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Efficacy of the lumbar stabilization and thoracic mobilization exercise program on pain intensity and functional disability reduction in chronic low back pain patients with lumbar radiculopathy: A randomized controlled trial

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Abstract.
BACKGROUND: Exercise programs in the treatment of chronic lumbar pain are quite diverse, but it has been proven that stabilization exercises are the most effective.
OBJECTIVE: We compared the lumbar stabilization exercise program in a closed and open kinetic chain (LSCO) and lumbar stabilization exercises and thoracic mobilization program in a closed kinetic chain (LSTMC), and evaluated the clinical effectiveness of each program.
METHODS: Prospective, randomized, controlled trial in 80 chronic low back pain (CLBP) patients with lumbar radiculopathy of both sexes (35 male, 45 female), average age (48.45 $\pm$ 10.22 years), divided in two groups that performed different sets of exercises. Participants were given laser therapy, transcutaneous electro-nerve stimulation and an eight-week kinesiotherapy that included exercises to strengthen the deep lumbar spine stabilizers. Retesting was done after four and eight weeks.
RESULTS: Statistically significant ($p < 0.05$) superior recovery of the LSTMC group subjects compared to the LSCO group was achieved at all measurement intervals in the pain intensity and functional disability parameters.
CONCLUSION: Patients who performed the lumbar stabilization and thoracic mobilization exercise program in a closed kinetic chain had the most effective reduction of pain intensity and functional disability.

Keywords: Chronic low back pain, lumbar stabilization, thoracic mobilization, closed kinetic chain

1. Introduction

Chronic low back pain (CLBP) is a heterogeneous group of disorders. According to the new classification of the International Association for Pain Research

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(IASP), it is recognized as an independent entity that belongs to the mixed pain type caused by central sensitization, and which is present for more than 12 weeks [1,2]. CLBP is the most common cause of disability in people under the age of 45 [3]. After six months of sick leave, the return to work for people with chronic lumbar pain is below 50%, and after 24 months, it is almost nonexistent [4]. It affects more than 50% of the world's population [5].

The well-known Panjabi's stabilization system theory is confirmed by the motor control disorders of the lumbo-sacral spine stabilizers, at both the peripheral and central level in subjects with CLBP. Studies that investigated the central activity of the m. erector spinae at maximum voluntary contraction showed a shifted expression for m. transversus abdominis in the motor cortex [6] that is restored after exercise programs for activation of these muscles [6–8]. This means that it is important to include the muscles of the thoracic spine when activating the lumbar spine muscles for the reduction of pain. Motor control disorders are related to the central regulatory mechanisms. Tsao et al. showed that the representation of m. transversus abdominis in the motor cortex is moved posteriorly and laterally in subjects with CLBP compared to the position of this muscle in healthy subjects [6], which is restituted after targeted exercise activating this muscle. This restoration of the cortical representation of m. transversus abdominis after exercise to strengthen the stabilizer of the lumbar segment of the spinal column coincides with the normalization of the anticipatory sequence of their activation [7,8]. This type of activity and motor learning leads to a decrease in pain and disability in subjects with CLBP [9].

Lumbar stabilization exercises are used in the treatment of patients with segmental instability and lumbar pain. The patient maintains a neutral position of the trunk while performing these exercises. In the past fifteen years, a large number of studies have highlighted the importance of activating the thoracic spine muscles in stabilization exercises to achieve full functional recovery [10,11]. The most flexible parts of the human spine form the largest angle of motion. Excessive movements of the lumbar spine are caused by motion reduction of the thoracic segments through compensatory mechanisms. The instability that develops in the facet joints is caused by abnormal movements of the lumbar spine, which eventually causes pain in the lower back [12]. With increased mobilization of the joints close to an unstable segment, through stabilization, and decreasing the hypermobility of the hypermobile segment, can promote pain intensity reduction. Thoracic mobilization may effectively help in stabilizing lumbar spine [10]. The basis of our lumbar stabilization and thoracic mobilization in closed kinetic chain (LSTMC) group exercises (Fig. 1) is the "cat-camel" (arching swaying) exercise. The effectiveness of this exercise in lumbar pain reduction has been demonstrated in various studies [13,14]. Several studies have emphasized the importance of stabilization exercises and maintaining a neutral position in activities of daily living, in order to prevent further reduction of intradiscal pressure and surrounding structures [15,16]. That is the reason why we believe that patients with radicular pain should be included in the exercise programs.

An important part of lumbar pain treatment is the principle of open and closed kinetic chains. An open kinetic chain occurs in the case of a body part system that is fixed only at one end, while the other end is free. A closed kinetic chain occurs in the case of a body part system that is fixed at both ends, and the aim is to perform a specific movement of the system in between the closed ends of the kinetic chain by a specific action [17,18]. Exercises in a closed kinetic chain could have an advantage in rehabilitation over exercises in the open kinetic chain because they better mimic functional movements of daily life and lead to joint contraction of several muscle groups.

The aim of the study was to compare the program of lumbar stabilization exercises in the open and closed kinetic chain to the lumbar stabilization exercises and thoracic mobilization program in a closed kinetic chain in order to evaluate the impact on pain intensity and functional disability of each exercise program.

2. Materials and methods

2.1. Design, setting, methods and population

The study was designed as a prospective, cohort, randomized and controlled trial involving 88 enrolled chronic low back pain (CLBP) patients with lumbar radiculopathy of both sexes (40 male, 48 female). The average patient age was 48.45 ± 10.22 years. After clinical examination and diagnosis of degenerative spine and disc disease using an imaging method examination (81 with MRI and seven with EMNG) by a PMR specialist, the participants were registered. Two to four patients per week were found suitable for the study and we agreed that the study should contain at least 80 patients divided into two groups in a 1:1 ratio (lumbar

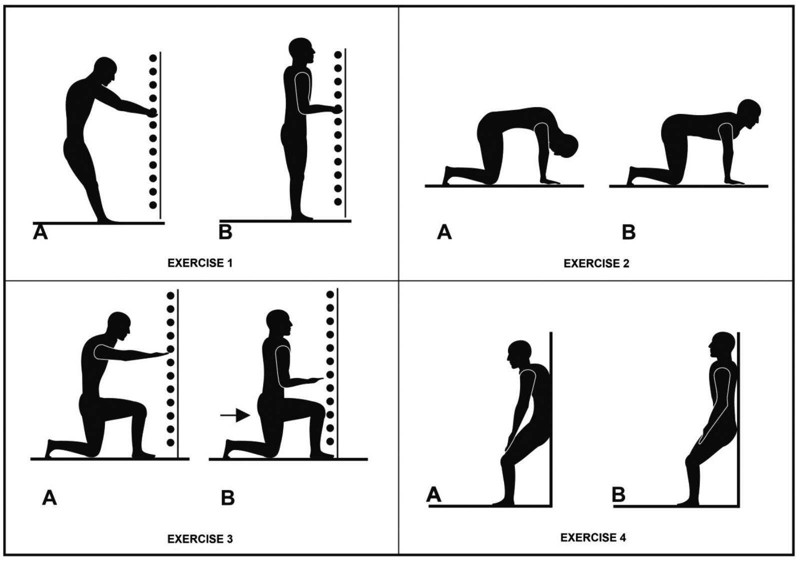

Fig. 1. Lumbar stabilization and thoracic mobilization exercises (LSTMC group).

stabilization and thoracic mobilization in a closed kinetic chain (LSTMC) versus lumbar stabilization in a closed and open kinetic chain (LSCO)), who performed various exercises to strengthen the deep lumbar spinal stabilizers. The final number of participants on whom the data analysis was performed is 80 (40 treated patients from each group). Taking data on patients with CLBP with lumbar radiculopathy, the calculation was made for a dichotomous outcome, for two independent samples, with a confidence interval of 80%, with a maximum error of 10% and a critical incidence value of 50% for the respondent ratio in groups 1: 1. In this manner, the total sample size was determined at 80 subjects, with half of those belonging to the LSTMC and the other half to those belonging to the LSCO group. Participants with CLBP with lumbar radiculopathy were given written information about the study protocol and provided written consent for participation in the research. Patients were treated at the rehabilitation clinic "Dr Miroslav Zotović" in Belgrade from June 2017 to March 2018.

The research was approved by the Commission for Ethics of Clinical Trials (No: 01-39/122/1) at the Faculty of Medicine, University of Novi Sad, as well as the Ethical Committee of the Rehabilitation Clinic "Dr. Miroslav Zotović" (No: 03-183/1). The study was registered under trial registration no. NCT03862898.

The inclusion criteria were: CLBP patients (both sexes) aged from 25 to 64 years, with lumbar radiculopathy with unilateral radiation of the lower limb (pain present $>$ 12 weeks).

The exclusion criteria were: cauda equina syndrome, ankylosing spondylitis, thoracic deformities (pectus carinatum, excavatum), spina bifida, fractures, postoperative spinal conditions, diabetes, inflammatory processes, tumors, pregnancy.

The collected data consisted of socio-demographic and anthropometric parameters (sex, age and BMI), and questionnaires for assessing pain intensity and characteristics: intensity according to the visual analogue scale (VAS) scales in the back and legs, functional disability (Oswestry Disability Index, ODI), sagittal spinal mobility (Schober Test), Douleur Neuropathique en 4 Questions (DN4) test for the assessment of the neuropathic pain component, and the Prone Instability Test.

The pain intensity assessment was done with a VAS. On a 10-cm-long scale drawn on paper, with marks beginning with 0 and ending with 10, patients marked the place that most closely describes their experience of pain intensity. These scales were completed for the lumbar spine and lower extremity (VAS) [19,20]. Functional disability was assessed using the ODI. The ODI questionnaire contains ten topics on pain intensity, lifting ability, ability to care for oneself, sit, walk and stand, sexual function, quality of social life, sleep and travel, sleep quality. Each topic category has six statements. The patient checks the statement which most closely resembles his or her situation. Each question is scored on a scale of 0–5 with the first statement being zero and indicating the least amount of disability, and the last statement is scored 5 indicating the most severe disability. The scores for all questions answered

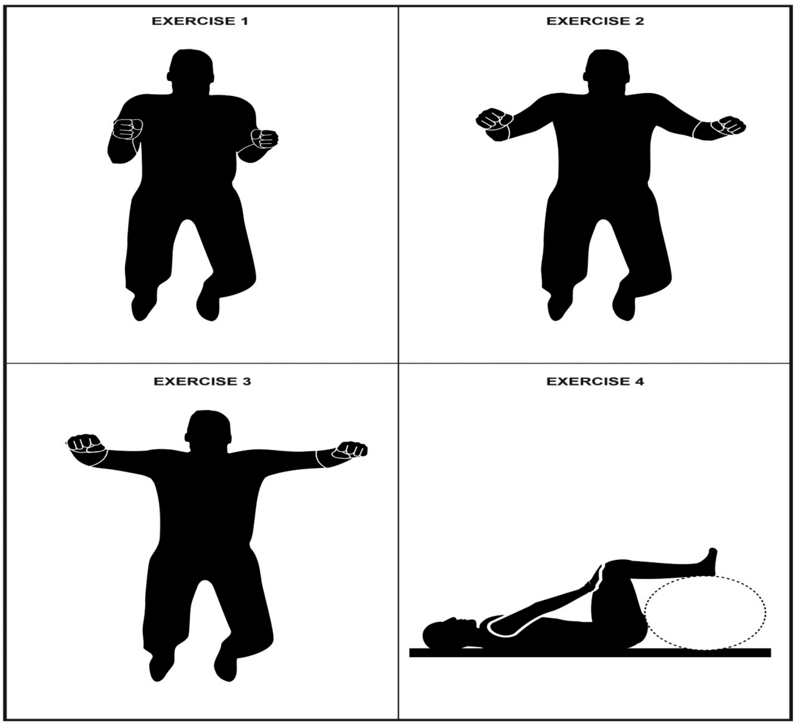

Fig. 2. Lumbar stabilization exercises (LSCO group).

are summed, and multiplied by two to obtain the index (range 0 to 100). Zero is equated with no disability and 100 is the maximum disability possible [19,21]. In the sagittal mobility of the spine (Schober Test), the patient is in a standing position. The examiner makes a mark at the level of L5 spinosus process. Two points are marked: 5 cm below and 10 cm above this point (for a total of 15 cm distance). The patient is asked to touch her/his toes while keeping the knees straight. If the distance of the two points does not increase by at least 5 cm (with the total distance greater than 20 cm), it is a sign of restricted sagittal mobility. Douleur Neuropathique en 4 Questions (DN4) questionnaire for assessment of the neuropathic component of the pain was performed, where a score of four or more is considered positive [22]. To test instability, the Prone Instability Test was performed. The patient lies prone with the body on the examining table, legs over the edge, and feet resting on the floor. The examiner applies pressure to a sensitive spinosus process of the lumbar spine. The patient reports any provocation of pain. She/he lifts legs off the floor (while holding onto the table), and the examiner applies pressure to the lumbar spine again. The test is considered positive if pain is present in the resting position but subsides in the second position, suggesting lumbo-pelvic instability [23].

2.2. *Interventions*

Both participant groups had two weeks of physical agents therapy: transcutaneous electro-nerve stimulation (TENS) for 20 minutes by stimulation with biphasic, rectangular pulses of 100 microseconds and a frequency of 110 Hz, with a maximum output amplitude of 100 mA; and a low power laser was then applied with a stable method, paravertebral, lumbar, total daily doses of 18 J. TENS and laser therapy were administered for two weeks. Both TENS and the laser therapy were applied for two weeks, once a day (ten therapies, five/week).

An individual kinesiotherapy program was created for the participants, which was implemented at the rehabilitation clinic "Dr. Miroslav Zotovic" in Belgrade, in relation to pain intensity, muscle strength and comorbidity. The program was performed from the lowest to the highest painless range of motion and accordingly divided into three phases. The first phase lasted for two weeks, the second lasted for three weeks, and the third phase lasted for another three weeks, for a total of eight weeks. Retesting was done after four weeks. After two full months, the final testing was performed where the same questionnaires and tests were done: the intensity of pain according to the VAS scales in the back and legs,

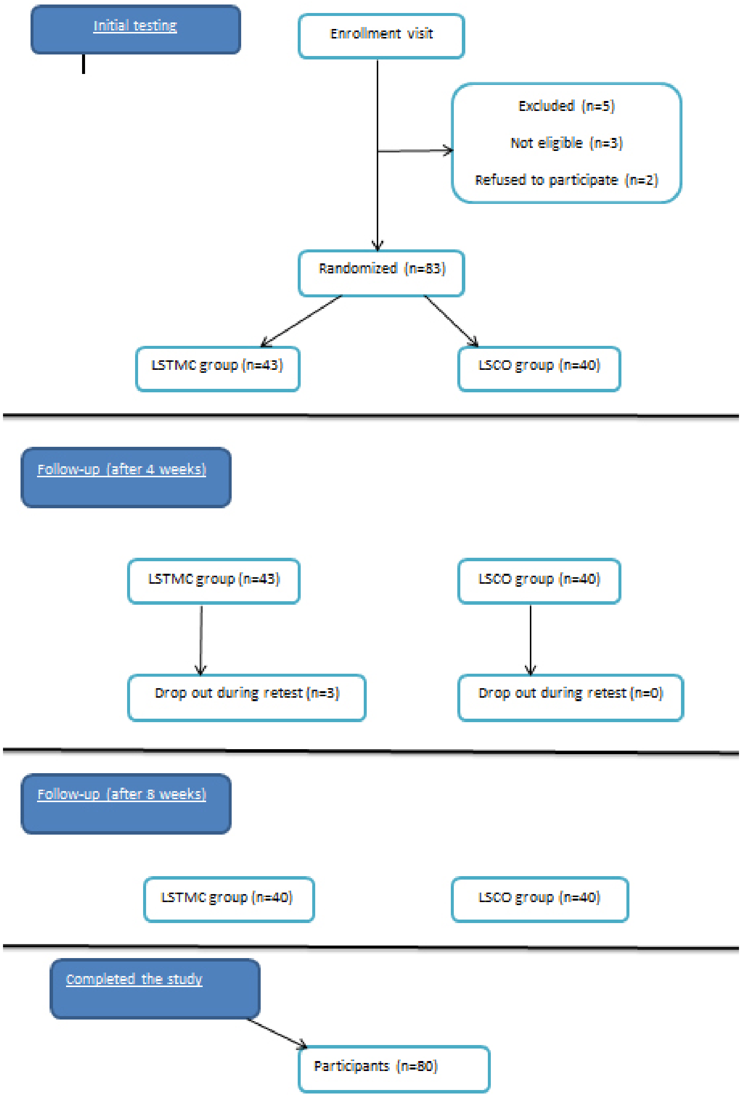

Fig. 3. Flowchart of the study.

functional disability (ODI), Schober Test, DN4, and the Prone Instability Test. The control of the patient's exercise regularity was carried out by telephone by the physical therapist once a week. The PRM specialist and physical therapist who ran the tests, completed the questionnaires and showed the exercises, and did not participate in other parts of this research. This was done to avoid the possibility of selective or outcome reporting bias. When the participant reported that she/he had forgotten to do the exercises, or was not sure whether she/he was doing them correctly, the physical therapist called the patient to the clinic, or, if necessary, went to the patient's home.

The patients were ergonomically educated about protective positions and movements [24]. Participants were individually explained not to do other exercises. In both groups, respondents who were thought not to pay enough attention to protective positions were reminded more often, in order to have an as uniform treatment as possible. This was done to prevent potential results from being diminished by a lack of awareness of protective positions.

2.3. Randomization

In this study, 83 patients were divided into two groups by simple randomization. We had a numbered series of pre-filled envelopes specifying the group which the

Table 1
Basic characteristics of the LSTMC and LSCO groups

Parameters	Characteristics	LSTMC group	LSCO group	p-value
Sex	Male	18 (45%)	17 (42.5%)	0.990
	Female	22 (55%)	23 (57.5%)	
Age		44.12 ± 10.25	44.3 ± 9.13	0.919
BMI		25.94 ± 4.48	24.63 ± 3.95	0.397
Beginning of current back pain episode	Suddenly	1 (3%)	3 (10%)	0.305
	Gradually	29 (97%)	27 (90%)	
Back pain problems before current episode	No	6 (20%)	7 (23%)	0.330
	Yes, one episode	0 (0%)	2 (7%)	
	Yes, two or more episodes	24 (80%)	24 (80%)	
Duration of symptoms	From 3 to 6 months	22 (55.0%)	24 (60.0%)	0.810
	From 6 to 12 months	11 (27.5%)	11 (27.5%)	
	Over 12 months	7 (17.5%)	5 (12.5%)	

patients drew from after they were registered, most often at the end of the week during their scheduled appointment (Fig. 3).

2.4. Blinding

The outpatients were not given any information about the group they would participate in. The patients exercised individually, and, together with other treatment procedures, were scheduled at the clinic at different times than other patients in the study. We could not blind the physical therapists because they needed to know which group each patient belonged to for the learning exercises.

2.5. Statistical methods

For the statistical analysis of data, RStudio software (0.98.976) and SPSS 17.0 (Chicago, IL, USA) were used. The analysis of the results obtained in this study was done using the following statistical methods: repeated measures ANOVA and post-hoc analyses, Friedman's test for categorical variables, Kohran's test, t-test for two independent samples, followed by Chi-square test and Fischer's test that was used to compare categorical parameters between groups. Cohen's d was used to indicate the standardized difference between two means. The statistical hypothesis testing was done by double-sided statistical tests at the 5% level of statistical significance.

3. Results

The participants of the lumbar stabilization exercises and thoracic mobilization program in a closed kinetic chain (LSTMC) and lumbar stabilization exercise program in a closed and open kinetic chain (LSCO) groups, according to the parameters of sex, age and BMI, statistically did not differ significantly (Sex: $p = 0.99$; Age: $p = 0.919$; BMI: $p = 0.397$) (Table 1). There was no significant difference in gender (the LSTMC group consisted of 18 men (45%), and 22 women (55%) and the LSCO group consisted of 17 men (42.5%), and 23 women (57.5%)) between the two groups. These characteristics are shown in Table 1. Three patients dropped out of the study after four weeks, all from the LSTMC group, due to failure to retest.

A significant decrease of visual analogue scale (VAS) scores ($p < 0.001$) was observed between the start of treatment and two follow up visits in the LSTMC group (59.4 ± 13.44 vs. 45.27 ± 12.66 vs. 22.75 ± 12.78) and in the LSCO group (61.44 ± 4.92 vs. 52.19 ± 5.01 vs. 45.02 ± 4.73). There was also a significant decrease of the Oswestry Disability Index (ODI) in the LSTMC group ($p < 0.001$), (17.77 ± 7.04 vs. 13.15 ± 6.11 vs. 6.15 ± 5.20) and in the LSCO group (21.1 ± 2.74 vs. 17.27 ± 2.59 vs. 14.05 ± 2.75), while for the neuropathic pain component assessment parameter, a statistically significant ($p < 0.001$) decrease of the Douleur Neuropathique en 4 Questions (DN4) value was found in the LSTMC group compared to the LSCO group (Table 2).

The clinical parameters of the participants in both groups are shown in Table 3, as well as the results of the comparison of the differences between groups in the parameters. There was a significant reduction in pain intensity (VAS ls and for the leg) at all intervals and in the functional disability (ODI) after eight weeks. The DN4 values of the neuropathic pain component assessment were also improved at all measurement intervals in the LSTMC group compared to the LSCO group. All chronic patients in our study had a moderate and approximate intensity of pain (VAS) and functional disability (ODI), so there were no differences and any additional divisions would be irrelevant.

Table 2
Mean and SD of LSTMC and LSCO groups at all measured intervals

Variables	Testing no.	LSTMC group	p-value	LSCO group	p-value
VAS ls	1	59.4 ± 13.44	< 0.001	61.44 ± 4.92	< 0.001
	2	45.27 ± 12.66		52.19 ± 5.01	
	3	22.75 ± 12.78		45.02 ± 4.73	
VAS for leg	1	60.05 ± 18.31	< 0.001	64.12 ± 4.89	< 0.001
	2	44.25 ± 18.91		54.81 ± 5.96	
	3	23.17 ± 19.15		47.75 ± 5.56	
ODI	1	17.77 ± 7.04	< 0.001	21.1 ± 2.74	< 0.001
	2	13.15 ± 6.11		17.27 ± 2.59	
	3	6.15 ± 5.20		14.05 ± 2.75	
Schober Test	1	6.95 ± 1.37	0.062	21.1 ± 2.74	< 0.001
	2	7.52 ± 1.24		6.55 ± 0.69	
	3	8.74 ± 1.46		7.69 ± 0.44	
DN4	1	2.95 ± 1.89	0.086	3 ± 1.24	0.133
	2	2.3 ± 1.63		2.92 ± 1.32	
	3	1.25 ± 1.49		2.57 ± 1.22	
Prone instability test	1	30 yes/10 no	/	26 yes/14 no	/
	2	30 yes/10 no		26 yes/14 no	
	3	8 yes/22 no		20 yes/20 no	

Table 3
Descriptive statistics of the differences in measurements between the clinical parameters of the LSTMC and LSCO groups

Parameters	Group	Pre/post therapy values after 4 weeks	Pre/post therapy values after 8 weeks	Values after 4 weeks in relation to values after 8 weeks
Pain intensity (VAS ls)	LSTMC	14.12 ± 9.09	36.65 ± 14.30	22.53 ± 10.71
	LSCO	9.25 ± 4.25	16.41 ± 3.54	7.16 ± 3.62
	p	0.01	< 0.01	< 0.01
	Cohen's d	0.68	1.94	1.92
Pain intensity (VAS for leg)	LSTMC	15.8 ± 13.02	36.38 ± 18.15	21.08 ± 11.45
	LSCO	9.31 ± 2.82	16.36 ± 3.84	7.06 ± 4.27
	p	0.04	< 0.01	< 0.01
	Cohen's d	0.68	1.52	1.62
Functional disability ODI	LSTMC	4.62 ± 3.03	11.62 ± 5.28	7.00 ± 3.21
	LSCO	3.82 ± 1.66	7.05 ± 1.68	3.22 ± 1.54
	p	0.434	< 0.01	< 0.01
	Cohen's d	0.32	1.16	1.50
Sagittal Spinal Mobility (Schober Test)	LSTMC	0.57 ± 0.57	1.79 ± 0.97	1.22 ± 0.82
	LSCO	0.54 ± 0.34	1.14 ± 0.54	0.61 ± 0.38
	p	0.637	0.003	< 0.01
	Cohen's d	0.06	0.82	0.95
Neuropathic component of pain (DN4)	LSTMC	0.65 ± 1	1.7 ± 1.45	1.05 ± 1.03
	LSCO	0.08 ± 0.42	0.42 ± 0.67	0.35 ± 0.53
	p	0.002	< 0.01	< 0.01
	Cohen's d	0.74	1.13	0.85

4. Discussion

Our study shows that the lumbar stabilization exercises with thoracic mobilization through enhanced and targeted activation of the deep stabilizers of the lumbo-sacral spine contribute to the reduction of pain intensity and functional disability. We suggested participants to carry out the "cat-camel" exercise while standing, following the high-kneeling position with a stepping stone, and, finally, a half-squat with the back to the wall. Our goal was to ensure a more efficient and easier engagement of the musculature in these positions. We respected all the principles of the "cat-camel" exercise, and also ensured that the exercises were carried out in the greatest, painless range of the motion amplitude in a closed kinetic chain, with the abdominal draw-in maneuver (ADIM) and pre-established breathing rules. The focus of our research was on a good selection of exercises, and that each lumbar stabilization exercises and thoracic mobilization program in a closed kinetic chain (LSTMC) group participant activates and strengthens, above all, the m. transversus abdominis through the ADIM. After a variety of exercise programs for strengthening the deep stabilizers, there are studies [25,26] that indicate that the activation of abdominal muscles using the ADIM maneuver does not contribute to the reduction of pain intensity and functional disability. These results are not directly comparable to our study because the authors of these studies announced the reliability of measurement, excluding from their program of exercises the activation of the thoracic spine through the closed kinetic chain.

In addition, chronic low back pain (CLBP) persistence and repair can be significantly influenced by biological and demographic factors, such as age, gender, and physical characteristics. Previous studies [27,28] showed that CLBP is more common among females, and that its magnitude increases with age [27]. Our results are in accordance with these findings.

When we look at the differences between men and women in our study, in total and by group, we can conclude that there is no statistical significance. Analyzing the values of the average age parameter, there were also no significant differences observed (44.12 ± 10.25 for LSTMC and 44.3 ± 9.13 for LSCO), which is in accordance with the age structure shown in the literature [27,28]. Instead of the influence of sex and age on lumbar pain recovery, some studies speak of more effective results in lumbar pain repair involving the inclusion of multidisciplinary biopsychosocial rehabilitation programs [29,30]. In our study, it was found that in older (> 50) patients, the outcome of treatment was indeed more unfavorable. The values of the pain intensity and functional disability were higher at the end of the treatment compared to the final values in younger patients (< 50).

Increased BMI values may affect the intensity of lumbar pain, as has been shown by numerous studies [31,32]. This is in line with the results of our research, but it was further established that in both groups of our study, higher values of BMI at the beginning of the study adversely affected the final outcome of pain intensity and disability levels.

Exercises of our LSCO group are quite similar to the exercises of most studies, but in the literature we did not find comparative exercises with our LSTMC group, except for the "cat-camel" exercise in a low-kneeling position. Reduction in pain intensity visual analogue scale (VAS) ls [33,34] and functional disability (Oswestry Disability Index, ODI) [35,36] was demonstrated in studies where patients performed stabilization exercises, and these results are similar to ours. The results of our study indicate a statistically significant and constant decrease in pain intensity (VAS ls and VAS leg), and functional disability (ODI), in the LSTMC group, after four weeks and after eight weeks of treatment compared to the initial values. The Prone Instability Test and the value of the neuropathic pain component Douleur Neuropathique en 4 Questions (DN4) also achieved statistical significance in improving the score at the end of the study compared to the initial values. The patients with a positive neuropathic pain component had a poorer outcome of the CLBP treatment with lumbar stabilization and thoracic mobilization exercises. In the LSCO group, statistical significance was also achieved in decreasing pain intensity (VAS ls and VAS leg) and functional disability (ODI). With Cohen's d effect size, we wanted to point to a standardized difference between two means. This effect was found to be large in all testing variables.

To the best of authors' knowledge, there are no studies which divided stabilization exercises without equipment in a closed and open kinetic chain in order to repair CLBP. However, there are several which dealt with this problem, who studied the use of additional equipment [37,38].

Recently, researchers have begun focusing on lumbar stabilization with thoracic mobilization exercises, and their studies have shown good results in reducing pain and functional disability in patients with CLBP, similar to our research results [10,11,39]. We believe that a better outcome in patients with LSTMC was achieved by increased mobility of the thoracic spine, which increased the stability of the lumbar spine, by decreasing the abnormal excessive motion of the unstable lumbar segments, and improved the physical disability by reducing pain intensity.

Our study has a few limitations. The first is the short duration of the study. A longer exercise interval should be included. It would be best if the exercises were performed for the entire duration of the lumbar disc absorption. The second is the small number of repetitions in exercises. More repetitions of each exercise need to be prescribed in order to activate the deep stabilizer muscles faster and more efficiently. The final limitation is related to setting the inclusion criteria for the study. Several different instability tests should be performed, where only those participants who are labeled as positive should participate in future research.

5. Conclusion

A statistically significant decrease in the pain intensity values (visual analogue scale, VAS ls and leg) and the degree of functional disability (Oswestry Disability Index, ODI) versus initial values was found in subjects with chronic low back pain (CLBP) with radiculopathy who performed both the lumbar stabilization and thoracic mobilization exercise programs in a closed and open kinetic chain at all times of measurement (after four and eight weeks). The patients who completed the lumbar stabilization and thoracic mobilization exercise program in a closed kinetic chain had better functional recovery and a significantly greater reduction in pain intensity compared to the respondents who performed a lumbar stabilization program in a closed and open kinetic chain. Larger initial and final values of pain intensity (VAS ls and leg) and functional disability (ODI) parameters were found in patients with a positive neuropathic pain component (Douleur Neuropathique en 4 Questions, DN4) compared to patients without the neuropathic pain component in both examined groups. Lumbar stabilization could be improved by thoracic mobilization exercise program and contribute to a more effective reduction of pain intensity and functional disability.

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Conflict of interest

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

References

[1] Loeser JD, Treede R-D. The kyoto protocol of IASP basic pain terminology. Pain. 2008; 137(3): 473-7.

[2] Treede R-D, Jensen TS, Campbell J, Cruccu G, Dostrovsky J, Griffin J, et al. Neuropathic pain redefinition and a grading system for clinical and research purposes. Neurology. 2008; 70(18): 1630-5.

[3] Staal JB, Hlobil H, Twisk JW, Smid T, Köke Ar J, van Mechelen W. Graded activity for low back pain in occupational health CareA randomized, controlled trial. Ann Intern Med. 2004; 140(2): 77-84.

[4] Waddell G. The clinical course of low back pain. The back pain revolution. 1998.

[5] Rozenberg S. Chronic low back pain: Definition and treatment. La Revue du Praticien. 2008; 58(3): 265-72.

[6] Tsao H, Galea M, Hodges P. Reorganization of the motor cortex is associated with postural control deficits in recurrent low back pain. Brain. 2008; 131(8): 2161-71.

[7] Tsao H, Hodges PW. Immediate changes in feedforward postural adjustments following voluntary motor training. Exp Brain Res. 2007; 181(4): 537-46.

[8] Tsao H, Hodges PW. Persistence of improvements in postural strategies following motor control training in people with recurrent low back pain. J Electromyogr Kinesiol. 2008; 18(4): 559-67.

[9] Ferreira PH, Ferreira ML, Maher CG, Herbert RD, Refshauge K. Specific stabilisation exercise for spinal and pelvic pain: A systematic review. Aust J Physiother. 2006; 52(2): 79-88.

[10] Heo M-Y, Kim K, Hur B-Y, Nam C-W. The effect of lumbar stabilization exercises and thoracic mobilization and exercises on chronic low back pain patients. J Phys Ther Sci. 2015; 27(12): 3843-6.

[11] Woo S-D, Kim T-H. The effects of lumbar stabilization exercise with thoracic extension exercise on lumbosacral alignment and the low back pain disability index in patients with chronic low back pain. J Phys Ther Sci. 2016; 28(2): 680-4.

[12] Yang S-R, Kim K, Park S-J. The effect of thoracic spine mobilization and stabilization exercise on the muscular strength and flexibility of the trunk of chronic low back pain patients. J Phys Ther Sci. 2015; 27(12): 3851-4.

[13] Kumar SP. Efficacy of segmental stabilization exercise for lumbar segmental instability in patients with mechanical low back pain: A randomized placebo controlled crossover study. N Am J Med Sci. 2011; 3(10): 456.

[14] Fredericson M, Moore T. Muscular balance, core stability, and injury prevention for middle-and long-distance runners. Phys Med Rehabil Clin. 2005; 16(3): 669-89.

[15] Rohlmann A, Claes L, Bergmann G, Graichen F, Neef P, Wilke H-J. Comparison of intradiscal pressures and spinal fixator loads for different body positions and exercises. Ergonomics. 2001; 44(8): 781-94.

[16] Beim GM, Giraldo JL, Pincivero DM, Borror MJ, Fu FH. Abdominal strengthening exercises: A comparative EMG study. J Sport Rehabil. 1997; 6(1): 11-20.

[17] Middleditch A, Oliver J. Functional anatomy of the spine: Elsevier Health Sciences; 2005.

[18] Mayer F, Schlumberger A, Van Cingel R, Henrotin Y, Laube W, Schmidtbleicher D. Training and testing in open versus closed kinetic chain. Isokinet Exerc Sci. 2003; 11(4): 181-7.

[19] Ostelo RW, de Vet HC. Clinically important outcomes in low back pain. Best Pract Res Clin Rheumatol. 2005; 19(4): 593-607.

[20] Von Korff M, Jensen MP, Karoly P. Assessing global pain severity by self-report in clinical and health services research. Spine (Phila Pa 1976). 2000; 25(24): 3140-51.

[21] Ostelo RW, Deyo RA, Stratford P, Waddell G, Croft P, Von Korff M, et al. Interpreting change scores for pain and functional status in low back pain: Towards international consensus regarding minimal important change. Spine (Phila Pa 1976). 2008; 33(1): 90-4.

[22] Bouhassira D, Attal N, Alchaar H, Boureau F, Brochet B, Bruxelle J, et al. Comparison of pain syndromes associated with nervous or somatic lesions and development of a new neuropathic pain diagnostic questionnaire (DN4). Pain. 2005; 114(1): 29-36.

[23] Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. Arch Phys Med Rehabil. 2005; 86(9): 1753-62.

[24] Frank JW, Kerr MS, Brooker A-S, DeMaio SE, Maetzel A, Shannon HS, et al. Disability resulting from occupational low back pain: Part I: What do we know about primary prevention? A review of the scientific evidence on prevention before disability begins. Spine (Phila Pa 1976). 1996; 21(24): 2908-17.
[25] Mannion A, Caporaso F, Pulkovski N, Sprott H. Spine stabilisation exercises in the treatment of chronic low back pain: A good clinical outcome is not associated with improved abdominal muscle function. Eur Spine J. 2012; 21(7): 1301-10.
[26] Unsgaard-Tøndel M, Nilsen TIL, Magnussen J, Vasseljen O. Is activation of transversus abdominis and obliquus internus abdominis associated with long-term changes in chronic low back pain? A prospective study with 1-year follow-up. Br J Sports Med. 2012; 46(10): 729-34.
[27] Thomas E, Silman AJ, Croft PR, Papageorgiou AC, Jayson MI, Macfarlane GJ. Predicting who develops chronic low back pain in primary care: A prospective study. BMJ. 1999; 318(7199): 1662-7.
[28] Bener A, Verjee M, Dafeeah EE, Falah O, Al-Juhaishi T, Schlogl J, et al. Psychological factors: Anxiety, depression, and somatization symptoms in low back pain patients. J Pain Res. 2013; 6: 95.
[29] Kamper SJ, Apeldoorn A, Chiarotto A, Smeets R, Ostelo R, Guzman J, et al. Multidisciplinary biopsychosocial rehabilitation for chronic low back pain: Cochrane systematic review and meta-analysis. BMJ. 2015; 350: h444.
[30] Dunnl KM, Jordan KP, Croft PR. Contributions of prognostic factors for poor outcome in primary care low back pain patients. Eur J Pain. 2011; 15(3): 313-9.
[31] Cooper NA, Scavo KM, Strickland KJ, Tipayamongkol N, Nicholson JD, Bewyer DC, et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. Eur Spine J. 2016; 25(4): 1258-65.
[32] Chou L, Brady SR, Urquhart DM, Teichtahl AJ, Cicuttini FM, Pasco JA, et al. The association between obesity and low back pain and disability is affected by mood disorders: A population-based, cross-sectional study of men. Medicine. 2016; 95(15).
[33] Cho I, Jeon C, Lee S, Lee D, Hwangbo G. Effects of lumbar stabilization exercise on functional disability and lumbar lordosis angle in patients with chronic low back pain. J Phys Ther Sci. 2015; 27(6): 1983-5.
[34] Chang W-D, Lin H-Y, Lai P-T. Core strength training for patients with chronic low back pain. J Phys Ther Sci. 2015; 27(3): 619-22.
[35] França FR, Burke TN, Hanada ES, Marques AP. Segmental stabilization and muscular strengthening in chronic low back pain: A comparative study. Clinics. 2010; 65(10): 1013-7.
[36] Gatti R, Faccendini S, Tettamanti A, Barbero M, Balestri A, Calori G. Efficacy of trunk balance exercises for individuals with chronic low back pain: A randomized clinical trial. J Orthop Sports Phys Ther. 2011; 41(8): 542-52.
[37] Lee S, Kim SY. Effects of hip exercises for chronic low-back pain patients with lumbar instability. J Phys Ther Sci. 2015; 27(2): 345-8.
[38] Unsgaard-Tøndel M, Fladmark AM, Salvesen Ø, Vasseljen O. Motor control exercises, sling exercises, and general exercises for patients with chronic low back pain: A randomized controlled trial with 1-year follow-up. Phys Ther. 2010; 90(10): 1426-40.
[39] Chitra R. Effect of lumbar stabilization exercise and lumbar extension exercise in the treatment of chronic low back pain. ESJ. 2014; 10(21).

Appendix: Exercise description

The LSTMC group performed the lumbar stabilization exercises with thoracic mobilization in a closed kinetic chain (Fig. 1).

Exercise 1: Standing position, the patient holding on to the Swedish ladder or similar at elbow level, and with retracted breasts and abdominal muscles, looking down and exhaling, straightens his or her back, attempting to bring the shoulder blades together and stand straight, inhaling. At the end of the movement, the patient contracts the abdominal and gluteal musculature. Three sets of ten repetitions with a one minute break in between.

Exercise 2: "Cat-camel" exercise. Three sets of ten repetitions with a one minute break in between.

Exercise 3: High kneeling position with a step forward, leg bent at the knee at 90 degrees to the floor, holding on to the Swedish ladder or similar at elbow level. With retracted breasts and abdominal muscles, looking down and exhaling, the patient straightens his or her back, attempting to bring the shoulder blades together and stand straight, inhaling and tightening the abdominal muscles. At the end of the movement, he or she moves the pelvis forward slightly, on the side of the leg behind it, in order to stretch the hip flexors. Three sets of ten repetitions with a one minute break in between.

Exercise 4: The patient is in a standing position, legs bent at the knees with the back against the wall. The patient grabs hold of his or her clothes with his or her hands, exhales and pulls his or her abdominal muscles and chest in, trying to accentuate the thoracic kyphosis. As the patient inhales, he or she brings his or her shoulders to the wall attempting to bring the shoulder blades together, hands reaching the pelvis and tightening the gluteal musculature. Three sets of ten repetitions with a one minute break in between.

The LSCO group performed the lumbar stabilization exercises in a closed and open kinetic chain (Fig. 2).

Exercises 1, 2, 3: The patient is in a lying position with a padlock placed beneath his or her knees. The patient's elbows are in three different positions: next to the body (slightly moved away from the body), at 45 and at 90 degrees, with the hands perpendicular to the ceiling. The patient pushes his/her elbows against the floor while exhaling. Ten repetitions, with a five second contraction and a five second break on the inhale for each position.

Exercise 4: The patient is in a supine; the starting position is with legs raised and bent at the knee, where thighs are at 90 degrees to the lower leg, as are the feet to the lower leg. The patient's hands are on his or her knees. The patient pushes his or her hands and legs against each other, tightening the abdominal muscles for five seconds, followed by a five second break on the inhale. Three sets of ten repetitions with a one minute break in between. The exercise is initially performed by putting a large 70-cm-diameter ball under the lower leg. After a few weeks, when adequate progress is made, the ball is no longer used, and the exercise is performed in the same position with the legs in the air.