Research Paper

The Effect of Core Stability Exercises Combined With Abdominal Hollowing on Postural Balance in Patients With Non-specific Chronic Low Back Pain: A Randomized Controlled Trial

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Citation Yalfani A, Mohamad Khani M, Ahmadi M, Asgarpoor A. The Effect of Core Stability Exercises Combined With Abdominal Hollowing on Postural Balance in Patients With Non-specific Chronic Low Back Pain: A Randomized Controlled Trial. Physical Treatments. 2023; 13(3):165-174. http://dx.doi.org/10.32598/ptj.13.3.442.5

doi: http://dx.doi.org/10.32598/ptj.13.3.442.5

Article info:
Received: 31 May 2023
Accepted: 15 Jun 2023
Available Online: 01 Jul 2023

Keywords:
Low back pain, Postural balance, Hollowing, Exercise

ABSTRACT

Purpose: Altered movement patterns and spine instability are crucial factors in the etiology of chronic non-specific low back pain (CNSLBP). The faulty recruitment pattern of core muscles causes poor support and increased loading on the lumbar spine, ultimately leading to postural instability. This study aims to examine the effect of core stability exercises (CSE) combined with abdominal hollowing (AH) on postural balance in patients with CNSLBP.

Methods: The present study is a double-blind clinical trial. Thirty women with CNSLBP were recruited for the clinical trial. Patients were randomly assigned to experimental and control groups (15 patients in each group). The experimental group followed CSE with AH for 8 weeks. The control group received no intervention. Primary outcomes included pain (10 cm visual analogue scale), disability (Oswestry questionnaire), and proprioception (goniometer). Secondary outcomes included static and dynamic balance (biodex balance system). Analysis of covariance (ANCOVA) was used to compare the results and confidence intervals between groups.

Results: The experimental group compared to the control group with a high effect size had a significant difference in reducing pain (P=0.021, ηp^2=0.183), disability (P=0.007, ηp^2=0.237), and postural reconstruction error (P=0.000, ηp^2=0.566). Also, the experimental group compared to the control group with a high effect size had a significant difference in the improvement of static (P=0.008, ηp^2=0.367) and dynamic balance (P=0.008, ηp^2=0.757).

Conclusion: The CSE combination with AH affects three active, passive, and nervous systems. It seems that the CSE combination with AH can modify the faulty movement control in local muscles, proprioception restoration, and subsequently lead to postural stability.

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Highlights

• Altered movement patterns and spinal instability are the cause of low back pain.

• Core local muscle co-contraction is necessary for spine stability.

• The stability exercises increase local muscle-isolated activation.

• The local muscle co-contraction leads to postural stability.

Plain Language Summary

Patients with chronic non-specific low back pain (CNSLBP) show weakness of core muscles and faulty lumbar-pelvic movement patterns. Weakness of stabilizing and respiratory muscles leads to instability and loading of the spine and ultimately low back pain. It seems that the combination of core stability exercises and abdominal hollowing by core muscle activation increases spine stability and postural balance in patients with back pain.

1. Introduction

Low back pain (LBP) is a painful discomfort defined between the costal margin and the gluteal folds, with or without referred pain in the legs [1]. A systematic review, including 54 countries reported that the prevalence of LBP in the population and lifetime is 18% and 40%, respectively [2]. The healthcare cost of LBP is estimated to be £14 billion in the United Kingdom and $14.5 billion in the United States [3]. In addition, LBP affects work absence and daily activities and causes depression, anxiety, low quality of life, and disability [4]. LBP is classified into two categories: Non-specific and mechanical [4]. Chronic non-specific low back pain (CNSLBP) accounts for 90%-95% of low back pain and affects 20% of the world's population [5, 6]. CNSLBP is a complex condition with unknown pathophysiology that occurs for three months or more [1, 7].

Although the cause of CNSLBP is still unclear, altered movement patterns and spinal instability seem to be crucial factors [8]. The spine's stability consists of three subsystems: Passive (bones, ligaments, and joint capsule), active (muscles and tendons), and nervous (central, and peripheral nervous system). According to the Punjabi model, the interaction of subsystems leads to movement control and spine stability [9]. In the nervous subgroup, proprioception is the main component of the sensory-motor system and the muscle spindle is the vital sensory source [10, 11]. Sensory information is processed in the spinal cord, brain stem, cerebral cortex, and cerebellum, which is vital in understanding the biomechanical and spatial position of the segments [10]. A previous study reported that proprioception is faulty in patients with CNSLBP [12]. Reduced proprioception feedback from mechanoreceptors at the pain location affects postural control [13]. Proprioception deficits in patients with LBP may reduce the maintenance of neutral spine posture and muscle coordination [11]. Muscle co-contraction is necessary to maintain the mechanical stability of the spine [14]. In healthy, the transverse abdominis (TrA) and multifidus (MF) muscles are activated as they feedforward before movement and thus stabilize the spine [15]. Nevertheless, in patients with LBP, the TrA and MF muscles are weak and delayed in activation, which ultimately leads to lumbar spine instability [8]. The faulty recruitment pattern of the TrA and MF causes poor support of the lumbar spine, increases the loading on the joints and ligaments of the lumbar spine, and ultimately leads to postural instability [8, 16].

Postural control is essential for daily life activities [17]. Posturography using center of pressure data examines integration and sensorimotor processing, which is a comprehensive method for evaluating motor control in CNSLBP patients [18]. A systematic review reported that postural stability was reduced in CNSLBP patients, indicating impaired motor control [18, 19]. Therefore, one of the crucial factors in restoring postural control in LBP patients is the co-contraction of TrA and MF muscles. Therapeutic strategies that focus on TrA and MF may improve postural stability in CNSLBP patients [17, 20]. Co-contraction of TrA and MF muscles may help with movement pattern restoration and lumbar-pelvic position sense [21].

European guidelines for the management of CNSLBP recommend exercise therapy as the primary treatment [22]. Core stability exercises (CSE) or motor control exercises have been considered as a treatment protocol for LBP [23]. The founders of CSE believe that LBP reduces the control and coordination of the trunk muscles, which affects movement control and spine stability [23]. As a result, CSE is intervention that aim to improve trunk muscle activation [22]. Using the principles of motor learning, CSE controls the intersegmental movement of the spine and improves the coordination of the spine and pelvis [22]. Previous studies have shown that CSE can reduce pain and disability and restore proprioception and postural stability in LBP patients [20, 24]. Another protocol, for trunk and spine stability is abdominal hallowing (AH) which focuses on the activation of local muscles, such as TrA, MF, and internal oblique (IO) through motor control [25]. Overall, the goal of AH is to minimize global muscle activity and increase local isolated muscle activation [25]. Therefore, AH can be effective in improving the activation pattern of the local muscles and increasing spine stability [25]. The goal of both approaches is to improve the patient's ability to control the trunk and spine stabilization during daily life activities. It seems that the CSE combined with AH provides stronger evidence about the effectiveness of these two protocols on postural stability in patients with CNSLBP. Therefore, this study was conducted to examine the effect of CSE combined with AH on postural balance in patients with CNSLBP. Based on the evidence, we hypothesized that CSE combined with AH has a significant effect on postural stability. It is hoped that the results of the study will provide new and practical insight for preventing and treating CNSLBP.

2. Materials and Methods

Research design

This study is a double-blind (assessors/patients) randomized controlled trial that follows the Consort guidelines. Our study was performed between April to October 2021. The statistical population includes women with CNSLBP who were recruited from orthopedic or sports medicine clinics in Hamedan Province, Iran.

Patients were assigned to experimental and control groups. The interventions were performed for 8 weeks. Primary outcomes included pain, disability, proprioception, and secondary outcomes included static and dynamic balance.

Sample size

We used G*Power software, version 3.1.9.2 to estimate the sample size. According to Abbasi et al, the type I error was 0.05, and the type II error rate was planned to be 0.20 (statistical power 80%). The output of the software reported 26 subjects in a clinical trial. Considering a drop of 10%, we planned 30 patients in a clinical trial (15 patients for each group) [26].

Participants

The statistical population of this clinical trial was women with CNSLBP. Patients were recruited from August to November 2022 from orthopedic and sports medicine clinics in Hamedan Province. An orthopedic surgeon evaluated patients before recruitment. Thirty women with CNSLBP (age: 43.83±9.19 years, height: 156.97±5.84 cm, weight: 70.09±6.80 kg, body mass index (BMI): 28.58±3.91 kg/m², pain: 61±9.94) were recruited for the trial based on the diagnosis of the spine orthopedic physician. The inclusion criteria included visual analog scale ≥45, Oswestry disability index ≥25, no history of spine surgery, CNSLBP more than 12 weeks, and age range between 30-60 years. The exclusion criteria included pain in other segments of the body, and lower limb deformity (we used available tools, such as a caliper to evaluate the deformities of the lower limbs that affect low back pain. Caliper was used to evaluate foot pronation and knee alignment), history of spine surgery, use of painkillers in the past 6 months, physical therapy in the past year, participation in sports, sciatica pain (a spine orthopedic specialist separation sciatica pain from back pain through SLR and slump tests), spondylolysis, neuromuscular disorders, neurological, respiratory, muscle spasm, and vertebral fracture.

Randomization and blinding

We used random allocation software for randomization. Random codes were generated in blocks 4 and 6. We used sequentially numbered opaque sealed envelopes (SNOSE) to conceal the allocation. This study was planned as double-blind (assessors/patient). The third researcher, who was not involved in data collection and was unaware of the research design, opened the envelopes and delivered them to the patients. Patients were unaware of group allocation. In addition, to maintain blinding, patients were instructed not to disclose information about the group allocation to the assessors. To ensure the effectiveness of blinding, the assessor was asked whether she/he was aware of the group allocation of the patients. If the assessors were aware of the group allocation of even one patient, the double-blind study was not considered.

Instrument

We used the Biodex balance system device made by the Biodex Company in the United States to evaluate postural balance. Biodex has a movable circular platform that allows 20° of surface tilt in the anterior-posterior, and medial-lateral directions [27]. Biodex balance produces 3 indices of medial-lateral stability, anterior-posterior stability, and overall stability [27]. Previous studies reported ICC for the anterior-posterior index of 0.60-0.88, medial-lateral index of 0.64-0.94, and the overall stability index of 0.63-0.91 [27]. In addition, a universal plastic goniometer was used to evaluate lumbar proprioception.

Primary outcome

Pain

We used a 100 mm visual analog scale for pain evaluation. This scale is a valid and reliable tool for pain evaluation in patients with LBP. On this scale, pain intensity is divided into four categories, 0-40 mm as no pain, 44-50 mm as mild pain, 45-74 mm as moderate pain, and 75-100 mm is classified as severe pain. The patient was asked to indicate the pain intensity during daily activities [28].

Disability

Oswestry disability index was used to disability evaluate (ICC=0.84) [29]. Disability is classified into four subcategories, including a score of less than 25 as the lowest level of disability, 25-50 as moderate disability, 50-75 as severe disability, and 75-100 as acute disability [28].

Proprioception

Newcomer's test was used to evaluate lumbar proprioception. The validity of the Newcomer test to evaluate lumbar proprioception is reported to be 87%. Three markers were placed on the acromion, iliac crest, and greater trochanter of the hip. The patients were taught to stand upright and spread both legs shoulder-width apart. The hands were placed crossed on the chest. Then, the goniometer's fixed arm was placed parallel to the femur, and the movable arm was placed in 30° trunk flexion position. The eyes were covered with a black cloth. Meanwhile, the patient was asked to move the trunk toward a 30° flexion position with a stable angular velocity. When the patient reached the 30° flexion position, audio feedback was provided. Meanwhile, the patients paused for 5 s to remember the target position and then returned to the initial position. To learn, they repeated the test 3 times. Then, the patient was asked to move the trunk to the 30° flexion position without feedback and to say "I arrived" when the patient target angle was reached [30]. This test was performed 3 times and the rest time between each trial was 5 s. Finally, the average of 3 trials was recorded as the position reconstruction error. If the average value of the errors was >3°, lumbar proprioception was considered healthy [31].

Secondary outcomes

Postural balance

The patients stood with bare feet on the platform and placed their hands crossed on chest. They were asked not to touch the fences during the trial and to stay stable when the platform was tilting. The test was performed with eyes closed; because patients with CNSLBP depend on the visual system for postural control [20]. In addition, the stability indices of the Biodex balance system are more reliable in the eyes-closed condition [27]. The Biodex balance platform stability ranges from level 1 as the most unstable to 12 as the least unstable [32]. The static and dynamic balance were evaluated in double-leg conditions. The stability level was set to "static" for static conditions and between "6 to 3" for dynamic conditions [28]. We only addressed the overall stability index [28]. The trial was conducted for 30 s with 3 repeated [27, 28]. The rest time between each trial was 10 s [28]. High values indicate poor posture stability.

Experimental protocol

Core stability exercises

First, low levels of muscle contraction were performed as isometric and in positions with minimal loading. As the patient progressed, dynamic functional (activities that require spinal or limb movements) were planned by integrating local muscle co-contraction into functional tasks [23]. According to the previous study, CSE includes lying on the back, an abdominal brace with heel slide while lying, an abdominal brace while bridging, an abdominal brace while lying leg raises, an abdominal brace with bridging and raising the leg, an abdominal bracket in a vertical position with the abdominal, quadruped arm lift, leg lift, hand, and leg lift alternated [7]. CSE was performed 3 times a week, each session lasting 40 minutes for 8 weeks. Core stability exercises were performed in two stages. First, the muscle endurance factor was considered (weeks 1-4). A total of 12-15 repetitions and 4-7 sets are very effective for local muscle endurance [33, 34]. The rest time depends on exercise goals [34]. Minimizing recovery between sets is a crucial stimulant for improving local muscular endurance [34]. Likewise, we included 30 s of rest to increase muscular endurance [35]. Progressive overload is essential for maximal muscle fiber recruitment [34]. In this line, the progressive principle was maintained as the position for 10 s in each repetition [35].

In the second stage, increased strength and muscle activation were considered (weeks 5-8). Ten repetitions and 1-3 sets are effective for increasing local muscle strength [34]. However, the studies have shown that 3 sets are more effective in increasing muscle strength [34]. Likewise, we considered 3 sets to increase strength. It is recommended that when the repetitions are considered to be 10 repetitions, the rest period to increase muscle strength is considered to be 1 minute [34]. In addition, it has been reported that slow-twitch muscle fibers recover very quickly and almost completely within 1 minute [36]. Consequently, we rested for 1 minute between each set. The progressive principle in this stage included changing the exercise position, resistance through the band, and slow to moderate execution velocity of the exercises.

Abdominal hallowing

Target muscles in AH included TrA, IO (low fibers), and MF (deep fibers) [37]. The co-contraction of trunk local muscles should be isolated from global muscles, such as rectus abdominis and external abdominal oblique [37]. AH in the first phase (weeks 1-4) focused on low-load isolated activation of TrA and MF muscles [11]. Meanwhile, for the first week, the wall support standing positions were considered for the TrA isolated activation [37]. The patients were asked to stand with their back against the wall with hips in flexion and extended knees. The distance from the wall to the heel was 6 inches. The patients were asked to pull the lower anterior abdominal wall "up and in" towards the spine. MF isolation was activated by arm raising on the opposite side during AH. The second phase (weeks 5-8) emphasized the accuracy and duration of AH [11]. The co-contraction of TrA and MF muscles was performed by controlling upper and lower limb movements and progressed to high-loading positions in lying and sitting positions. During AH, patients were instructed to monitor the contraction of TrA and MF by palpating the muscles. To TrA contraction, the index and middle fingers touched the 2 cm area medial to the anterior superior iliac spines. In contrast, for MF contraction, the index and middle fingers were placed near the L5 spinous process [11]. During AH, no movement was performed in the spine, ribs, or pelvis [37]. The patients were taught to hold the abdominal contraction for 10 s and breathe continuously [37]. CSE combined with AH was performed 3 times a week, each session was 20 minutes for 8 weeks.

Statistical analysis

SPSS software, version 26 was used for statistical analysis. The Shapiro-Wilk test was used to ensure the data's normal distribution. The equality of error variances was checked using Levene's test. The covariance test was used for between-group comparison. The effect size was calculated through Cohen's index. Cohen's index is classified into three categories (0.01-0.059 small effect size, 0.06-0.14 medium effect size, and 0.14 large effect size) [38]. A significance level of $P<0.05$ was considered.

3. Results

Table 1 presents the demographic characteristics of the groups. The results of the Shapiro-Wilk test showed no statistically significant difference between the groups for demographic characteristics. Therefore, the data distribution is normal and the variances are equal. Table 2 presents the results of the covariance test. Covariance re-

Table 1. Shapiro–Wilk test result (n=15)

Variables	Mean±SD		P
	Experimental	Control	
Age (y)	45.66±8.83	42.00±9.48	0.154
Height (cm)	154.78±5.41	159.16±5.58	0.856
Weight (kg)	69.74±6.76	70.45±7.07	0.221
BMI (kg/m²)	29.34±3.34	27.81±4.38	0.304
Pain (VAS)	62.33±10.15	59.33±10.49	0.154

VAS: Visual analogue scale.

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Table 2. ANCOVA results and descriptive statistics for outcome measuring

Variables	Groups	Mean±SD		95% CI (Post-test)		F	$η^2$	P
		Pre	Post	Lower	Upper			
Pain (VAS)	Experimental	62.33±10.15	29.00±12.84	21.88	36.11	6.041	0.183	0.021*
	Control	59.66±9.90	53.20±6.66	32.89	73.50			
Disability (numeric)	Experimental	44.86± 11.12	26.13±11.52	19.75	32.51	8.368	0.237	0.007*
	Control	40.53±12.50	34.93±14.28	27.02	42.84			
Proprioception (angle)	Experimental	7.46±3.79	2.14±3.16	0.39	3.89	35.232	0.566	0.000*
	Control	7.40±6.50	9.38±3.48	7.45	11.30			
Static OS (degrees)	Experimental	1.86±0.46	1.11±0.53	0.82	1.41	15.660	0.367	0.000*
	Control	1.47±0.87	1.79±0.78	1.45	2.32			
Dynamic OS (degrees)	Experimental	3.48±0.91	1.90±0.51	1.61	2.18	83.980	0.757	0.000*
	Control	2.92±0.62	3.80±0.56	3.49	4.12			

VAS: Visual analogue scale; OS: Overall stability.

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*Significant difference between groups (P<0.05)

sults showed that CSE combined with AH had a significant difference with a high effect size in reducing pain (P=0.021, $ηp^2$=0.183), disability (P=0.007, $ηp^2$=0.237) and position reconstruction error (P=0.000, $ηp^2$=0.566). In addition, the covariance results showed that CSE combined with AH had a significant difference with high effect size in improving static (P=0.008, $ηp^2$=0.367) and dynamic balance (P=0.008, $ηp^2$=0.757).

4. Discussion

This study was conducted to examine the effect of CSE combined with AH on postural balance in patients with CNSLBP. The primary outcome showed that CSE combined with AH had a significant effect on reducing pain, disability, and position reconstruction error. Also, the secondary outcome showed that CSE combined with AH had a significant effect on improving postural balance. The results were consistent with some of the studies focusing on CSE and AH. For example, Ogunniran et al. reported pain reduction [7], Kim et al. reported disability reduction [39], Hlaing et al. (2021) reported proprioception restoration [11], and Puntumetakul et al. (2021) reported improved postural stability [40]. Panjabi stated that spinal instability is likely due to dysfunction of the passive (non-contractile) or active components (trunk muscles) of the spine or a defect in neural control, leading to LBP [17]. Stabilizing exercises facilitate local muscle activity and inhibit global muscle activity [7, 41]. This mechanism increases stability and reduces the overload of the lumbar spine; as a result, pain and disability decrease [11, 21].

Pain harms the sensory feedback from muscle spindle afferents. The proprioceptive deficiency causes feedforward and feedback motor control disorders and inefficiency of the sensory-motor system [11, 21]. As a result, joint stability decreases and posture oscillation increases. Therefore, poor stability in LBP patients may be due to altered sensory feedback from the lumbar spine [42]. This pathophysiology may be due to a defect in the central processing of sensory information from mechanoreceptors [42]. The sensory impulse defect can lead to greater movements of the lumbar spine; as a result, the body sway responses increase for postural control [43]. Therefore, faulty motor planning caused by pain disrupts feedforward and feedback control [21]. The TrA and MF muscles are the main sources of trunk sensory inputs and play a critical role in providing sensory impulses to the posture control system [11, 20]. Lee reported that AH focuses on the deep muscle system and is more effective than CSE for postural stability [44]. Recruitment at the low threshold of TrA and MF muscles can proprioception facilitation by motor integration [11].

The body core consists of passive (thoracolumbar fascia) and active components (trunk muscles) [45]. The thoracolumbar fascia acts as a "nature's back belt" [46]. TrA and MF muscles act as primary generators of intra-abdominal pressure [15]. Of The total core muscles, TrA has the widest and closest connection with the thoracolumbar fascia and is essential for spinal stability [46]. Due to the horizontal orientation of the TrA muscle, the contraction of this muscle can increase the tension in the thoracolumbar fascia and thus increase intra-abdominal pressure [28, 41]. Increased intra-abdominal pressure leads to the stiffness of stabilizing muscles and provides spine segmental stability [15, 41, 47]. In addition, previous studies showed that AH increases the isolated activity of the TrA muscle and the lower fibers of the IO muscle [37, 41]. The TrA and IO muscles act synergistically [37]. TrA and IO muscles can strengthen the lumbar-pelvic complex and improve force transmission from the upper limb to the lower limb. Meanwhile, if core stability is poor, a higher force is imposed on the spine, leading to fatigue and risk of injury [15]. Another effective factor in the balance is the interaction between the feedforward and feedback mechanisms [45]. TrA and MF muscles are activated before movements and can increase postural stability [15]. Evidence shows that feedforward control can be restored with exercises focused on core muscle recruitment [20]. Meanwhile, it has been reported that the feedforward mechanism and activation of trunk muscles in the motor cortex are restored following stabilization exercise emphasizing the co-contraction of TrA and MF muscles [11, 20].

On the other hand, McNeill reported that CSE affects the brain and sensory-motor inputs [48]. Modulation of the central nervous system is vital for motor integration and may strengthen joint position sense [21]. With the co-contraction of TrA and MF muscles, the thoracolumbar fascia is activated as a proprioceptor and provides feedback [46]. Increasing the sensory impulse about joint position and changes in the length and tension of muscles improves the ability of the nervous system to recruit muscles, increasing the number of movement units, and muscle coordination [10]. Following proprioceptive facilitation, the feed-forward and feedback motor control is improved; as a result, it leads to joint stability, coordination, and postural stability [10, 49]. Finally, sensory-motor integration following CSE increases the ability of patients to maintain the center of pressure on a supportive basis [7]. CSE combined with AH is based on motor learning, which, by focusing on the TrA and MF muscles recruitment, can reverse the pain experience in the motor cortex, and modify faulty motor integration and muscle imbalance [7, 11].

In this study, we had three limitations. First, our sample size was only women, second, the unavailability of ultrasound and electromyography for assessment of the thickness and activity of the core muscles, third, failure to follow up results in the long term. Therefore, we recommended that future studies evaluate the effect of CSE combined with AH in men and women on the thickness and activation of the core muscles in the long term.

5. Conclusion

The CSE combined with AH affects the active, passive, and nervous systems. It is believed that stability exercises can improve the activation pattern in local muscles, facilitate proprioceptive, control spine movement, and finally lead to postural stability. Therefore, following the functional improvement of the three subgroups of active, passive, and nervous after CSE combined with AH, lumbar spine stability and postural stability are improved.

Ethical Considerations

Compliance with ethical guidelines

The Ethics Committee of Bio-Medical Research of Bu-Ali Sina University approved the present study (Code: IR.BASU.REC.1399.036). This research followed the Helsinki Declaration of 2008.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

All authors contributed equally to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors thank all patients for participating in this clinical trial.

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