20. Hori Y, Hoshino M, Inage K, Miyagi M, Takahashi S, Ohyama S, *et al.* Gender-specific analysis for the association between trunk muscle mass and spinal pathologies. Sci Rep 2021;11:7816.

21. Yukawa Y, Kato F, Suda K, Yamagata M, Ueta T, Yoshida M. Normative data for parameters of sagittal spinal alignment in healthy subjects: an analysis of gender specific differences and changes with aging in 626 asymptomatic individuals. Eur Spine J 2018;27:426–32.

22. Thu KW, Maharjan S, Sornkaew K, Kongoun S, Wattananon P. Multifidus muscle contractility deficit was not specific to the painful side in patients with chronic low back pain during remission: a cross-sectional study. J Pain Res 2022;15:1457–63.

23. Galbusera F, Niemeyer F, Tao Y, Cina A, Sconfienza LM, Kienle A, *et al.* ISSLS Prize in Bioengineering Science 2021: in vivo sagittal motion of the lumbar spine in low back pain patients-a radiological big data study. Eur Spine J 2021;30:1108–16.

24. Özcan-Ekşi EE, Ekşi MŞ, Turgut VU, Canbolat Ç, Pamir MN. Reciprocal relationship between multifidus and psoas at L4-L5 level in women with low back pain. Br J Neurosurg 2021;35:220–8.

25. Özcan-Ekşi EE, Turgut VU, Küçüksüleymanoğlu D, Ekşi MŞ. Obesity could be associated with poor paraspinal muscle quality at upper lumbar levels and degenerated spine at lower lumbar levels: is this a domino effect? J Clin Neurosci 2021;94:120–7.

26. Owens EF Jr, DeVocht JW, Gudavalli MR, Wilder DG, Meeker WC. Comparison of posteroanterior spinal stiffness measures to clinical and demographic findings at baseline in patients enrolled in a clinical study of spinal manipulation for low back pain. J Manipulative Physiol Ther 2007;30:493–500.

27. Wattananon P, Silfies SP, Tretriluxana J, Jalayondeja W. Lumbar multifidus and erector spinae muscle synergies in patients with nonspecific low back pain during prone hip extension: a cross-sectional study. PM R 2019;11:694–702.

28. Hodges PW, Danneels L. Changes in structure and function of the back muscles in low back pain: different time points, observations, and mechanisms. J Orthop Sports Phys Ther 2019;49:464–76.

29. Ward SR, Tomiya A, Regev GJ, Thacker BE, Benzl RC, Kim CW, *et al.* Passive mechanical properties of the lumbar multifidus muscle support its role as a stabilizer. J Biomech 2009;42:1384–9.

30. Beneck GJ, Kulig K, Landel RF, Powers CM. The relationship between lumbar segmental motion and pain response produced by a posterior-to-anterior force in persons with nonspecific low back pain. J Orthop Sports Phys Ther 2005;35:203–9.

31. Wallwork TL, Stanton WR, Freke M, Hides JA. The effect of chronic low back pain on size and contraction of the lumbar multifidus muscle. Man Ther 2009;14:496–500.

32. Freeman MD, Woodham MA, Woodham AW. The role of the lumbar multifidus in chronic low back pain: a review. PM R 2010;2:142–6, quiz 1, 167.

Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Funding
This study was funded by National Research Council of Thailand (N42A650360) and the Faculty of Physical Therapy, Mahidol University (Research Assistant Fund).

Authors' contributions
Soniya Maharjan has significantly contributed to the conception, research design, data collection, data analysis, and drafting the manuscript; Khin W. Thu, Sasithorn Kongoun, and Kanphajee Sornkaew have significantly contributed to research design and data collection; Jim Richards has substantially contributed to data analysis, editing, and revising the manuscript; Peemongkon Wattananon has substantially contributed to the conception, research design, data analysis, drafting, and revising the manuscript. All authors read and approved the final version of the manuscript.

Acknowledgements
We would like to thank the Faculty of Physical Therapy, Mahidol University for providing research equipment and space for data collection. We also would like to thank all participants for their contribution to the study.

History
Article first published online: July 27, 2023. - Manuscript accepted: July 17, 2023. - Manuscript revised: July 4, 2023. - Manuscript received: December 12, 2022.