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Diaphragm excursion and thickness in patients with chronic low back pain with and without lumbar instability

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Diaphragm is crucial for respiration and plays a significant role in trunk stabilization, particularly during postural tasks. Several studies have focused primarily on trunk muscles in lumbar instability (LI) patients. However, the role of diaphragm remains underexplored. Therefore, this study aimed to compare diaphragm excursion, diaphragm thickness, and lung function represented by predicted percentage of forced vital capacity (%FVC predicted) during a load-lifting at tidal breathing between CLBP patients with ($CLBP_{LI}$) and without LI ($CLBP_{NLI}$). Ninety-six participants with CLBP, aged between 20 and 59 years, were divided into $CLBP_{LI}$ and age-matched $CLBP_{NLI}$ groups based on screening tools and clinical tests. Diaphragm excursion and diaphragm thickness were assessed using real-time ultrasound imaging during load-lifting with tidal breathing. Additionally, lung function was measured using a spirometer. $CLBP_{LI}$ group had significantly decreased total diaphragm excursion (*p*-value = 0.003) and diaphragm thickness at inspiration (*p*-value = 0.027) and expiration (*p*-value = 0.34) compared to $CLBP_{NLI}$ group. There were no differences between the groups in excursions during inspiration and expiration, total thickness, thickness change, and %FVC predicted. Individuals with $CLBP_{LI}$ exhibited decreased diaphragm excursion and diaphragm thickness during inspiration and expiration. Addressing diaphragm training in rehabilitation programs may lead to more effective treatment outcomes for LI patients.

Keywords Diaphragm excursion, Diaphragm thickness, Chronic low back pain with lumbar instability, Ultrasonography, Lumbar instability

Chronic low back pain (CLBP) is particularly prevalent and enduring, which results in long-term disability, economic losses from reduced work hours, and increased use of healthcare services[1]. Lumbar instability (LI) is one of the most common causes of CLBP, defined as the mechanical low back pain subgroup[2]. Previous studies reported LI was observed in 13–75.42% of patients with CLBP across various occupations[3]. LI is characterized by excessive inter-segmental movement, which can provoke pain, particularly when accompanied by deep core muscle weakness[3–6]. These symptoms are often exacerbated by activities that challenge spinal stability, such as lifting, prolonged standing, or carrying objects[7,8].

The classic stability system theory proposed by Panjabi suggests that there are three stabilizing subsystems: passive, neural control, and active subsystems[9]. LI arises when at least one of the three sub-stabilizing systems loses functionality. Although the impairment of the active subsystems, which focuses on core muscles, has garnered significant attention from researchers[10–12] and is known as movement control impairment[13], the passive subsystem remains especially important, particularly in patients with intervertebral disc degeneration. The dysfunction of the passive subsystem requires compensation from the active and neural control subsystems and inadequate compensation can result in further injury and produce low back pain[5,7,14,15]. Supported by Silfies et al.'s study (2005), it was reported that the pathology of the intervertebral disc can lead to compensatory increases in the activity from the remaining subsystems[10], which may contribute to lumbar instability.

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The core trunk muscles are categorized into global and local stabilizers. Global muscles are crucial for controlling trunk and pelvis movements[16]. Local muscles are vital for maintaining lumbar segment stability, these muscles include the lumbar multifidus (LM), transversus abdominis (TrA), pelvic floor muscles (PF), and the diaphragm[17]. Alterations in abdominal and back muscles have been reported in CLBP with LI, involving higher activities of the superficial abdominal muscle (Rectus Abdominis (RA) and External Oblique (EO)), lower activities of the deep abdominal muscle (TrA and Internal Oblique (IO)) and weakness of deep back muscle (LM) compared with CLBP without LI[10–12,18,19]. However, the role of the diaphragm has never been reported in lumbar instability patients.

The diaphragm is the primary respiratory muscle and also plays a crucial role in postural control by regulating intra-abdominal pressure (IAP)[20]. During physical activities such as jumping, running, or lifting, IAP increases[21,22] by appropriate activation between the diaphragm and TrA before limb movement[23]. Moreover, these muscles work synergistically to precisely control excessive joint motion and prevent injuries caused by external loads[24].

Based on previous studies, ineffective diaphragm contraction could result in inadequate IAP generation, compromising spinal stiffness[25]. Several studies have reported diaphragm dysfunction in patients with CLBP, including improper positioning (e.g., higher position in the trunk compared to healthy individual)[26,27], decreased mobility (excursion)[28] and morphological changes (e.g., decreased thickness)[29,30]. Consequently, diaphragm dysfunction can disrupt both respiration and spinal stabilization.

Diaphragmatic contraction can be assessed using static and dynamic techniques[31,32], . Real-time ultrasound imaging is widely utilized for this purpose, offering a non-invasive, non-radiation exposure, being portable, and a safe method to evaluate diaphragm contraction[30–33]. Several studies have investigated diaphragm contraction during various tasks in patients with CLBP compared to healthy individuals[26,28–30]. Notably, studies that applied a load to the diaphragm may enhance the detection of diaphragm impairments[26,27,33].

To date, no studies have specifically compared diaphragm contraction during postural tasks using real-time ultrasound imaging in CLBP patients with and without LI. Therefore, the current study aimed to compare diaphragm excursion, diaphragm thickness, and lung function represented by predicted percentage of forced vital capacity (%FVC predicted) during load-lifting at tidal breathing in CLBP patients with and without LI. We hypothesized that diaphragm contraction would be more diminished in individuals with CLBP with LI. Understanding the activity pattern of the diaphragm during loading tasks can assist therapists in designing optimal training protocols for individuals CLBP with and without LI.

Methods

This study was designed as a matched case-control study, pairing individuals with CLBP with and without LI across four age groups: 20–29, 30–39, 40–49, and 50–59 years. The study was approved by the Human Research Ethics Committee of Khon Kaen University, Thailand (HE 662168), in accordance with the Declaration of Helsinki. It was prospectively registered with the Thai Clinical Trials Registry (TCTR 20231010001). All experiments were conducted following relevant guidelines and regulations, adhering to the STROBE criteria. The study was conducted at the Physical Therapy Laboratory, Faculty of Associated Medical Sciences, Khon Kaen University.

Participants

Males and females with a history of intermittent low back pain for more than twelve weeks and mild to moderate low back pain (3–7 cm on 10 cm of visual analog scale; VAS scale) aged between 20 and 59 years were invited to participate in the current study. They were recruited through notice boards and social media advertisements between October 2023 and January 2024. They were excluded if they had: pregnancy, body mass index (BMI) over 30 kg/m^2, history of surgery (e.g., spine, abdominal, cardiothoracic, lower limb), chronic respiratory disease (e.g., chronic obstructive pulmonary disease, asthma, pulmonary hypertension), history of neuromuscular disorder, history of pain or dysfunction (e.g., serious spinal pathologies, spondylolisthesis, scoliosis), history of pelvic traumatic injury, cigarette smoking, or were an athlete (who participates in an organized team or individual sport that requires regular competition against others by self-reported)[34]. Participants were withdrawn if they experienced pain beyond their t1olerance during testing.

The sample size was calculated based on a formula for calculating the difference of mean between group[35] with the referent of the diaphragm excursion from Sembera et al.'s study (2022). In their study, the diaphragm excursion was measured using ultrasound imaging during load-lifting. Two formulas were used to calculate the sample size: (1) $= \frac{S1+S2}{2}$

(S1 = 8.79, S2 = 6.85), resulting in 7.82 and (2) $2\left[\frac{(Z_\alpha + Z_\beta\ )_d}{\Delta}\right]^2$ ($Z_\alpha = 1.65$, $Z_\beta = 0.84$, $\Delta = 2.82$), which was determined to achieve a power of 80% at a significance level of 0.05[33]. According to these formulas, the current study required a total of 96 participants. They were informed about the study procedures, and written consent was obtained prior to the commencement of data collection.

Procedures

The participants' flow and study process were summarized in Fig. 1. The details of each process were described below.

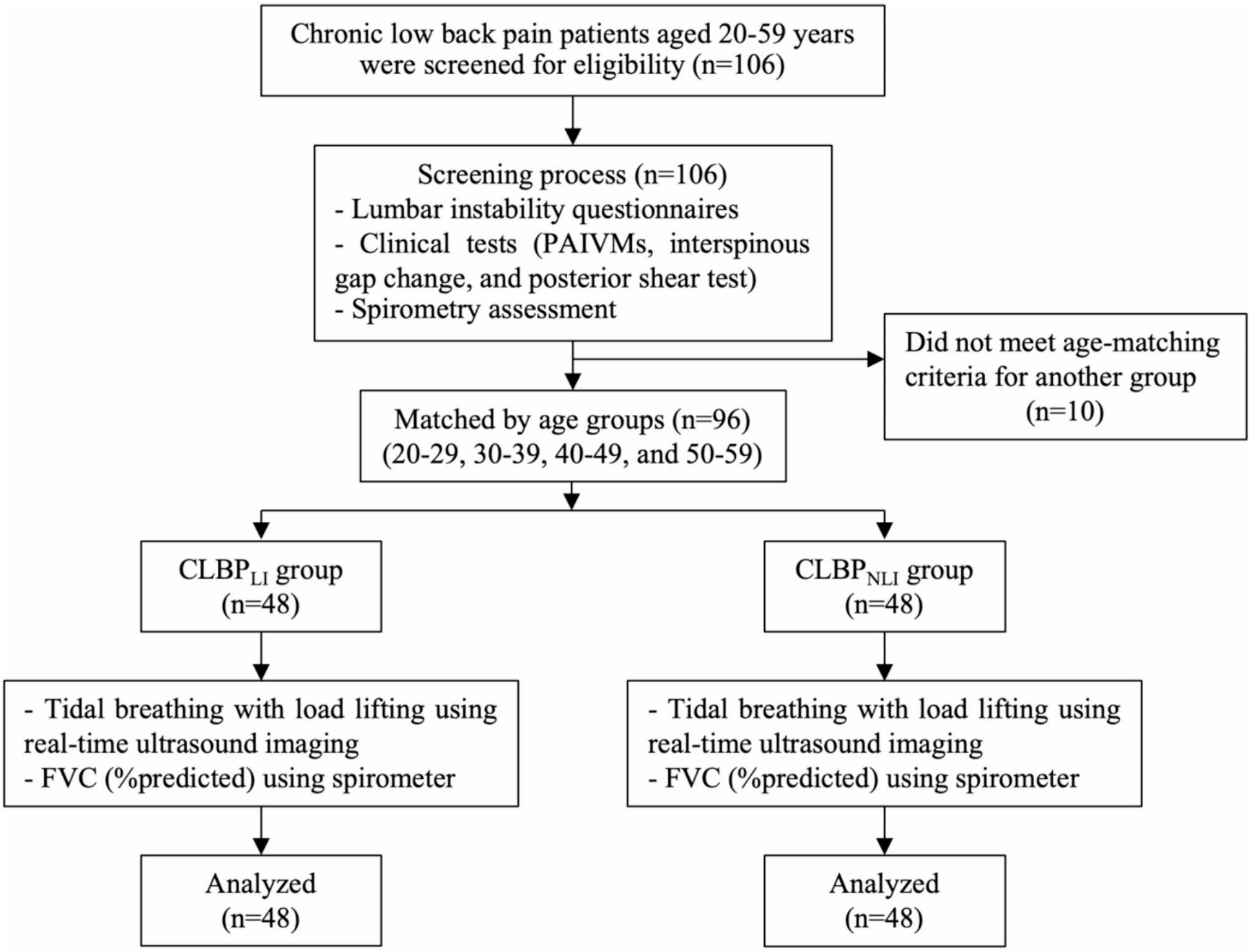

Fig. 1. Flow diagram of participants throughout the study.

Screening protocols

Screening tests were used to determine the eligibility of the participants for the study. Demographic data, including age, weight, height, BMI, pain duration, and pain intensity (VAS), were recorded. This process was conducted by the principal researcher WB.

Then CLBP was determined for presenting lumbar instability using the 14-item lumbar instability questionnaire and three clinical tests (interspinous gap change during flexion-extension, passive accessory intervertebral movement (PAIVMs), and the posterior shear test) by the research assistant, a physiotherapist with seven years of clinical experience AL. Participants were categorized into CLBP with LI (CLBP$_{LI}$) group if they scored 7/14 on the lumbar instability questionnaire and tested positive on all three clinical tests[5,8]. Those who did not meet these criteria were placed in the CLBP without LI (CLBP$_{NLI}$) group. Next, two groups were matched by the following age range of 20–29, 30–39, 40–49, and 50–59 years by the researcher assistant (TC).

Lung function assessment

Lung function was performed using a spirometer (Vyntus™ SPIRO PC Spirometer). Research assistant TC entered the participant's information, including age, height, gender, and ethnicity, into the spirometer program. Participants were instructed to perform the FVC protocol. The three acceptable and repeatable trials were recorded. The program automatically reports all of the values related to FVC testing. The FEV_1/FVC% ratio of less than 80 was used as an exclusion criterion for participants with active respiratory disease[36]. The predicted percentage of forced vital capacity (%FVC predicted) of the best trial was selected for future analysis. This assessment followed the standard protocol of the American Thoracic Society (ATS) and European Respiratory Society (ERS) spirometry guidelines (2019) with was selected the Thai predicted reference values[37] for calculating the percentage of predicted FVC[36]. The process was overseen by the research assistant TC, the FEV_1/FVC% and %FVC predicted were selected as the baseline and outcome measurement, respectively.

Diaphragm function assessments – Training and rater reliability

Researcher WS was trained by a radiologist with 30 years of clinical experience on how to use ultrasound imaging to assess the diaphragm, including using measurement tools, landmarks to place the ultrasound probe, identifying the diaphragm, and how to draw the measurement line. Training proceeded until the radiologist was satisfied with the accuracy of the results from researcher WS. Ten participants with CLBP were invited to participate in an intra-rater reliability test, their results were not included in the main study. The intra-rater reliability of the diaphragm excursion was 0.98 (95% CI: 0.92–0.99), and the diaphragm thickness was 0.98 (95% CI: 0.93–0.99).

Researcher WS, who was blinded to the participant group allocation, performed real-time ultrasound imaging measurements. Before testing, participants were familiarized with the study protocol, including tidal breathing patterns, and each participant was asked about their pain level. Then, they were instructed to stand with their feet shoulder-width apart, their shoulders slightly abducted, with shoulder flexion of no more than 15 degrees and elbow flexion approximately 130 degrees (Fig. 2A and B), similar to the process described by Sembeara et al. (2022) study[33]. The dumbbell was placed on the table in front of participants, then they were asked to hold a dumbbell with approximately 10% of their body weight (weight range between 50 and 59 kg, the dumbbell weight was 5 kg). While holding the dumbbell, participants were instructed to perform tidal breathing with three breaths to challenge the diaphragm, given its dual tasks of respiration and stabilization[33,38,39]. One out of three breaths were selected for analysis for each patient. The ultrasound probe was placed on the chest wall during the measurement (Fig. 2C). After completing the test, participants were asked about their pain level again, but the level was not recorded formally. The details of each diaphragm parameters testing are as follows.

Diaphragm excursion

Diaphragm excursion was measured using M-mode ultrasound with a 3.6-5.0 MHz convex transducer (SonoScape P15/P10 Plus Digital Color Doppler Ultrasound machine, Guangdong, China). The probe was placed on the lower intercostal area between the mid-clavicular and anterior axillary lines to measure the right hemidiaphragm. The probe was positioned medially, cranially, and dorsally to obtain the clearest view (Fig. 3A). Three breaths of tidal breathing were required for each patient while they were holding a dumbbell. The breathing that gives the highest inspiration relative to expiration was selected to calculate the diaphragm excursion, which was recorded in millimeters (mm) (Fig. 3B). The diaphragm excursion at inspiration (E^{ins}) was defined as the highest point following arrow pointing down in the Fig. 3B. The diaphragm excursion at expiration (E^{exp}) was defined as the steepest point following arrow pointing up in the Fig. 3B. Total diaphragm excursion was identified as the difference values between the highest (inspiration) and steepest (expiration) points.

Diaphragm thickness and thickness change

Diaphragm thickness was measured using B-mode ultrasound with a 7.0-12.2 MHz linear transducer (SonoScape P15/P10 Plus Digital Color Doppler Ultrasound machine, Guangdong, China). The probe was placed perpendicular to the chest wall between the mid and anterior axillary lines on the right hemidiaphragm, typically between the 8th and 10th intercostal spaces, to obtain the most precise image of the zone of apposition of the diaphragm, with the probe spanning two ribs (Fig. 4A). Each patient performed three breaths of tidal

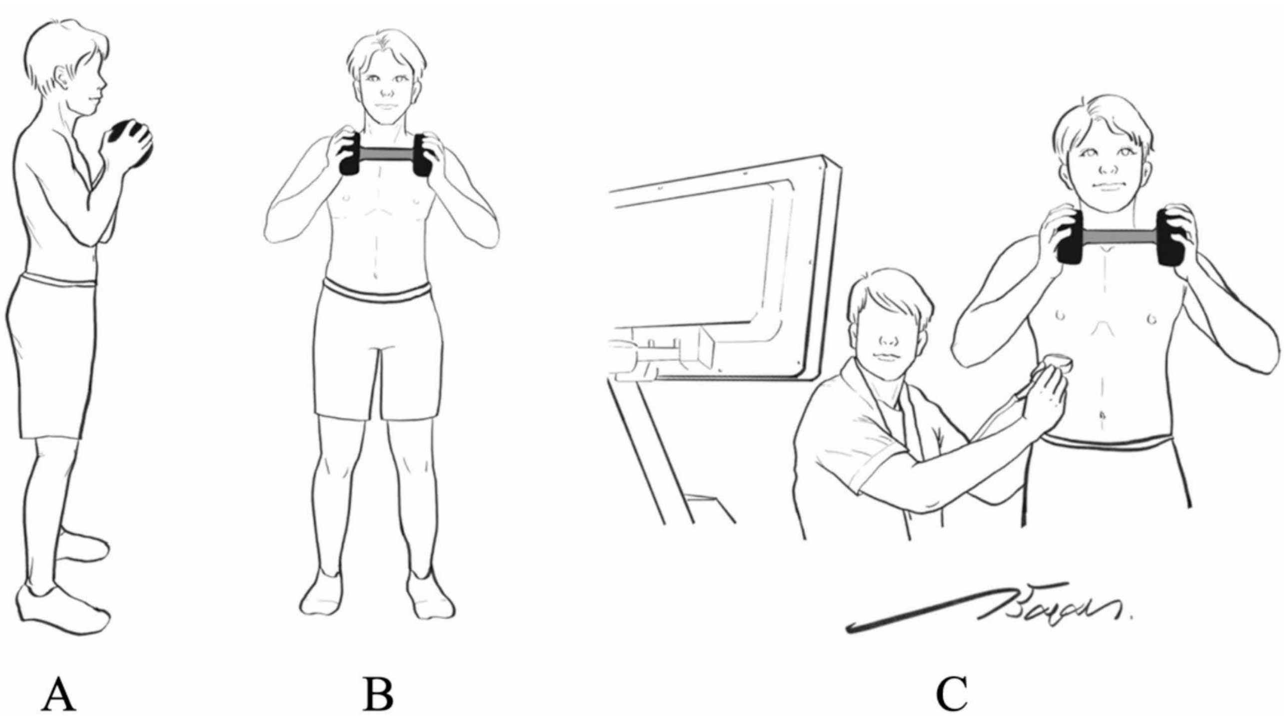

Fig. 2. (**A**) Participant with the dumbbell at front view (**B**) Participant with the dumbbell at lateral view (**C**) Ultrasound probed placing at participant's chest wall.

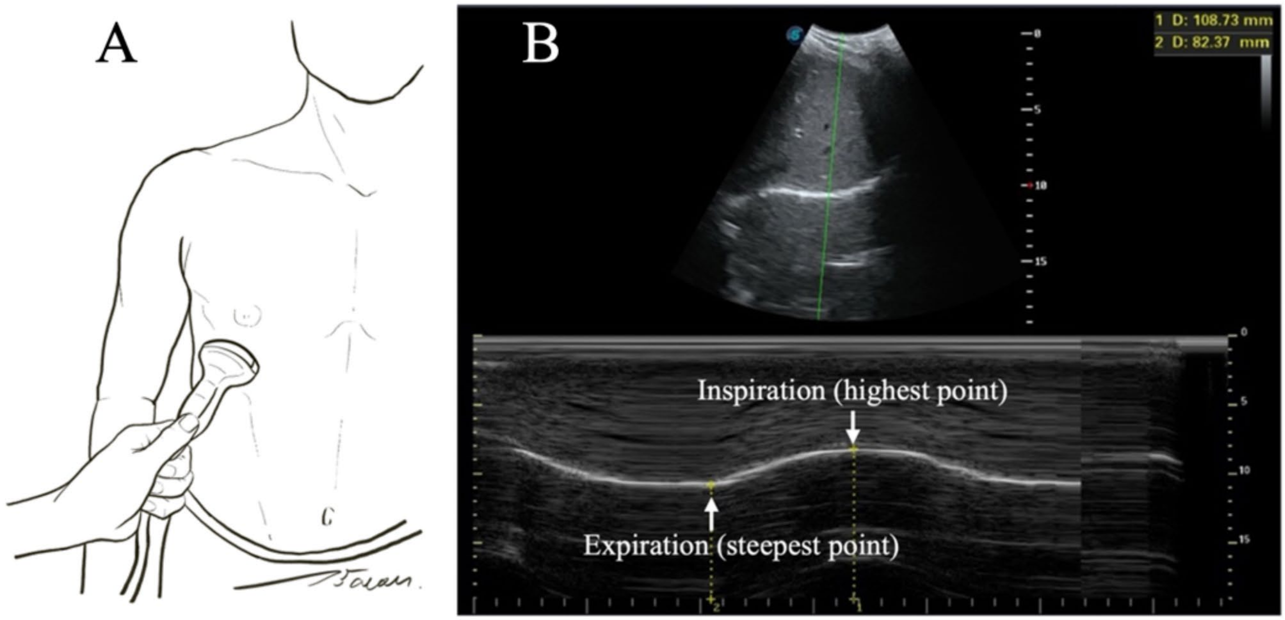

Fig. 3. (**A**) Position the M-mode ultrasound transducer (**B**) Ultrasound images were obtained over this area.

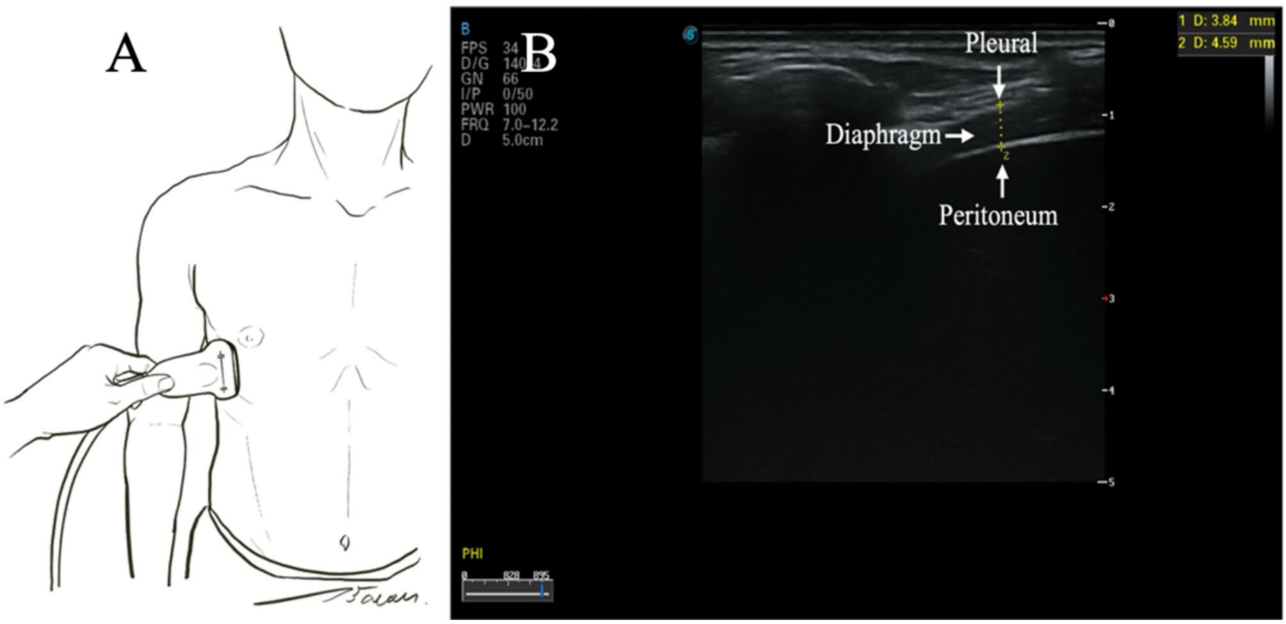

Fig. 4. (**A**) Position the B-mode ultrasound transducer (**B**) Ultrasound images were obtained over this area.

breathing while holding a dumbbell. The diaphragm thickness was identified as the muscle fibers that line between the pleura and peritoneum margins (Fig. 4B). The breathing that gives the highest inspiration thickness relative to expiration thickness was selected to calculate the diaphragm thickness, which was recorded in millimeters (mm). Inspiratory thickness (T^{ins}) was observed during the peritoneum margin layer moving to the right and T^{ins} was the distance between the pleural and peritoneum layers (Fig. 4B). Expiratory thickness (T^{exp}) was observed during the peritoneum margin layer returning to its baseline position (move to the left) and T^{exp} was the distance between the pleural and peritoneum layers (Fig. 4B). Total thickness was calculated as the difference between inspiratory and expiratory thickness. Thickness change was calculated by this formula: $(T_{ins} - T_{exp})/T_{exp} \times 100$.

Variables	$CLBP_{LI}$ (n = 48) Mean ± SD	$CLBP_{NLI}$ (n = 48) Mean ± SD	p-values
Age (years)	44.42 ± 10.41	44.19 ± 11.19	0.92
20–29 years	23.83 ± 2.14	23.17 ± 2.93	
30–39 years	36.70 ± 2.45	35.70 ± 2.95	
40–49 years	45.55 ± 2.34	44.00 ± 3.13	
50–59 years	53.38 ± 2.48	54.33 ± 2.54	
Height (cm)	160.02 ± 6.92	160.25 ± 7.68	0.88
Weight (kg)	61.71 ± 8.78	62.00 ± 10.96	0.89
BMI (kg/m^2)	24.10 ± 3.01	24.05 ± 3.22	0.94
Pain intensity VAS (cm)	5.24 ± 1.35	4.55 ± 1.44	0.02*
Pain duration (month)	61.48 ± 43.10	57.04 ± 45.82	0.63
FEV_1/FVC (%)	88.18 ± 5.61	87.66 ± 6.55	0.28
Gender, n (%)			0.44
Male	8 (16.67)	11 (22.92)	
Female	40 (83.33)	37 (77.08)	

Table 1. Demographic characteristics of CLB with and without LI. $CLBP_{LI}$, chronic low back pain with lumbar instability; $CLBP_{NLI}$, chronic low back pain without lumbar instability; BMI, body mass index; VAS, visual analog scale; m, meter; kg, kilogram. $p < 0.05$ was considered statistically significant (*).

Variables	Group	Mean ± SD	Mean Difference (95% CI)	p-value	Effect size (Cohen's d)
E^{ins} (mm)	$CLBP_{LI}$	82.02 ± 19.89	2.81 (−5.48 to 11.12)	0.502	20.48
	$CLBP_{NLI}$	79.21 ± 21.10			
E^{exp} (mm)	$CLBP_{LI}$	68.40 ± 19.09	6.85 (−1.25 to 14.95)	0.096	19.98
	$CLBP_{NLI}$	61.55 ± 20.84			
Total excursion (mm)	$CLBP_{LI}$	13.63 ± 6.28	−4.03 (−6.69 to −1.38)	0.003*	6.54
	$CLBP_{NLI}$	17.67 ± 6.80			
T^{ins} (mm)	$CLBP_{LI}$	3.40 ± 0.94	−0.51 (−0.96 to −0.06)	0.027*	1.10
	$CLBP_{NLI}$	3.91 ± 1.25			
T^{exp} (mm)	$CLBP_{LI}$	2.78 ± 0.85	−0.44 (−0.85 to −0.03)	0.034*	1.01
	$CLBP_{NLI}$	3.21 ± 1.15			
Total thickness (mm)	$CLBP_{LI}$	0.63 ± 0.38	−0.06 (−0.23 to 0.01)	0.436	0.40
	$CLBP_{NLI}$	0.70 ± 0.42			
Thickness change (%)	$CLBP_{LI}$	24.43 ± 16.15	1.18 (−4.98 to 7.34)	0.704	15.20
	$CLBP_{NLI}$	23.25 ± 14.18			
%FVC predicted	$CLBP_{LI}$	93.79 ± 11.89	−0.92 (−5.75 to 3.92)	0.708	11.94
	$CLBP_{NLI}$	94.71 ± 11.98			

Table 2. Compare the diaphragm function and lung function between groups with CLBP with and without LI (n/group = 48). E^{ins}, excursion at inspiration; E^{exp}, excursion at expiration; T^{ins}, thickness at inspiration; T^{exp}, thickness at expiration; FVC, forced vital capacity; Mean ± SD, mean ± standard deviation; CI, confidence interval; $p < 0.05$ was considered as statistically significant (*).

Statistical analysis

Statistical analyses were performed using SPSS version 28 statistical software. Data distribution was tested using the Shapiro-Wilk test, with $p > 0.05$ indicating normality. Descriptive statistics were presented as mean ± standard deviation (SD) for normally distributed data and as median (interquartile range) for non-normally distributed data. Independent t-tests were used to compare variables between the $CLBP_{LI}$ and $CLBP_{NLI}$ groups when the data were normally distributed, and the Mann-Whitney U test was used for non-normally distributed. Statistical significance was set at $p < 0.05$ for all tests.

Results

There were no statistically significant differences ($p > 0.05$) of the demographic characteristic including: age, height, weight, BMI, pain duration, FEV_1/FVC (%), and gender between groups, except pain intensity, which showed $CLBP_{LI}$ had higher pain intensity than the $CLBP_{NLI}$ group ($p = 0.02$) as Table 1.

The results indicated a normal distribution for all outcome variables; therefore, an independent sample t-test was selected for analysis. Among the outcome variables, Table 2 indicated a statistically significant difference

($p = 0.003$) in total diaphragm excursion between the $CLBP_{LI}$ group and the $CLBP_{NLI}$ group, with a large effect size (Cohen's $d = 6.54$). However, no statistically significant difference was found in excursion during expiration and inspiration between groups ($p > 0.05$).

Regarding the diaphragm thickness during inspiration and expiration, the $CLBP_{LI}$ group showed a significant decrease compared to $CLBP_{NLI}$ group, with p-value of 0.027 and 0.034. However, total thickness in the $CLBP_{LI}$ group was not statistically significant with the $CLBP_{NLI}$ groups ($p > 0.05$). The diaphragm thickness change was slightly greater in the $CLBP_{LI}$ group, but there were no statistically significant differences ($p > 0.05$) between the groups.

Additionally, the mean of %FVC predicted a slight decrease in the $CLBP_{LI}$ group, with no statistically significant difference between groups ($p > 0.05$).

Discussion

The current study is the first case-control study investigating diaphragm excursion and thickness during load lifting with tidal breathing using real-time ultrasound comparing $CLBP_{LI}$ and $CLBP_{NLI}$ groups. We also investigated lung function using the spirometer. Between-group comparison showed statistically significant differences in total diaphragm excursion and thickness during inspiration and expiration, whereas there were no statistically significant differences in diaphragm excursion during inspiration and expiration, total diaphragm thickness, diaphragm thickness change, and %FVC predicted.

The researchers developed an age-matched control study to reduce any confounding factors that age might introduce, such as the degeneration of the spine and natural reduction of lung capacity[6,41,42]. We also used the screening questionnaire combined with three clinical tests, each validated against x-ray films[5,8], to confirm that all participants included had low back pain due to lumbar instability. Considering each clinical test, patients with lumbar instability in this study may be more likely to exhibit passive subsystem dysfunction with compensation mechanisms in other subsystems.

Although we did not measure each part of the diaphragm using magnetic resonance imaging (MRI), our study employed real-time ultrasound imaging to measure diaphragm excursion in two dimensions (2D). This technique appeared to capture measurements primarily from the mid-posterior portion of the diaphragm[32], and is particularly suitable for measuring diaphragm movement during postural tasks in a standing position[33,43].

The current research was designed to incorporate load lifting by holding approximately 10% of the participant's body weight while performing tidal breathing. A previous study claimed that carrying this weight did not cause pain in the lower back region, even in CLBP patients who walked for 20 min with the weight[44]. Tidal breathing was employed because it could expose diaphragm dysfunction without exerting the participant and could replicate the breathing pattern in real-life situations during participants' daily activities.

Diaphragm excursion between $CLBP_{LI}$ and $CLBP_{NLI}$

There was a significant decrease in total diaphragm excursion in the $CLBP_{LI}$ group compared to the $CLBP_{NLI}$ group (p-value $= 0.003$), consistent with the findings of several studies. However, their studies compared participants with CLBP to healthy individuals[26–28] and linked the decreased movement of the diaphragm to the presence of low back pain. We have identified potential mechanisms that could explain why participants with $CLBP_{LI}$ showed a decrease in total diaphragm excursion compared to those in $CLBP_{NLI}$.

The decreased in diaphragm excursion may be due to pain, as observed in earlier studies[26–28] and our results show significantly higher pain intensity in the $CLBP_{LI}$ group than $CLBP_{NLI}$ group (p-value $= 0.02$). Consistent with prior studies, pain was found to reduce muscle contraction amplitude and velocity, decreasing the force exerted[45]. Several studies have suggested that lumbar stability is maintained by a coordinated response of muscle groups surrounding the lumbar spine[11,46,47]. The standing posture and load-lifting task in our protocol used a neutral trunk position. In this scenario, stabilizing muscles synergistically generate intra-abdominal pressure (IAP) and trigger diaphragmatic postural function to maintain spinal stability[25,33].

Our findings indicate a decrease in diaphragm excursion, consistent with previous electromyography studies that reported an alternation in trunk stabilizer muscle in patients with lumbar instability. These studies observed decreased activation of deep abdominal muscles and deep back muscles, including the IO, TrA, and LM[10,11,19]. Supported by Vostatek et al.'s study, they assessed the diaphragm excursion between CLBP and healthy individuals. They found reduced recruitment of the diaphragm at the crural part (part of the diaphragm that has a direct anatomical connection to the spine; L1-L4 at the right crus and L1-L3 at the left crus) during the postural challenge in the participants with CLBP. Their participants had low back pain due to the degeneration of the lumbar spine, including spondylolisthesis, stenosis, and disc degeneration[48], which was in accord with our participants who had lumbar instability.

Therefore, a reduced ability to contract or an altered recruitment pattern of muscle surrounding the lumbar spine could reduce IAP generation[49], lead to an inability to stiffen the spine efficiently during load challenges, and increase the anterior shear forces on the lumbar vertebrae[26], which could result in ongoing trauma to the spinal structures[11,12]. The current study highlights that participants with LI exhibit impaired diaphragm activity along with weakening of local stabilizing muscles, which could result in pain; however, it remains unclear whether pain or muscle dysfunction occurs first.

Another reason used to explain the reduced diaphragm excursion might be related to neural adaptation and altered motor control in $CLBP_{LI}$ group during postural tasks. Study conducted by Tsao et al. (2008) found that patients with recurrent LBP experience reorganization in the motor cortex's representation of trunk muscle, suggesting that neural network alteration may impair postural control of these muscles[50]. This finding was supported by Silfies et al. (2009), who found that patients with segmental instability had delayed onset of muscle activity and limited feedforward activation of trunk extensors compared to individuals with CLBP and healthy controls[11]. Moreover, studies have reported altered breathing patterns in CLBP patients, such as upper costal breathing (minimal diaphragm engagement) and breath-holding during motor control tests[51,52].

In our study, participants breathed at tidal volume during the load-lifting task, which may have been insufficient to generate IAP for enhancing spinal stiffness[33]. They might have limited diaphragm recoil during expiration to maintain their IAP, possibly due to central nervous system (CNS)-driven changes in breathing control, which could explain their decreased diaphragm excursion.

The current study conducted a subgroup analysis of total diaphragm excursion across age groups using a one-way repeated measure ANOVA, followed by Bonferroni post hoc test analysis. Figure 5 shows a significant decrease in diaphragm excursions in the 20–29, 30–39, and 50–59 age ranges, with a trend to decrease in the 40–49 age range (not statistically significant) in $CLBP_{LI}$ group when compared with $CLBP_{NLI}$ group. These findings confirm that lumbar instability patients had a reduction in diaphragm activity even when age was controlled.

Diaphragm thickness between $CLBP_{LI}$ and $CLBP_{NLI}$

In the current study, diaphragm thickness during inspiration and expiration was significantly decreased in the $CLBP_{LI}$ group compared to the $CLBP_{NLI}$ group, consistent with previous studies that compared CLBP patients with healthy controls[29,30,48,54,55]. Rondinel et al. (2024) confirmed that a decrease in diaphragm thickness may reflect diaphragm weakness, inspiratory muscle efficiency, and diaphragm atrophy[56–58].

One possible explanation for decreased diaphragm thickness is weakness in the local stabilizing muscles, commonly reported in individuals with LI[9–11,14,19]. Effective spinal stabilization during postural tasks, such as lifting, requires maintaining adequate IAP[59,60], which is driven by diaphragm contraction during inspiration and supported by the abdominal muscles[23,61]. Previous studies reported the compensatory overactivation of global muscles (RA and elector spinae (ES)) and reduced activation of local muscles (TrA and IO)[10,11,19,62], as well as weakness of the diaphragm. This compensatory strategy likely increases spinal compressive loads, potentially straining the discs and facet joints, which may contribute to vertebral translation seen in $CLBP_{LI}$ patients[6,8,63].

The current study also investigated the subgroup analysis of the diaphragm thickness during inspiration and expiration in each age range between $CLBP_{LI}$ and $CLBP_{NLI}$ groups. Figure 6A and B show a tendency for decreased diaphragm thickness during inspiration and expiration in individuals with $CLBP_{LI}$ compared to those with $CLBP_{NLI}$. However, there was no statistical significance.

Participants with $CLBP_{LI}$ in the current study showed a slightly increased diaphragm thickness change of 1.18 mm, which was not statistically significant compared to the $CLBP_{NLI}$ group during standing load-lifting. This finding contrasts with previous studies, which assessed diaphragm thickness in a supine as unloaded position and reported a significant decrease in thickness change in CLBP patients compared to healthy individuals[30,55]. The difference in diaphragm thickness change between our study and earlier studies may be influenced by participants' posture and gravity. Hellyer et al. (2017) observed greater diaphragm thickness during inspiration in standing compared to supine or sitting postures. In standing, gravity pulls the abdominal and thoracic viscera downward, shifting the diaphragm caudally and increasing diaphragm thickness change as seen via ultrasound imaging[64]. While gravity and posture likely affect diaphragm thickness change, task demands on the stabilizing muscles may also increase that muscle thickness. Supported Rasouli et al.'s study (2020) found increased TrA and

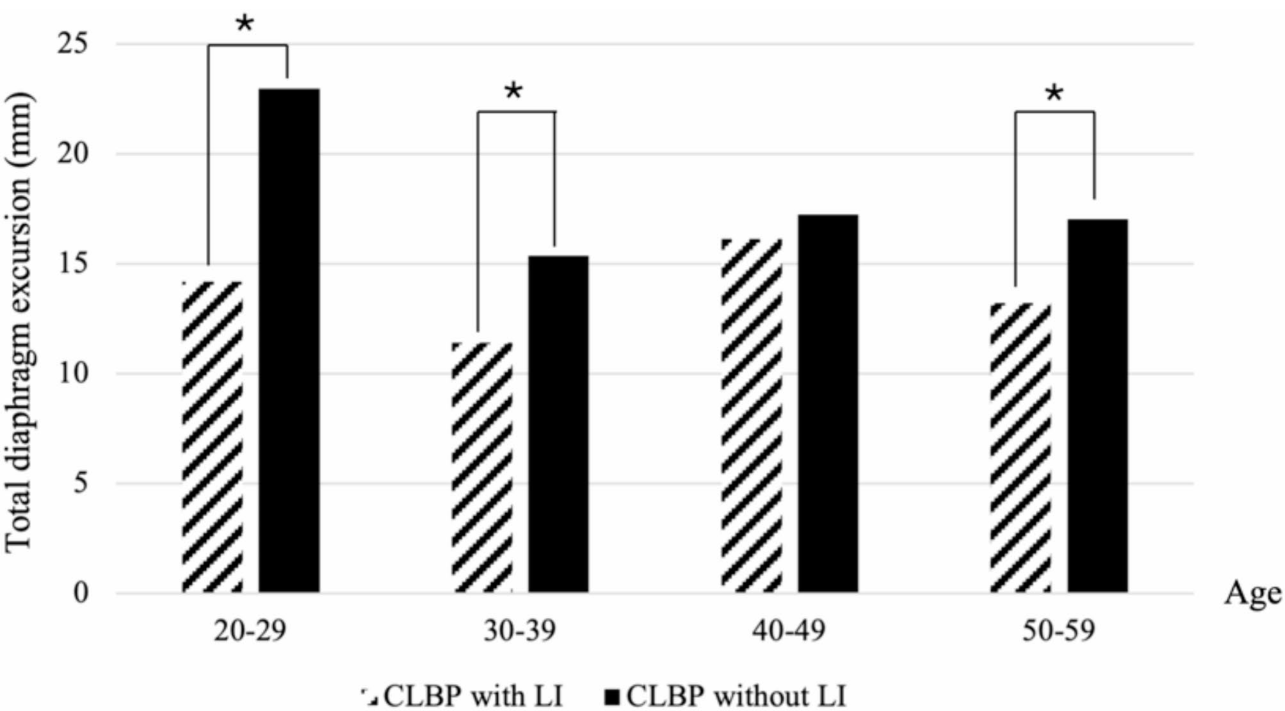

Fig. 5. Total diaphragm excursion in each age group, *p-value < 0.05.

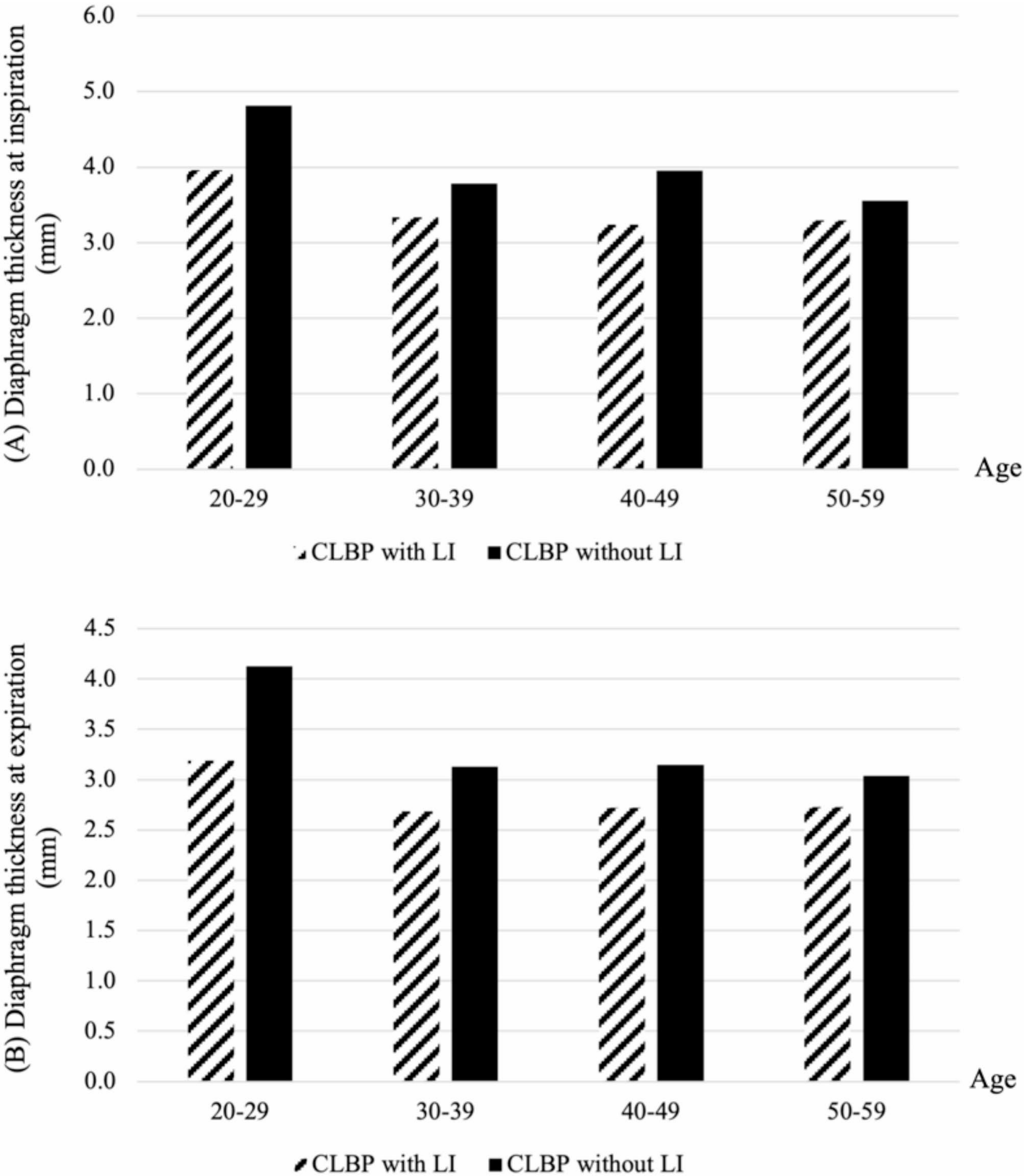

Fig. 6. (**A**) Diaphragm thickness at inspiration in each age group (**B**) Diaphragm thickness at expiration in each age group.

IO muscle thickness change in CLBP patients during a leg task compared to a relaxed sitting position[62]. Ehsani et al. (2016) reported that dynamic standing on an unstable surface activates deep abdominal muscles more than static standing in CLBP patients[65]. Based on the above evidence, we speculate that the slight increase in diaphragm thickness change observed in the $CLBP_{LI}$ group may contribute to posture, gravity, and the increasing task demand (e.g., load-lifting). However, this change was not significant, possibly due to the speculation that participants with lumbar instability have diaphragm weakness.

%FVC predicted between $CLBP_{LI}$ and $CLBP_{NLI}$.

The present study indicates that %FVC predicted in $CLBP_{LI}$ group was slightly decreased compared to the $CLBP_{NLP}$ group, with no significant difference. The results align with the study by Uddin and Vaish (2023). They found that %FVC predicted was lower in the LBP groups than in healthy groups, with no significant difference. This change may be due to altered abdominal muscle recruitment, such as decreased activation of the TrA and IO in patients with LBP and lumbar instability, which could affect deep inspiration and cause a decrease in FVC[28,66]. Although our participants showed reduced diaphragm excursion and thickness, it was not enough to reduce the predicted %FVC. Moreover, they did not have any lung disease as having $FEV_1/FVC > 80\%$[36].

Limitations

Although our study has clinical implications, there are limitations that should be considered. The current study did not measure respiratory effort and postural activation of the diaphragm simultaneously during postural tasks. This limited us from directly linking the two tasks of the diaphragm and accurately defining the actual tidal volume. Therefore, future studies should assess these dual functions to better understand the roles of the diaphragm in respiration and postural function during postural tasks and to strengthen our measurement methods. The weight of the dumbbell may not have been consistent for all participants, as this approach did not precisely define the dumbbell weight as exactly 10% of each participant's body weight. This could potentially confound the results. Our study did not record the pain scale after testing, which is a limitation that should be addressed in future research. Our study did not include a non-loading condition to compare diaphragm contraction under loading conditions or to confirm diaphragm weakness in the absence of load. Further research should explore this to better understand the diaphragm's dual function. The results show decreased diaphragm excursion and thickness. To confirm these alternations, inspiratory muscle strength should be measured. To enhance future studies, the inter-rater reliability measure between the radiologist and researcher should be conducted.

Conclusions

Our study showed that patients with lumbar instability exhibited diaphragm weakness in terms of decreased diaphragm excursion and thickness, which may result in less effective intra-abdominal pressure regulation. This could lead to poor lumbar segment control, increasing the risk of injury or exacerbating existing structural degeneration. These findings highlight the importance of precautions when patients perform activities such as running, lifting, or sports, which require coordination between the diaphragm and other core muscles. However, this physiological alternation, represented by decreased diaphragm excursion and thickness, was not associated with breathing difficulty.

Although it can be difficult to determine whether the altered excursion and thickness of the diaphragm in lumbar instability is a cause or effect of the condition, the current study suggests that diaphragm function, particularly its role in postural control, should be emphasized by physiotherapists.

Data availability

The data will be available for anyone who wishes to access them for any purpose. The data will be accessible after publication, and contact should be made via the Corresponding author thiwch@kku.ac.th.

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Author contributions
All the authors have made substantial contributions to the conception or design of the work. WB performed the experiments with assistance from TC, RP, and AL; WB and TC analyzed the data; WB and TC wrote the manuscript; TC, RP, and RB drafted the work or substantively revised it; RP and TC supervised the project.

Declarations

Competing interests
The authors declare no competing interests.

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