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RESEARCH

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The effectiveness of pelvic floor muscle training on lumbar function and muscle performance in sedentary women with lower back pain: a randomized controlled trial

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Abstract

Objective This study aimed to investigate the impact of combined core and pelvic floor muscle (PFM) training on lumbar function in sedentary women with lower back pain (LBP).

Methods This randomized controlled study included 60 female patients divided into three groups: a control group ($n = 20$), a core training group ($n = 20$), and a combined PFM and core training group ($n = 20$). The participants underwent three weekly interventions over four weeks. Trunk muscle endurance, deep lumbar stabilizing muscle activity, and LBP severity were assessed before and after the intervention.

Results Following the 4-week intervention: 1. In the combined PFM and core training group, significant improvements in muscle endurance ($p < 0.01$) were observed, particularly in the flexor, extensor, and right abdominal muscles compared to the control group ($p < 0.05$). 2. In the core training group, significant increases in muscle endurance were seen in various directions ($p < 0.05$), with highly significant improvements in flexion and right flexion directions ($p < 0.01$). The flexor muscles exhibited greater endurance than the control group ($p < 0.05$). 3. In the control group, dorsal muscle endurance significantly decreased after four weeks ($p < 0.01$). 4. Pain scores after 2 h of sitting significantly decreased ($p < 0.01$), along with reduced LBP differences ($p < 0.05$). There was a decrease in pain scores ($p < 0.05$) and a significant reduction in LBP after 2 h of sitting ($p < 0.01$).

Conclusion Core training, either independently or combined with PFM training, can enhance trunk muscle endurance and alleviate LBP in sedentary women with LBP. Core training alone appeared to have a more pronounced effect.

Keywords Pelvic floor muscle training, Sedentary, Low back pain, Lumbar function, Core training

Introduction

Nonspecific low back pain (LBP)

Nonspecific LBP is characterized by pain and discomfort of uncertain origin, localized below the ribcage, above the lower buttock creases, and between the midaxillary lines on both sides. This pain arises from causes unrelated to specific spinal diseases or radicular pain and may or may not include pain referred to the thigh [1]. In recent years, sedentary behavior has become increasingly common across all age groups. Research has indicated that

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sedentary lifestyles can lead to structural changes in the spine [2], resulting in a degenerative process. People who engage in sedentary activities and experience LBP tend to have elevated levels of pro-inflammatory cytokines [3], which can limit their range of motion and lead to work absences. Moreover, LBP is more prevalent among workers and significantly affects their job performance and daily activities, resulting in substantial economic losses for society [4]. However, not everyone develops LBP as a result of a sedentary lifestyle, despite its negative health consequences. In experiments involving sedentary behavior, 25%–50% of participants reported experiencing LBP symptoms, and those whose pain increased by more than 1 point before and after the sedentary period were categorized as individuals with sedentary-related LBP [5].

Core muscle training

The management of LBP in individuals with a sedentary lifestyle primarily involves less active approaches, such as modifying workplace setups by adjusting chair and desk heights or extending break intervals [6]. Furthermore, core muscle control training, recognized globally as a crucial strategy for treating and managing LBP, is a preventative and rehabilitative method that can alleviate non-specific LBP resulting from a sedentary lifestyle. It enhances lumbar function, increases flexibility, and reduces the likelihood of recurrence.

Pelvic floor muscle (PFM) training

There is ongoing debate regarding the link between pelvic floor dysfunction and LBP due to variations in experimental design. Some studies indicate that there are no significant differences in PFM strength between individuals with LBP and those without, and that the effectiveness of rehabilitation programs with or without PFM training on LBP is comparable [7, 8]. Nevertheless, the majority of experts tend to support the association between pelvic floor dysfunction and LBP. Additionally, prior studies on LBP intervention programs typically extended over a longer duration, typically lasting 6–12 weeks. Without exception, the PFM are an integral part of both the core stabilizing muscle group and the accessory muscles involved in respiration. Additionally, they share a close connection with other deep stabilizing muscles. Research has indicated that training the PFM can enhance the performance of the transversus abdominis (TrA) and can have a positive impact on alleviating LBP, making PFM contraction a valuable component of abdominal muscle training [8]. An increase in the thickness of the lumbar multifidus (LM) and TrA can mitigate LBP, whereas their dysfunction can raise the risk of LBP [9, 10].

During breathing, the diaphragm and PFM should move in coordination. When inhaling, the diaphragm contracts, pulling the lumbar spine forward while preventing the chest from rising excessively. The TrA runs horizontally across the abdomen, connecting to the lumbar vertebrae transverse processes through the thoracolumbar fascia [11]. In the lumbar region, the LM is particularly developed and works primarily to counter spinal rotation and sliding, maintaining spinal curvature and ensuring close alignment of the vertebrae. The simultaneous contraction of the TrA and LM provides stability to the spine, sustaining intra-abdominal pressure (IAP) to indirectly enhance spinal stability.

Strong PFM contractions enhance recruitment and contraction force of other respiratory muscles, also allowing for increased breathing speed [12, 13]. Furthermore, the combined activation of the PFM and TrA can raise IAP, thereby stabilizing the pelvic and lumbar areas. The PFM helps maintain IAP via a feedforward activation mechanism that stabilizes the trunk against disturbances, such as lifting an arm, where trunk muscles activate preemptively to maintain stability. This feedforward mechanism is similar to that of the TrA, diaphragm, and LM [14, 15].

Research shows that PFM training can improve TrA function and has positive effects on lower back pain, making PFM contraction beneficial for core muscle activation training [8]. Conversely, TrA training can enhance PFM function, suggesting that TrA training could serve as an indirect form of PFM training [16]. However, although PFM and TrA influence each other, there is ongoing debate about the effectiveness of separate versus combined training of these muscles. Some studies suggest that isolated PFM training is more effective than combined TrA and PFM training (e.g., simultaneous PFM contraction during inhalation) [17], potentially because TrA contraction increases IAP, which may reduce PFM activation [18].

Study objective

In this study, we aim to compare core training combined with PFM training to conventional core training, with the goal of highlighting the similarities and differences in how these two programs affect the lumbar function, such as muscle endurance and muscle thickness change, and muscle performance of sedentary individuals suffering from LBP.

Data and methods

Participants

In this randomized controlled study, from January 1, 2021, to July 31, 2022, we enlisted 60 females living a sedentary lifestyle, comprising both students and individuals from the community, who were associated with the Beijing Rehabilitation Hospital under Capital Medical University. Data collection took place subsequent to their completion of the informed consent form. Inclusion criteria: (1) Aged 18–40 years; (2) Sitting for more than 6 h daily in the past 3 months [19]; (3) LBP > 3 points measured by Visual Analog Scale (VAS) under normal circumstances, or LBP < 3 points under normal circumstance with the pain change greater than 1 point after sitting for 2 h [20]; (4) No treatment for LBP, if any, within one month.

Exclusion criteria

(1) Presence of specific pathological and anatomical lumbar conditions (e.g., compression fracture, lumbar disc herniation); (2) Neurological abnormalities in the spine (e.g., paresthesia of lower limbs, weakness of lower limbs); (3) Pelvic floor dysfunction, assessed by the supine position test of bladder base movement; [21].(4) A history of spinal surgery; (5) Pregnant or lactating.

Grouping methods

Participants were randomly assigned to three different groups: the control group (referred to as Group C), the core training group (referred to as Group T), and the combined PFM and core training group (referred to as Group P) using a numerical randomization method (1, 2, 3; 1, 2, 3…). Essential demographic information about the participants can be found in Table 1. There was no significant difference in each item among the three groups in Table 1.

Evaluation methods

The examination occurred at the Musculoskeletal Rehabilitation Center in Beijing Rehabilitation Hospital, which is associated with Capital Medical University. Ultrasound was used to assess the thickness of the deep lumbar stabilizing muscle both before the experiment and four weeks after the training intervention. All ultrasound evaluations were performed by the same investigator. Additionally, the assessment of LBP in individuals leading a sedentary lifestyle was conducted. Women's physical activity level was assessed by the International Physical Activity Questionnaire-short Form [22]. The participants were blinded to the intervention. However, since the therapists worked within the hospital and were familiar with the treatment plans, blinding was not applied to them.

(1) Muscle endurance tests

- Extensor muscle endurance test: The participant lies prone on a treatment bed with the hip, knee, and ankle joints of the lower limbs secured to the bed, and the anterior superior iliac spine aligned with the edge of the bed. The upper body extends outward from the bed with arms crossed, maintaining a position parallel to the floor.
- Flexor muscle endurance test: The participant sits on a treatment bed with arms crossed and hands placed on opposite shoulders. The trunk is angled at 60° relative to the ground, with the hip and knee joints flexed at 90° and feet stabilized.
- Side bridge test: The participant lies on their side on a mat with the upper foot positioned in front of the lower foot. The supporting arm is flexed, while the opposite hand rests on the shoulder. Upon starting, the participant lifts their hip off the mat.

(2) TrA test

The participants were positioned comfortably, sitting with their knee and hip joints bent at a 90° angle. They had their hands either folded over their legs or resting on the bed, while their upper limbs were supported and relaxed. Images were captured to show the thickness of abdominal muscles at the conclusion of a regular exhale. Following these initial postures, the participants were instructed to perform an abdominal draw-in maneuver (ADIM), after which images were taken to showcase the thickness of the abdominal muscles during activation. The level of activation was determined using

Table 1 Basic information of sedentary participants with LBP

	Age (y)	Height (cm)	Weight (kg)	Sedentary time (h)	Physical activity level (h/d)
Group C ($n = 20$)	23.75 ± 1.83	164.70 ± 2.60	56.39 ± 3.59	10.90 ± 2.82	2.65 ± 2.21
Group T ($n = 20$)	26.15 ± 5.39	166.40 ± 2.44	55.25 ± 3.85	10.55 ± 2.70	2.63 ± 2.23
Group P ($n = 20$)	24.55 ± 3.36	165.90 ± 4.29	57.60 ± 4.31	11.15 ± 2.30	1.87 ± 1.16

No significant difference was observed in each characteristic among groups the formula [(thickness during activation – thickness during relaxation] / thickness during relaxation] * 100% [23].

(3) LM test

The participants were positioned comfortably in a seated posture, with both the knee and hip joints bent at a 90-degree angle. They placed their hands either on their laps or the bed, while their upper limbs were adequately supported and relaxed. The participants maintained their hands on either side of their legs to offer support and relaxation to their upper limbs. Images were captured during the exhalation phase to depict the muscle thickness at rest. For the opposite arm, a 1-pound dumbbell was held, and it was straightened until the shoulder joint reached a 90-degree flexion. Subsequently, images were taken to illustrate the muscle thickness during activation. The degree of activation was determined using the following formula: [(thickness during activation—thickness at rest) / thickness at rest] * 100% [24].

(4) Degree of PFM activation

To achieve sharp images, the participants were made to drink 600–750 ml of water 30 min before the test and finish drinking it 1 h prior to the examination. During this period, participants were not allowed to urinate to maintain a full bladder for optimal results. Participants were positioned on their backs with their feet resting on the bed, their hip and knee joints bent at a 60-degree angle, and their lower back in a neutral position. An ultrasound probe was positioned between the symphysis pubis and the navel, aligned perpendicularly with the center line. The probe was adjusted by tilting and angling it within a range of approximately 15 to 30 degrees, depending on each participant, until a clear image was achieved. A reference point was marked at the base of the bladder, and participants were instructed to contract their PFM by following the guidance to "contract and lift the PFM, as if holding in urine." Another point was marked at the peak of this contraction, and the distance between these two points was measured and recorded as data indicating the activation of the PFM [12].

(5) VAS

The impact of LBP on patients was assessed using a 10-cm line segment. A scale ranging from 0 to 100 points was employed, with 0 points representing "absolutely no pain" and 100 points indicating "excruciating pain" [25]. Pain levels were measured both before a period of inactivity and 2 h after, and the alterations in pain were computed.

Training program

Participants underwent intervention training three times per week over a four-week period. The training sessions took place at the Musculoskeletal Rehabilitation Center in Beijing Rehabilitation Hospital, which is affiliated with Capital Medical University. All subjects adhered well to the protocol and successfully completed the total number of repetitions as required.

(1) Group C did not receive any form of intervention

(2) Group T followed a program based on prior research [26, 27]. In the core training, each exercise was performed for two sets of 10 repetitions, with a 20-s rest interval between sets. In the core dynamic stability training, each exercise was performed for two sets of 10 repetitions, with a 1-min rest interval between sets. In the core static stability training, each exercise was performed for two sets with specific durations: the ventral bridge was held for 30 s, the side bridge on each side was held for 20 s, the hip bridge using both legs was held for 1 min, and the hip bridge on each leg was held for 30 s. After each exercise, muscles such as the abdominal muscles, dorsal muscles, lateral abdominal muscles, glutes, and posterior thigh muscles were stretched for relaxation, with each stretch held for 30 s. The specific exercises are detailed in Table 2.

(3) Group P underwent the same intervention program as Group T, with the addition of PFM contraction training [28]. During the pre-intervention testing, PFM contractions were assessed. If the patient was unable to perform the contractions, visual feedback via ultrasound imaging was used for training. Once the patient had mastered the movement, subsequent exercises began. During weeks 1–2, the participants were instructed to contract their PFM while in a supine position, with a 6-s contraction followed by a 6-s relaxation, for a continuous duration of 5 min. In weeks 3–4, participants were required to contract their PFM while sitting, with a 10-s contraction followed by a 5-s relaxation, also for a continuous duration of 5 min.

Statistical analysis

All test metrics were subjected to statistical analysis using SPSS 25.0 software, and data values are represented as mean ± standard deviation ($x \pm s$). Comparisons between the three groups were conducted either through a one-way ANOVA or a rank sum test for multiple

Table 2 Movements in core training program

Number of weeks	Activation training	Dynamic stability training	Static stability	Stretching
Weeks 1–2	1. Activation of erector spine muscle in a prone position 2. Activation of TrA in a supine position 3. Abdominal breathing in a supine position 4. Hold breath in a supine position 5. Cat and camel pose in a four-point kneeling position	1. Crunch: flexion of the hip joint and knee joint in a supine position with feet on the mat 2. Straight leg raised in a supine position: flexion of the hip joint and knee joint in a supine position 3. Extension of the hip joint in a four-point kneeling position: extension of the hip joint and knee joint 4. Dorsiflexion in a prone position: for 5 s 5. Dynamic side bridge: knee support	1. Ventral bridge: knee support 2. Side bridge: knee support 3. Hip bridge: double-leg support	Abdominal muscles, dorsal muscles, lateral abdominal muscles, glutes, and posterior thigh muscle stretching
Weeks 3–4	1. Activation of erector spine muscle in a sitting position 2. Activation of TrA in a sitting position 3. Abdominal breathing in a sitting position 4. Hold breath in a sitting position 5. Anterior and posterior tilt of pelvis in a sitting position 6. Left and right tilt of pelvis in a sitting position	1. Crunch: flexion of the hip joint and knee joint at 90°, with both feet off the mat 2. Straight leg raised in a supine position: straighten both legs in a supine position 3. Extension of the hip joint in a four-point kneeling position + raise the contralateral hand 4. Dorsiflexion in a prone position: in a prone position for 5 s 5. Dynamic side bridge: foot support	1. Ventral bridge: foot support 2. Side bridge: foot support 3. Hip bridge: single-leg support	Abdominal muscles, dorsal muscles, lateral abdominal muscles, glutes, and posterior thigh muscle stretching

independent samples, depending on the approximate normal distribution of the sample data. Meanwhile, within each group, the mean of metrics before and after sample intervention was assessed using either the paired *t*-test or the rank sum test for paired samples, contingent on the sample data's approximate normal distribution. When $p > 0.05$, it signified no statistically significant differences; when $p < 0.05$, it indicated statistical differences, and when $p < 0.01$, it denoted highly significant statistical differences.

Results

As indicated in Table 3, there were no significant statistical differences in each of the indices among the three groups before the intervention ($p > 0.05$).

Following a 4-week intervention, Group P demonstrated a significant improvement in the endurance of all muscles ($p < 0.01$). Specifically, the endurance of the flexor, extensor, and right abdominal muscles in Group P was notably superior to that in Group C ($p < 0.05$). In Group T, there was an increase in muscle endurance in the extension and left flexion directions ($p < 0.05$), and a significant increase in endurance in the flexion and right flexion directions ($p < 0.01$). Additionally, the endurance of the flexor was better than that in Group C ($p < 0.05$). Conversely, in Group C, the endurance of the extensor decreased significantly after 4 weeks ($p < 0.01$). (Table 3).

After 4 weeks of intervention, Group C exhibited a slight reduction in TrA activation and a slight increase in LM and PFM activation, although these differences were not statistically significant ($p > 0.05$). In Group T, there was an increase in TrA and LM activation, and a slight decrease in PFM activation, yet these differences were not statistically significant ($p > 0.05$). In Group P, the activation of all muscles increased, but the differences were not statistically significant ($p > 0.05$). After a 4-week intervention, Group C did not exhibit any significant alterations in LBP indicators when compared to their baseline measurements from before the intervention ($p > 0.05$). However, in Group T and Group P, the pain scores notably improved after sitting for 2 h compared to their baseline measurements before the 4-week intervention, and this difference was statistically significant ($p < 0.01$). Furthermore, the differences in pain scores also showed a significant improvement ($p < 0.05$). In typical situations, the pain scores and differences in Group P also displayed improvement, although the change was not statistically significant ($p > 0.05$). (Table 3).

Discussion

Key findings of this study

Both core training alone and when coupled with PFM training exhibit the potential to enhance lumbar function in sedentary women experiencing LBP, as well as improve

Table 3 Assessing alterations in lumbar function among the three groups prior to and following the intervention $(\bar{x} \pm s)$

	Group C ($n = 20$)		Group T ($n = 20$)		Group P ($n = 20$)	
	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Muscle endurance test (s)						
Flexion	69.70 ± 18.73	74.50 ± 35.92	77.15 ± 21.25	$94.75 \pm 15.14^{**+}$	72.10 ± 15.75	$95.95 \pm 19.38^{**+}$
Extension	80.15 ± 14.22	$66.90 \pm 17.10^{**}$	78.40 ± 22.21	$111.00 \pm 53.40^{*}$	70.30 ± 19.05	$120.18 \pm 38.71^{**+}$
Left flexion	44.50 ± 22.80	45.70 ± 19.70	38.85 ± 18.58	$47.45 \pm 17.32^{*}$	44.80 ± 29.78	$59.60 \pm 27.37^{**}$
Right flexion	43.85 ± 22.83	44.15 ± 21.44	39.45 ± 20.61	$47.80 \pm 16.86^{**}$	45.45 ± 29.72	$59.35 \pm 23.12^{**+}$
Muscle thickness						
TrA (%)	47.27 ± 20.24	44.93 ± 30.81	47.56 ± 22.10	63.81 ± 35.93	46.01 ± 21.05	63.19 ± 32.08
LM (%)	6.67 ± 4.98	7.37 ± 6.34	5.99 ± 3.76	7.68 ± 5.89	7.27 ± 4.36	8.92 ± 4.82
PFM (mm)	55.40 ± 25.18	59.15 ± 29.90	62.10 ± 38.78	61.00 ± 30.29	50.65 ± 25.79	69.65 ± 31.06
Pain score (point)						
Initial score	1.64 ± 0.79	1.62 ± 0.99	2.10 ± 1.05	1.72 ± 0.88	2.00 ± 1.10	$1.70 \pm 0.80^{*}$
Score after sitting for 2 h	4.96 ± 1.30	4.82 ± 1.57	5.62 ± 1.39	$4.51 \pm 1.37^{**}$	5.72 ± 1.55	$4.98 \pm 1.25^{**}$
Differences in pain scores	3.32 ± 0.88	3.20 ± 1.05	3.53 ± 1.39	$2.79 \pm 1.45^{*}$	3.73 ± 1.14	$3.28 \pm 1.06^{*}$

TrA transversus abdominis, *LM* lumbar multifidus, *PFM* pelvic floor muscle

* $p < 0.05$, there is a significant difference before and after intervention. ** $p < 0.01$, there is a significant difference before and after intervention. + $p < 0.05$, there is a significant difference, compared with the control group. + + $p < 0.01$, there is a significant difference, compared with the control group

trunk muscle endurance and alleviate LBP. Notably, the combined approach appears to be more effective in achieving these outcomes.

Lumbar muscle endurance

Reduced muscle endurance is a potential contributor to chronic LBP. Moreover, insufficient endurance in the dorsal muscles independently predicts LBP among workers [29]. Engaging in muscle endurance training can offer several benefits for LBP management: enhancing dorsal muscle strength provides significant protection for the lumbar region, helping to prevent or mitigate injuries. Additionally, improved dorsal muscle endurance reduces lumbar muscle fatigue during extended periods of work, thereby reducing the strain on the spinal structure and the risk of injuries. Furthermore, the assessment of muscle endurance is a key component of evaluating trunk stability and muscular endurance. Assessments of flexor endurance in a seated position and extensor endurance in a prone position are common methods for testing muscle endurance, and they demonstrate good reliability and validity [30]. Carter et al. [31] conducted a 10-week Swiss ball core stability training program on sedentary individuals, leading to a significant improvement in their dorsal muscle endurance. Similarly, Sekendiz et al. [32] observed substantial enhancements in abdominal and dorsal muscle strength and endurance in sedentary women after an 8-week Swiss ball core stability training regimen. These findings align with previous research, despite the relatively short duration of the intervention. Panjabi [33] suggested that spinal stability is upheld through three distinct subsystems: the central nervous subsystem, the passive subsystem, and the positive subsystem.

In this study, we adopted a progressive training approach. Initially, activation training aimed to engage the deep stabilizing muscles and enhance proprioception within them [34]. Subsequently, dynamic core stability training was conducted to bolster neuromuscular control capacity [35]. To facilitate progressive training and enhance central nervous subsystem functionality, the difficulty level and unstable elements were gradually intensified. Next, static core stability training was implemented to enhance the performance of global muscles, with particular emphasis on the endurance of the dorsal muscles among the participants [36]. This not only led to increased muscle endurance but also yielded positive effects on muscle strength, stability, coordination, and control capacity, ultimately improving the functioning of the positive subsystem.

Furthermore, combined PFM and core training results in more significant improvements in muscle endurance across various directions compared to core training [37]. Despite the prolonged training time due to the additional PFM training, it remained shorter than the time devoted to global training. The PFM activation training primarily centered on low-intensity and targeted contractions, exerting minimal direct impact on global muscle endurance. Consequently, it is plausible that PFMs, being a vital component of the stability system, engage with other lumbar muscles to mutually reinforce each other. The contraction of PFMs indirectly influences the contraction of other localized stabilizing muscles, thereby fortifying core stability.

Deep lumbar stabilizing muscle thickness

Several studies have investigated alterations in muscle engagement among patients with LBP. Firstly, patients with LBP tend to activate more superficial muscles [38]. Additionally, there is a delay in muscle contraction and relaxation times [39], as well as reduced muscle activation during functional movements when compared to individuals without LBP [40]. Furthermore, during the ADIM, patients with LBP exhibit significantly lower TrA activation compared to those without LBP [41]. The TrA activation is also delayed during rapid body movements in patients with LBP [42]. The changes observed in the appearance of the deep LM indirectly indicate a decrease in muscle recruitment [43]. Consequently, in response to these muscle changes, it is imperative to develop corresponding training methods in clinical rehabilitation to enhance the control and coordination capabilities of trunk muscles, especially the deep stabilizing muscles [44]. The 4-week core training program, which included the activation of deep stabilizing muscles, enhanced proficiency in activating these muscles through the process of motor learning, and involved three stages: the cognitive stage, the associative stage, and the automatic stage. During the cognitive stage, individuals rely heavily on external information and declarative memory, carefully thinking, coordinating, and processing information before executing actions. However, as this process is conscious and relatively slow, it often leads to more errors and variations in their movements. In the associative stage, individuals become less reliant on declarative memory and require less conscious control over each aspect of their movements. As a result, their motions become quicker, smoother, and less error-prone. The duration of the associative stage can vary based on the complexity of the movements and the learning capacity of individuals. In the automatic stage, conscious control is no longer necessary, and skills are governed by procedural memory. This allows learners to divert their attention to other aspects, thereby improving the accuracy, speed, and efficiency of their movements [45].

As a part the training plan, we used targeted activation training to engage the TrA through the ADIM motion. This approach aimed to enhance TrA functionality while reducing the activation and contraction of superficial muscles during stability motions [40, 43]. LM muscle plays a crucial role in trunk stability, but it often experiences dysfunction in patients with LBP. LM activation training aimed to reeducate the LM through specific activation motions and finger strength guidance. This process stimulated the neural control of the LM and transformed its inactive state.

During this study, the PFM activation slightly decreased in Group T after intervention. It appears that core training alone may have a negative impact on PFM contraction function. One potential explanation is that core training effectively strengthens the diaphragm, abdominal muscles, and dorsal muscles, but it does not adequately address PFM training [18]. As a result, the PFM, being a weak link, experiences reduced contraction when intra-abdominal pressure increases. However, combining core training with PFM training has a positive impact on PFM activation. This leads to an improvement or tendency toward improvement in muscle activation in all directions, ensuring intra-abdominal pressure and spinal stability.

Furthermore, since the combined PFM and core training significantly increased PFM activation, and considering that TrA, LM and PFM are all integral parts of the deep lumbar stabilizing muscles, they mutually influence each other. Consequently, increased PFM activation positively affects other deep stabilizing muscles. Through intervention targeting these deep stabilizing muscles, the participants gradually gained better control over muscle contractions. However, it is worth noting that previous studies typically involved interventions lasting 6–12 weeks, and the relatively short intervention time in this study may explain the insignificant improvement in certain indicators.

LBP

It is crucial to quantify pain for measurement and analysis to evaluate the effectiveness and impact of pain management as well as innovative pain treatment methods. Improvements in LBP have been regularly seen in studies focused on training interventions for people with sedentary lifestyles suffering from both LBP and nonspecific LBP [46, 47]. This is consistent with the inference made here. Three subsystems are said to maintain spinal stability according to Panjabi [33]. The passive and central nervous systems' abilities are effectively improved by the experimental program presented in this study. This program improves overall muscle function when combined with PFM training and aids in maintaining intra-abdominal pressure to guarantee spinal stability [48]. As a result, it lessens the symptoms of LBP, lowers pain-avoidance behaviors brought on by LBP, and helps patients improve their lumbar and general physical functions, easing the transition back to normal life.

Limitations

To reduce variances, we exclusively selected and assessed healthy women between the ages of 18 and 40. Exploring how PFM training relates to and affects middle-aged people, the elderly, and men is essential as there is still much to be said about this topic. Future research should explore the long-term impacts of this intervention because certain metrics in this study significantly improved after a 4-week session.

Conclusion

Both core training alone and the combination of core and PFM training demonstrate significant potential for improving lumbar function in sedentary women experiencing LBP. This combined approach not only enhances trunk muscle endurance but also alleviates LBP more effectively than core training alone. Given these findings, incorporating PFM training into rehabilitation programs may offer additional benefits and should be considered in future clinical practices and research efforts. Further studies are needed to validate these results and explore the mechanisms underlying the enhanced efficacy of the combined training approach.

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Authors' contributions
Xiangyue Si made substantial contributions to conception and design of the research; Xiangyue Si and Fanglei Li were involved in drafting the manuscript and revising it critically for important intellectual content and conception and design; Fanglei Li, Hongyang Liang and Xiangyue Si made substantial contributions to acquisition and interpretation of data; Xiangyue Si and Hongyang Liang analyzed the data; All authors given final approval of the version to be published.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the declaration of Helsinki and approved by the Ethics Committee of Beijing Rehabilitation Hospital Affiliated to Capital Medical University. Written informed consent was obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Van Middelkoop M, Rubinstein SM, Verhagen AP, et al. Exercise therapy for chronic nonspecific low-back pain. Best Pract Res Clin rheumatol. 2010;24(2):193–204.
2. Billy GG, Lemieux SK, Chow MX. Changes in lumbar disk morphology associated with prolonged sitting assessed by magnetic resonance imaging. PM&R. 2014;6(9):790–5.
3. Bergens O, Nilsson A, Papaioannou KG, et al. Sedentary patterns and systemic inflammation: sex-specific links in older adults. Front Physiol. 2021;12:625950.
4. Damato TM, Christofaro DGD, Pinheiro MB, et al. Does sedentary behaviour contribute to the development of a new episode of low back pain? A systematic review of prospective cohort. Eur J Pain. 2022;26(7):1412–23.
5. Sheahan PJ, Diesbourg TL, Fischer SL. The effect of rest break schedule on acute low back pain development in pain and non-pain developers during seated work. Appl Ergon. 2016;53:64–70.
6. Balci R, Aghazadeh F. Effects of exercise breaks on performance, muscular load, and perceived discomfort in data entry and cognitive tasks. Comput Ind Eng. 2004;46(3):399–411.
7. Stuge B, Mørkved S, Dahl HH, et al. Abdominal and pelvic floor muscle function in women with and without long lasting pelvic girdle pain. Man Ther. 2006;11(4):287–96.
8. Mohseni-Bandpei MA, Rahmani N, Behtash H, et al. The effect of pelvic floor muscle exercise on women with chronic non-specific low back pain. J Bodyw Mov Ther. 2011;15(1):75–81.
9. Hodges P, Richardson C, Jull G. Evaluation of the relationship between laboratory and clinical tests of transversus abdominis function. Physiother Res Int. 1996;1(1):30–40.
10. Hides J, Stanton WS, Sims K, et al. Effect of stabilizaton training on multfdus muscle cross-sectonal area among young elite cricketers with low back pain. J Orthop Sports Phys Ther. 2008;38(3):101–8.
11. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain: a motor control evaluation of transversus abdominis[J]. Spine. 1996;21(22):2640–50.
12. Talasz H, Kofler M, Kalchschmid E, et al. Breathing with the pelvic floor? Correlation of pelvic floor muscle function and expiratory flows in healthy young nulliparous women[J]. Int Urogynecol J. 2010;21(4):475–81.
13. Cavaggioni L, Ongaro L, Zannin E, et al. Effects of different core exercises on respiratory parameters and abdominal strength [J]. J Phys Ther Sci. 2015;27(10):3249–53.
14. Sapsford RR, Hodges PW. Contraction of the pelvic floor muscles during abdominal maneuvers[J]. Arch Phys Med Rehabil. 2001;82(8):1081–8.
15. Madill SJ, McLean L. Relationship between abdominal and pelvic floor muscle activation and intravaginal pressure during pelvic floor muscle contractions in healthy continent women[J]. Neurourology and Urodynamics: Official Journal of the International Continence Society. 2006;25(7):722–30.
16. Dufour S, Vandyken B, Forget MJ, et al. Association between lumbopelvic pain and pelvic floor dysfunction in women: A cross sectional study[J]. Musculoskeletal Science and Practice. 2018;34:47–53.
17. Ehsani F, Arab AM, Assadi H, et al. Evaluation of pelvic floor muscles activity with and without abdominal maneuvers in subjects with and without low back pain[J]. J Back Musculoskelet Rehabil. 2016;29(2):241–7.
18. Bø K, Mørkved S, Frawley H, et al. Evidence for benefit of transversus abdominis training alone or in combination with pelvic floor muscle training to treat female urinary incontinence: a systematic review[J]. Neurourology and Urodynamics: Official Journal of the International Continence Society. 2009;28(5):368–73.
19. Patel AV, Bernstein L, Deka A, et al. Leisure time spent sitting in relation to total mortality in a prospective cohort of US adults. Am J Epidemiol. 2010;172(4):419–29.
20. Dunton GF, Berrigan D, Ballard-Barbash R, et al. Joint associations of physical activity and sedentary behaviors with body mass index: results from a time use survey of US adults. Int J Obes. 2009;33(12):1427–36.
21. Thompson JA, O'Sullivan PB, Briffa K, Neumann P, Court S. Assessment of pelvic floor movement using transabdominal and transperineal ultrasound. Int Urogynecol J Pelvic Floor Dysfunct. 2005;16(4):285–92. https://doi.org/10.1007/s00192-005-1308-3.
22. Lee PH, Macfarlane DJ, Lam TH, Stewart SM. Validity of the International Physical Activity Questionnaire Short Form (IPAQ-SF): a systematic review.

Int J Behav Nutr Phys Act. 2011;8:115. Published 2011 Oct 21. https://doi.org/10.1186/1479-5868-8-115
23. Cho SH, Kim KH, Baek IH, et al. Comparison of contraction rates of abdominal muscles of chronic low back pain patients in different postures. J Phys Ther Sci. 2013;25(8):907–9.
24. Kiesel KB, Uhl T, Underwood FB, et al. Rehabilitative ultrasound measurement of select trunk muscle activation during induced pain. Man Ther. 2008;13(2):132–8.
25. Zemp R, Fliesser M, Wippert PM, et al. Occupational sitting behaviour and its relationship with back pain–A pilot study. Appl Ergon. 2016;56:84–91.
26. Noormohammadpour P, Kordi M, Mansournia MA, et al. The role of a multi-step core stability exercise program in the treatment of nurses with chronic low back pain: a single-blinded randomized controlled trial. Asian spine journal. 2018;12(3):490–502.
27. Shamsi MB, Sarrafzadeh J, Jamshidi A. Comparing core stability and traditional trunk exercise on chronic low back pain patients using three functional lumbopelvic stability tests. Physiother Theory Pract. 2015;31(2):89–98.
28. Bi X, Zhao J, Zhao L, et al. Pelvic floor muscle exercise for chronic low back pain. J Int Med Res. 2013;41(1):146–52.
29. Hamberg-van Reenen HH, Ariëns GAM, Blatter BM, et al. Physical capacity in relation to low back, neck, or shoulder pain in a working population. Occup Environ Med. 2006;63(6):371–7.
30. Biering-Sørensen FIN. Physical measurements as risk indicators for low-back trouble over a one-year period. Spine. 1984;9(2):106–19.
31. Carter J, Beam W, McMahan S, et al. Effects Of Stability Ball Training On Spinal Stability In Those Who Work In Sedentary Occupations. Med Sci Sports Exerc. 2005;37(5):S177–8.
32. Sekendiz B, Cug M, Korkusuz F. Effects of Swiss-ball core strength training on strength, endurance, flexibility, and balance in sedentary women. The Journal of Strength & Conditioning Research. 2010;24(11):3032–40.
33. Panjabi MM. The stabilizing system of the spine Part II Neutral zone and instability hypothesis. Journal of Spinal Disorders. 1992;5:390–390.
34. Shi J, Liu Z, Zhou X, Jin F, Chen X, Wang X, Lv L. Effects of breathing exercises on low back pain in clinical: A systematic review and meta-analysis. Complement Ther Med. 2023;79:102993. https://doi.org/10.1016/j.ctim.2023.102993. (Epub 2023 Oct 10 PMID: 37827444).
35. Gorji SM, Mohammadi Nia Samakosh H, Watt P, Henrique Marchetti P, Oliveira R. Pain Neuroscience Education and Motor Control Exercises versus Core Stability Exercises on Pain, Disability, and Balance in Women with Chronic Low Back Pain. Int J Environ Res Public Health. 2022;19(5):2694. https://doi.org/10.3390/ijerph19052694. PMID: 35270384; PMCID: PMC8910692.
36. Adnan H, Ghous M, Shakil Ur Rehman S, Yaqoob I. The effects of a static exercise programme versus Swiss ball training for core muscles of the lower back and pelvic region in patients with low back pain after child delivery. A single blind randomized control trial. J Pak Med Assoc. 2021 Apr;71(4):1058–1062. https://doi.org/10.47391/JPMA.784. PMID: 34125743.
37. Yu D, Yu Y, Peng Q, Luo J, He X. Clinical efficacy of breathing training combined with core stability training in chronic nonspecific low back pain. Pak J Med Sci. 2023 Jul-Aug;39(4):1008–1012. https://doi.org/10.12669/pjms.39.4.6918. PMID: 37492324; PMCID: PMC10364287.
38. Flor H, Haag G, Turk DC, et al. Efficacy of EMG biofeedback, pseudotherapy and conventional medical treatment for chronic rheumatic back pain. Pain. 1983;17(1):21–31.
39. Radebold A, Cholewicki J, Panjabi MM, et al. Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain. Spine. 2000;25(8):947–54.
40. Sihvonen T, Lindgren KA, Airaksinen O, et al. Movement disturbances of the lumbar spine and abnormal back muscle electromyographic findings in recurrent low back pain. Spine. 1997;22(3):289–95.
41. Critchley DJ, Coutts FJ. Abdominal muscle function in chronic low back pain patients: measurement with real-time ultrasound scanning. Physiotherapy. 2002;88(6):322–32.
42. Hodges PW, Richardson CA. Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. Arch Phys Med Rehabil. 1999;80(9):1005–12.
43. Rantanen J, Hurme M, Falck B, et al. The lumbar multifidus muscle five years after surgery for a lumbar intervertebral disc herniation. Spine. 1993;18(5):568–74.
44. Ferreira PH, Ferreira ML, Maher CG, et al. Changes in recruitment of transversus abdominis correlate with disability in people with chronic low back pain. Br J Sports Med. 2010;44(16):1166–72.
45. Wang LJ. The Influence of Abdominal Drawing-in Maneuver with Different Types of Biofeedback on Patients with Chronic Low Back Pain. MA thesis, Beijing Sport University, 2017. http://cdmd.cnki.com.cn/Article/CDMD-10043-1017181624.htm
46. Miranda IF, Souza C, Schneider AT, et al. Comparison of low back mobility and stability exercises from Pilates in non-specific low back pain: A study protocol of a randomized controlled trial. Complement Ther Clin Pract. 2018;31:360–8.
47. Seshagirirao M, Susmitha K, Sundari KS. A randomised controlled study on core stability exercise programme using swiss ball, theraband and floor exercises in cricketers with low back pain. International journal of physiotherapy. 2015;2(6):885–93.
48. Chown M, Whittamore L, Rush M, et al. A prospective study of patients with chronic back pain randomised to group exercise, physiotherapy or osteopathy. Physiotherapy. 2008;94(1):21–8.

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