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Original Article

Investigation of the effects of different treatment approaches on lumbar stabilizer muscles and diaphragm motility in individuals with chronic low back pain

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ABSTRACT

Objectives: This study aimed to examine effects of core stabilization and aerobic exercises on lumbar stabilizer muscles and diaphragm motility in individuals with chronic low back pain (CLBP).

Patients and methods: Fifty-one patients (19 males, 32 females; mean age: 32.7±8.8 years; range, 20 to 60 years) with CLBP were included in this randomized controlled trial between March 2021 and May 2022. The patients were divided into three groups: the core group, the aerobic group, and the control group. Conventional treatments (hotpack, transcutaneous electrical nerve stimulation, ultrasound, and McKenzie exercises) were applied to all three patient groups. The core group received core stabilization exercises, and the aerobic group received aerobic exercises. The control group received only conventional treatments. Exercises were continued for six weeks. All patients were assessed through the Beck Depression Inventory (BDI), Visual Analog Scale (VAS), Roland Morris Disability Questionnaire (RMDQ), and Nottingham Health Profile (NHP). Trunk flexor and extensor strength, as well as trunk flexor and back extensor endurance, was examined. Structural features of the multifidus (MF), transversus abdominis (TrA), external oblique (EO), internal oblique (IO), and diaphragm muscles, as well as diaphragm motility, were evaluated with ultrasound imaging. All measurements were repeated before and after six weeks of treatment.

Results: In all groups, post-treatment values of VAS rest/activity, trunk flexor endurance, back extensor endurance, trunk flexor/extensor muscle strength, BDI, RMDQ and, NHP scores improved significantly compared to pre-treatment (p=0.001). Resting and contraction thicknesses of TrA, MF, EO, and IO muscles increased significantly in both the core (p=0.001/0.001, p=0.001/0.002, p=0.001/0.001, and p=0.001/0.001, respectively) and aerobic groups (p=0.001/0.013, p=0.002/0.020, p=0.001/0.004, and p=0.001/0.010, respectively), while the control group did not show any significant difference (p=0.229/0.064, p=0.052/0.102, p=0.069/0.449, and p=0.094/0.146, respectively). After treatment, all groups showed significant increments in end-expiratory thickness (p=0.001), end-inspiratory thickness (p=0.001), motility of diaphragm during normal breathing (control, p=0.003; core, p=0.001; aerobic, p=0.001), and deep breathing (control, p=0.007; core, p=0.001; aerobic, p=0.001).

Conclusion: While aerobic and core stabilization exercises provided significant improvements in individuals with CLBP, the core stabilization group showed the best improvement in all parameters. Accordingly, the necessity of aerobic and core stabilization exercises in treatment programs comes to the fore in individuals with CLBP.

Keywords: Core exercise, diaphragm motility, low back pain, lumbar stabilizer muscles.

Low back pain (LBP) is one of the most common clinical problems. The annual incidence of LBP is 5%, while its prevalence is 60 to 80%. Mostly, LBP occurs for a short time and improves with treatment. In some cases, the duration of LBP exceeds 12 weeks and is considered chronic. According to the definition of the National Institutes of Health Task Force, chronic LBP (CLBP) is defined as the presence of LBP for at least three months and more than half a day in the last six months.[1] Since it is common in society, it has a

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negative effect on the quality of life of individuals and, eventually, on their social environment. It is also the main cause of inactivity and absenteeism.[2]

Among the factors that cause CLBP, the effect of repetitive traumas is great. Some of the risk factors that play a role in its emergence are weakness of trunk muscle strength and imbalance between trunk flexor/extensor muscles.[3,4] It is known that risk factors such as the decrease in strength and flexibility of abdominal and back muscles over time, decrease in cardiovascular endurance, smoking, and vibration, together with occupational conditions, cause LBP.[5] It is the most common cause of disability and loss of workforce in the population under 45 years.[3,4]

The muscles and joints of the hip, pelvis, and spine are centrally located. This structure is also known as the center (core). Proximally from the diaphragm distally to the pelvic floor muscles and anteriorly from the transversus abdominis (TrA) posteriorly to the multifidus (MF), it includes a large muscle group. Core stabilization exercises are the training of the central and deep trunk muscles in isolation. Segmental exercises are based on the achievement of co-contraction of the TrA and lumbar MF muscles, which play a key role in stabilizing the lumbar region. These muscles attach directly to the lumbar vertebrae and affect local spinal segmental support by increasing intra-abdominal pressure and tension in the thoracolumbar fascia.[6,7]

It is possible that pain may be caused by the weaknesses of lumbar stabilization muscles and abdominals or be the result of their effect in individuals with CLBP.[2,5] In reality, both alternatives might be correct. This study aimed to increase the strength and flexibility of lumbopelvic core muscles, along with strengthening of abdominal muscles. Therefore, the effect of these exercises on pain and quality of life were examined.

PATIENTS AND METHODS

In this randomized controlled trial, LBP patients who attended to the Near East University Faculty of Health Sciences, Physical Medicine and Rehabilitation Department, were screened between March 2021 and May 2022. A total of 96 patients with LBP lasting for at least three months were recruited. Exclusion criteria were as follows: spinal abnormality, patients suffering from a neurologic disease, LBP with rheumatologic etiology, acute extremity pain, patients who have received treatment for LBP in the last six months, and regular exercise habits. Thirty-eight patients were not eligible for the study, and thus 58 patients were registered for the study. The patients were divided into three groups: the core group, the aerobic group, and the control group. Due to the loss of seven patients (four in the core group, one in the aerobic group, and two in the control group), 51 patients (19 females, 32 males; mean age: 32.7±8.8 years; range, 20 to 60 years) completed the study.

After the initial assessments, participants were randomly assigned to one of the three groups (Figure 1). All participants were sequentially evaluated by the same physiotherapist blinded to the groups at baseline and after six weeks. Conventional treatments (hotpack, transcutaneous electrical nerve stimulation, ultrasound, and McKenzie exercises) were applied to all three patient groups. In addition, core stabilization exercises were given to the core group, and aerobic exercises were given to the aerobic group. Exercises were continued for six weeks under the supervision of a physiotherapist in 40-min sessions, three days a week. All measurements were repeated before and after six weeks of treatment.

For core exercises, abdominal hollowing (pull-in), followed by curl-up, side plank, and bird-dog (alternate arm/leg raising in crawling position) exercises, then prone plank and bridge exercises were taught. In the following stages, to improve balance and coordination, different movements were added to the program by using balance boards and exercise balls on unstable surfaces and in different positions. The aerobic group was given walking and cycling exercises. The intensity of the exercise was determined as 75% of the age-predicted maximum heart rate (calculated by subtracting the age of the patient from 220), and a Polar heart rate watch (Apple watch SE, Apple, California, United States) was used to determine the intensity during the study.

Assessment tools

Individual's pain intensity was assessed using a Visual Analog Scale (VAS), which consisted of a 100-mm long horizontal line. One end of the line (0 mm) was considered no pain, and the other end (100 mm) was considered the worst pain possible.[8]

Trunk flexor and extensor muscle strengths were evaluated using the test developed by Lovett and Martin.[9] The test is scored between 0 and 5. The Biering-Sorensen[10] test was used to evaluate the endurance of the back extensors. Trunk flexor endurance test was used to evaluate trunk flexor muscle endurance.[11] The time that the participants

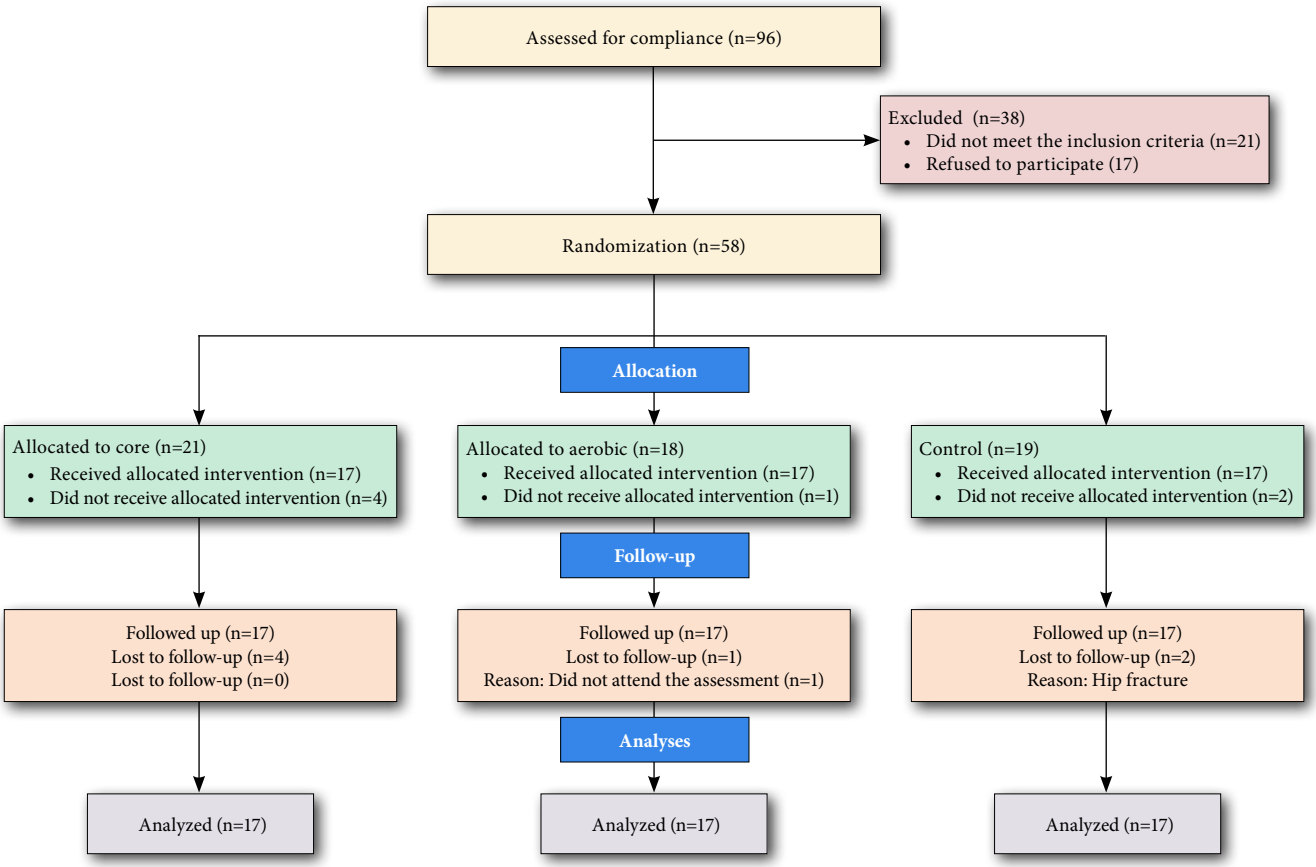

Figure 1. Selection process and grouping of the individuals included in the study.

were able to hold their test positions was recorded in seconds.

The Turkish version of the Roland–Morris Disability Questionnaire (RMDQ) was used to measure disability in all participants at the beginning of the study and after six weeks. This questionnaire is a 24-item questionnaire designed to assess the degree of functional limitation in patients with LBP. In the questionnaire, the answers vary as yes or no (yes=1 point; no=0 points), and high scores indicate severe disability.[12]

Quality of life was measured using the Turkish version of the Nottingham Health Profile (NHP) before and after six weeks. The questionnaire consists of 38 items. It evaluates six dimensions of health status: energy (3 items), pain (8 items), emotional reactions (9 items), sleep (5 items), social isolation (5 items), and physical activity (8 items). Each section is scored between 0 and 100. A score of 0 indicates the best possible health condition, while 100 indicates the poorest possible health condition.[13]

Turkish version of the Beck Depression Inventory (BDI) was used to assess the depression level of the patients. It consists of 21 items that measure the symptoms of depression in vegetative, emotional, cognitive, and motivational areas. The total score varies between 0 and 63. A higher total score indicates more severe depression.[14]

Stabilizer muscle thickness and diaphragm motility

Diaphragmatic thickness was measured with a high-frequency 9 MHz linear probe at the level of the eighth and ninth intercostal spaces at the mediolateral junction between the midclavicular-parasternal lines of the right anterior rib cage. At this level, the thickness was obtained after normal expiration and deep inspiration. Each measurement was made three times, and the mean value was recorded. The probe was longitudinally applied at this level, with an angle of 90° to the axis. The diaphragm appears as two moderately hyperechoic lines with hypoechoic space between

them. Diaphragmatic thickness was measured by freezing the view at the peak of tidal breathing and deep inspiration where breathing was stopped. During deep inspiration, the thickness appears to increase, and the measurement becomes difficult since the lung tissue also comes into the area and the diaphragm flattens down. The increase in respiratory efficiency can also be held responsible for the increase in thickness here. Likewise, the mobility of the diaphragm was measured with a 7.5 MHz convex probe in B-mode. Here, its motility was measured during normal breathing and during rapid deep breathing. The patient was placed in the supine position, parallel to the axis of the lowest rib, at the level of the right midclavicular line. The liver was used as the acoustic window. A 7.5 MHz probe was placed in the subcostal area mediocranially and dorsally.[15] After the hyperechoic image of the liver sheath was obtained with B-mode on the upper part of the screen, the waves of the same area were obtained and frozen with M-mode. On M-mode imaging, the movement of the moving diaphragm is observed as an undulating hyperechoic band. The measurement of wavelengths was done in millimeters. Afterward, the patient was asked to breathe quickly and deeply. After the stable wave image was taken, the wavelengths were measured by freezing. The distance between the up and down fluctuations indicates the depth of the breath. Here, it is aimed to reveal the changes in diaphragmatic mobility before and after treatment at rest and during deep inspiration.

For abdominal muscles, the probe was measured from the most raised region by finding the muscle belly region with the highest thickness of the desired muscles, 3 to 4 cm lateral on the umbilicus line at both sides. The patients were in the supine position, with the hands at the side of the trunk and the feet straight. The thickness of the three abdominal muscles (EO, IO, and TrA) on both sides was measured before and after the treatment, at normal rest, and with the trunk slightly flexed. Each measurement was made three times, and the mean values were taken as the basis.

Multifidus muscle examination was performed on both sides of the lowest lumbar level, both at rest and during activity. The patient was in the prone position with the hands free to the side. A 7.5 MHz convex probe was used. The most protruding areas on both sides of the spinous processes corresponding to the L4-5 space, connecting with the straight line drawn from the crista iliaca, were chosen as the measurement area. At the same time, L5 and then L4 spinous processes were detected by longitudinally placing them on the lower lumbar spinous processes. Subsequently, the probe was placed perpendicular to the spine axis, corresponding to the L4-5 spacing. Here, when the appropriate image was determined, it was frozen, and the lines determined by the MF muscle fascia were measured with upper-lower and medial-lateral markings. It was recorded by measuring the lower-upper and lateral-medial axes of the MF muscle at rest. Measurements were repeated in the same regions with the opposite leg straight and the hip extended, with the muscle contracted. At least three measurements were made, and the mean was recorded. All views have been photographed.

Statistical analysis

The IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Fit to normal distribution was examined by the Shapiro-Wilk test and skewness-kurtosis values, and it was determined that it showed a normal distribution. Analysis of variance was used to compare the pre-treatment and post-treatment values between groups, and a paired sample t-test was used for in-group comparisons. Analysis of covariance was

TABLE 1
Demographic characteristics of the participants

	Core group (n=17)			Aerobic group (n=17)			Control group (17)			
Variables	n	%	Mean±SD	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			38.7±12.9			34.5±7.0			24.8±6.5	
Sex										
Female	3	17.60		10	58.80		6	35.3		
Male	14	82.40		7	41.20		11	64.7		
Body mass index (kg/m²)			24.21±1.99			25.20±3.41			23.34±3.89	0.356*

SD: Standard deviation; * p<0.05.

TABLE 2
Comparison of VAS, trunk flexor endurance, back extensor endurance, and trunk flexor and extensor muscle strength scores before and after treatment according to groups

	Before treatment				After treatment								
	$\bar{\chi}$	S	F	*p*	$\bar{\chi}$	S	F	*p*	t	*p*	F	*p*	η^2
VAS resting													
Control group	5.47	1.59	0.344	0.711	2.29	1.72	0.152	0.860	9.818	0.000*	0.175	0.840	
Core group	5.47	1.66			2.00	1.70			9.024	0.000*			
Aerobic group	5.88	1.76			2.18	1.24			10.555	0.000*			
VAS activity													
Control group	6.35	1.84	0.396	0.675	2.47	1.81	0.151	0.860	13.725	0.000*	0.349	0.707	
Core group	5.82	1.59			2.18	1.51			8.351	0.000*			
Aerobic group	6.24	2.02			2.35	1.37			8.147	0.000*			
Trunk flexor endurance													
Control group	31.06	15.77	2.730	0.075	55.71	16.45	5.672	0.006*	−9.728	0.000*	5.192	0.009*	0.178
Core group	40.94	19.76			89.94	51.16			−5.111	0.000*			
Aerobic group	28.24	13.87			58.65	18.67			−11.996	0.000*			
Back extensor endurance													
Control group	35.29	12.88	3.683	0.032*	67.88	26.41	4.818	0.012*	−6.579	0.000*	4.936	0.011*	0.171
Core group	61.00	40.54			104.82	46.59			−5.534	0.000*			
Aerobic group	41.76	25.81			75.53	34.00			−7.343	0.000*			
Trunk flexor													
Control group	3.24	0.44	6.110	0.004*	4.12	0.49	12.241	0.000*	−10.954	0.000*	10.723	0.000*	0.309
Core group	3.88	0.70			4.88	0.33			−6.733	0.000*			
Aerobic group	3.41	0.51			4.47	0.51			−10.182	0.000*			
Trunk extensor muscle strength													
Control group	3.29	0.47	8.960	0.000*	4.18	0.53	9.798	0.000*	−10.954	0.000*	10.376	0.000*	0.302
Core group	4.00	0.50			4.88	0.33			−10.954	0.000*			
Aerobic group	3.53	0.51			4.47	0.51			−16.000	0.000*			

VAS: Visual Analog Scale.

TABLE 3
Comparison of groups' pre-treatment and post-treatment diaphragm measurements

	Before treatment				After treatment							
	$\bar{\chi}$	S	F	*p*	$\bar{\chi}$	S	F	*p*	t	*p*	F	*p*
Diaphragm end-expiratory thickness												
Control group	0.20	0.05	0.081	0.923	0.26	0.06	0.524	0.596	−6.753	0.000*	0.113	0.893
Core group	0.20	0.03			0.29	0.05			−5.943	0.000*		
Aerobic group	0.21	0.07			0.27	0.08			−8.388	0.000*		
Diaphragm end-inspiratory thickness												
Control group	0.36	0.11	2.463	0.096	0.45	0.13	0.493	0.614	−4.888	0.000*	1.084	0.346
Core group	0.30	0.05			0.43	0.08			−6.331	0.000*		
Aerobic group	0.34	0.09			0.42	0.11			−9.433	0.000*		
Diaphragm motility normal respiration												
Control group	1.52	0.31	0.077	0.926	1.71	0.40	1.938	0.155	−3.429	0.003*	0.785	0.462
Core group	1.54	0.32			1.98	0.38			−4.845	0.000*		
Aerobic group	1.50	0.38			1.84	0.42			−4.663	0.000*		
Diaphragm motility deep breathing												
Control group	2.78	0.80	0.967	0.388	3.35	0.80	4.762	0.013*	−3.121	0.007*	2.787	0.072
Core group	3.14	0.64			4.19	0.71			−5.832	0.000*		
Aerobic group	3.10	1.01			3.69	0.87			−4.784	0.000*		

* $p<0.05$.

TABLE 4
Comparison of pre-treatment and post-treatment measurements of TrA, MF, EO, and IO according to groups

	Before treatment				After treatment								
	$\bar{\chi}$	S	F	*p*	$\bar{\chi}$	S	F	*p*	t	*p*	F	*p*	η^2
TrA resting thickness													
Control group	0.28	0.13	1.380	0.261	0.30	0.13	5.708	0.006*	–1.250	0.229	14.873	0.000*	0.388
Core group	0.33	0.12			0.42	0.12			–14.192	0.000*			
Aerobic group	0.27	0.10			0.32	0.10			–6.473	0.000*			
TrA contraction thickness													
Control group	0.40	0.14	1.860	0.167	0.44	0.16	6.055	0.005*	–1.989	0.064	4.244	0.020*	0.153
Core group	0.49	0.13			0.62	0.14			–6.847	0.000*			
Aerobic group	0.44	0.14			0.54	0.16			–2.803	0.013*			
MF resting thickness													
Control group	3.10	0.78	0.495	0.613	3.16	0.77	0.275	0.761	–2.104	0.052	5.303	0.008*	0.184
Core group	2.94	0.46			3.24	0.44			–4.611	0.000*			
Aerobic group	3.15	0.60			3.32	0.58			–3.633	0.002*			
MF contraction thickness													
Control group	3.87	0.89	0.066	0.936	3.92	0.93	0.804	0.453	–1.734	0.102	4.374	0.018*	0.157
Core group	3.77	0.66			4.28	0.74			–3.686	0.002*			
Aerobic group	3.83	0.69			4.13	0.81			–2.580	0.020*			
EO resting thickness													
Control group	0.34	0.14	2.340	0.107	0.35	0.14	6.471	0.003*	–1.953	0.069	24.569	0.000*	0.511
Core group	0.38	0.19			0.50	0.18			–7.510	0.000*			
Aerobic group	0.28	0.09			0.34	0.10			–9.315	0.000*			
EO contraction thickness													
Control group	0.49	0.14	0.751	0.477	0.49	0.14	3.269	0.047*	–0.776	0.449	21.220	0.000*	0.475
Core group	0.53	0.25			0.64	0.25			–9.750	0.000*			
Aerobic group	0.45	0.16			0.50	0.16			–3.403	0.004*			
IO resting thickness													
Control group	0.36	0.16	2.123	0.131	0.38	0.17	3.807	0.029*	–1.780	0.094	10.486	0.000*	0.309
Core group	0.36	0.11			0.48	0.14			–5.290	0.000*			
Aerobic group	0.29	0.08			0.35	0.09			–9.286	0.000*			
IO contraction thickness													
Control group	0.50	0.21	1.671	0.199	0.53	0.20	3.259	0.047*	–1.529	0.146	4.478	0.017*	0.160
Core group	0.53	0.12			0.67	0.16			–5.107	0.000*			
Aerobic group	0.43	0.11			0.53	0.19			–2.941	0.010*			

TrA: Transversus abdominis; MF: Multifidus; EO: External oblique; IO: Internal oblique; * $p<0.05$.

TABLE 5
Comparison of BDI, RMDQ, and NHP pre-treatment and post-treatment scores according to groups

	Before treatment				After treatment						
	$\bar{\chi}$	S	F	*p*	$\bar{\chi}$	S	F	*p*	t	*p*	F	*p*
BDI												
Control group	18.18	11.67	2.828	0.069	7.35	4.34	1.142	0.328	4.808	0.000*	2.541	0.089
Core group	11.12	4.50			5.12	3.71			8.679	0.000*		
Aerobic group	19.00	13.49			6.47	4.90			4.682	0.000*		
RMDQ												
Control group	10.29	5.67	0.534	0.590	3.65	4.30	0.491	0.615	6.853	0.000*	0.581	0.563
Core group	11.59	4.15			4.88	3.43			7.909	0.000*		
Aerobic group	9.94	4.74			3.88	3.81			8.539	0.000*		
NHP												
Control group	241.80	114.79	3.494	0.038*	76.37	66.07	0.405	0.669	5.257	0.000*	2.076	0.136
Core group	150.63	83.16			66.24	47.00			6.978	0.000*		
Aerobic group	180.44	107.04			85.29	69.72			6.537	0.000*		

BDI: Beck depression inventory; RMDQ: Roland Morris disability questionnaire; NHP: Nottingham health profile.

used to compare changes after treatment. A *p*-value <0.05 was considered statistically significant.

The G*Power 3.1.9.2 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) was used to determine the sample size. Based on the study of Suh et al.,[16] it was determined that the pain values between the groups were statistically significant, and the effect size was d=1.836. In this study, the effect size was taken as d=1, and the sample size required for 95% power at the α=0.05 level was determined to be 17 individuals from each group. Since the patients who would be included in the study were not known, they were randomized using the block randomization technique in GraphPad software (GraphPad Software Inc., La Jolla, California, USA), with 51 participants among three groups, to assign the same number of participants to each group before the study.

RESULTS

There was no significant difference between the groups in terms of physical characteristics. There was no difference between the pre-treatment values according to the groups in all parameters examined. Table 1 shows the distribution of sociodemographic characteristics of the patients participating in the study according to their groups. Anthropometric measurements were compared according to the groups of the patients included in the study, and it was determined that there was no statistically significant difference between the height, body weight, and body mass index of the patients according to the groups (p>0.05).

The VAS resting and VAS activity scores of the patients in the control, core, and aerobic groups decreased statistically significantly after the treatment compared to the pre-treatment (p<0.001). There was no statistically significant difference between VAS resting and VAS activity scores measured after the treatment according to the groups of the patients (p>0.05). There was no difference between the changes in the VAS resting and VAS activity scores after the treatment according to the groups of the patients (p>0.05).

Trunk flexor endurance, back extensor endurance, trunk flexor muscle strength, and trunk extensor muscle strength scores of the patients in the control, core, and aerobic groups increased statistically significantly after the treatment compared to the pre-treatment (p<0.001).

It was observed that the trunk flexor endurance and back extensor endurance post-treatment scores of the patients in the core group were higher than in the control group and aerobic group patients (p=0.001). The amount of increase in trunk flexor muscle strength and trunk extensor muscle strength values of the patients in the core and aerobic groups were found to be higher than in the control group (p<0.05, Table 2).

Diaphragm end-expiratory thickness, diaphragm end-inspiratory thickness, diaphragm motility normal breathing, and diaphragm motility deep breathing values measured after the treatment were found to be significantly higher than pre-treatment values in the patients of the control, core, and aerobic groups (p<0.001). There was no difference between the diaphragm end-expiratory thickness, diaphragm end-inspiratory thickness, and diaphragm motility normal respiration values after the treatment according to the groups of the patients (p>0.05), but diaphragm motility deep breathing values measured after the treatment of the core group patients were statistically significantly higher than the control group patients (p=0.001, Table 3).

There was no statistically significant difference between the TrA, MF, EO, and IO muscle resting thickness and contraction thickness values after treatment and before treatment in the control group (p>0.05), but there was a statistically significant difference in the core and aerobic groups (p<0.001).

After treatment, the TrA, EO, and IO resting thickness and contraction thickness values of the core group were higher than the control and aerobic groups (p<0.05).

The amount of increase in TrA, MF, EO, and IO muscle contraction thickness and resting thickness values of the patients in the core group after treatment was found to be significantly higher than the patients in the control group (p<0.05, Table 4).

It was determined that there was no statistically significant difference between BDI, RMDQ, and NHP scores measured after treatment according to the groups (p>0.05). It was determined that the BDI, RMDQ, and NHP scores measured after the treatment in the control, core, and aerobic groups were significantly lower than the pre-treatment scores (p<0.05), and there was no statistically significant difference between the changes in the scores before and after the treatment according to the groups (p>0.05, Table 5).

DISCUSSION

In all groups, post-treatment values of VAS rest/activity, trunk flexor endurance, back extensor endurance, trunk flexor/extensor muscle strength, BDI, RMDQ, and NHP scores improved significantly compared to pre-treatment (p<0.05). Resting and contraction thicknesses of TrA, MF, EO, and IO muscles increased significantly in both the core and aerobic groups (p<0.05), while the control group did not show any significant difference (p>0.05). After treatment, all groups showed significant increments in end-expiratory thickness, end-inspiratory thickness, and motility of the diaphragm during normal and deep breathing (p<0.05).

Pelvic floor muscles and diaphragm are in synergism with the TrA and responsible for maintaining and increasing intra-abdominal pressure during various postural tasks.[17] Individuals with CLBP have a higher diaphragm position, a smaller diaphragm excursion, and more diaphragmatic fatigue. This is compensated by increased lung volume to provide an adequate increase in intra-abdominal pressure.[18,19]

Core stability has gained importance when considering the studies that observed delayed or decreased activation of lumbar MF and TrA and loss of physiological tonic activation of TrA during walking and extremity movements in individuals with CLBP. Dysfunction of these muscles, along with loss of lumbar spine support, can determine increased stress and load on the joints and ligaments of the lumbar spine.[20-23]

This concern has recently formed the basis for the development of special exercises related to segmental stabilization, which has been emphasized to be more effective in LBP.[24] Evidence supporting this approach relates to clinical and laboratory results showing the biomechanical co-contraction effect of local muscles, motor control, joint stabilization, and reduction of motor control problems in trained muscles.[6,25]

For example, when compared to the McKenzie approach, stabilization exercises have been shown to significantly increase TrA and MF muscle thickness and reduce pain intensity.[26] In another study, it was observed that breathing exercises given in addition to trunk strengthening exercises provided a better result in muscle thickness ratio than only strengthening.[27]

In our study, there was no change in TrA, MF, IO, and EO muscle thickness values in the control

group before and after treatment, while a significant improvement in thickening was observed both in the aerobic exercise and core exercise groups. Compared to the aerobic group, there is a significant difference favoring the core group in TrA, IO, and EO muscle thickness. In the study conducted by Nabavi et al.,[28] it was determined that the core exercises were not superior to the general exercise program when muscle dimensions of TrA and lumbar MF were assessed. While the exercise program was four weeks in the study of Nabavi et al., it lasted six weeks in our study. This result highlights the importance of exercise duration.

Significant improvement was found in all groups in VAS, BDI, RMDQ, and NHP compared to pre-treatment in our study, and there was no difference between the groups. In a similar study, the core exercise group was compared to a control group that did not receive any treatment, and an improvement was found in RMDQ and VAS.[29] Unlike this study, the control group received conventional treatment in our study. Therefore, there was a significant improvement in muscle strength and endurance in all groups after treatment compared to pre-treatment, while trunk flexor and extensor muscle strength was found to be higher in the core and aerobic groups compared to the control group. Additionally, trunk flexor and extensor endurance improved significantly only in the core group compared to the aerobic group and control groups. In the study of Alp et al.,[30] core stabilization exercises caused a significant increase in the endurance of dorsal extensors when compared to home-based conventional exercises.

When we look at the literature, the effect of core stabilization or aerobic exercises is generally considered alone, and it is seen that there is insufficient data on the effect of exercises on diaphragm motility.[26,27,31] In our research, it caused a significant change in diaphragm thickness and motility values in both aerobic and core exercise groups. However, the best increase in all parameters examined occurred in the core exercise group.

Frizziero et al.[32] concluded that although there are studies showing that core stability exercises are more effective than others, the results of combination treatments of core stability with other exercises appear to be more effective. Decreased abdominal muscle contraction thickness has been reported in patients with CLBP during abdominal pulling maneuvers and lower extremity tasks compared to healthy individuals.[33] It has been suggested that deep abdominal muscles, particularly TrA, contribute to segmental stiffness in the lumbar spine, possibly by stretching the thoracolumbar fascia and increasing intra-abdominal pressure.[20] In addition, data from a study confirm that the coordination of the abdominal muscles can be restored by training specific activation of the trunk muscles.[34]

In our study, general exercises did not show any change in TrA, MF, IO, and EO muscle thickness in contrast to the study of Akbari et al.,[35] which stated that motor control and general exercises increased the thickness of the TrA and MF muscles by reducing pain in patients with CLBP. However, motor control exercises were found to be more effective than general exercises in reducing pain.

Dülger et al.[31] showed that stabilization exercises increased diaphragm muscle thickness and improved lumbopelvic stability in females with LBP. While significant improvement was observed in diaphragm muscle thickness in the study, no change was observed in diaphragm motility. Although these exercises do not affect the abdominal and MF muscles, our study showed a significant increase in diaphragm muscle thickness. In addition, significant changes were observed in diaphragm muscle thickness and motility. We think that treatment duration and differences between studies may play a role in these results.

In a study on the diaphragm muscle, which plays an important role in spinal stability, diaphragm training, in addition to exercise, provided an improvement in TrA, MF, and diaphragm muscle thicknesses.[27] The results of this study explain the significant improvement in the aerobic group in our study. Similarly, the results of our study show that muscle strengthening alone is not sufficient to provide recovery in the core muscles, and it is important to include exercises that increase cardiorespiratory activity in the program.

The main limitation of the study is the likely interpersonal measurement differences. Although detailed information has been given and explained with applications in individuals requiring muscle contraction, we cannot be sure whether the same level of muscle contraction occurs in all patients. Nonetheless, the present study represents the first comprehensive study investigating the effects of core stabilization, aerobic, and general exercises on the abdominal muscle, MF, and diaphragm muscle thickness and diaphragm motility.

In conclusion, core stabilization exercises gave the best results in all parameters in individuals with

LBP. It was observed that aerobic exercises provided significant improvement after core stabilization exercises. Patients' muscle endurance, strength, pain level, disability status, quality of life, and depression level improved positively in all treatment groups. Stabilizer muscle thicknesses and diaphragm motility increased in the core and aerobic groups, while the control group, which received general treatment, increased only diaphragm thickness. The results show the importance of including aerobic and core stabilization exercises as a part of the treatment in individuals with CLBP. These results may be eye-opening for pathologies that cause pain in the lower lumbar region.

Ethics Committee Approval: The study protocol was approved by the Near East University Scientific Research Ethics Committee (date: 25.02.2021, no: YDU/2021/88-1280). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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