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CLINICAL TRIALS

Investigation of the effect of different intensity stabilization exercises on core muscle stiffness and pain in chronic low back pain: a single-blind, randomized controlled trial

Esin Akbaş[1] · Mustafa Özdemir[2] · Abuzer Akbaş[3] · Serkan Usgu[4] · Hacı Taner Bulut[2]

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Abstract

The primary aim of this study was to investigate the effects of different intensities of spinal stabilization exercises (SSE) on the core muscle stiffness; the secondary aim was to investigate the effects of these exercises on pain and disability. Participants were randomly assigned into three groups. Group 1 (n = 16) received supervised SSE 4 days a week; group 2 (n = 17) received supervised SSE 2 days a week; and the control group (n = 17) received a home exercise program. Stiffness of transversus abdominis (TrA) measured by shear wave elastography at baseline and 12 weeks. Pain and disability evaluated by visual analog scale (VAS) and Oswestry Disability Index (ODI) at baseline, 6 weeks and 12 weeks. Post-intervention median left and right TrA stiffness were measured as group 1 = 31.4 (25.6–37.8) and 33.3 (27.6–36.2); group 2 = 27.8 (21.6–34.8) and 28.2 (21.9–35.6); control group = 19.4 (14.8–28.2) and 20.6 (15.2–30.2). The muscle stiffness of the group 1 was found to be statistically higher than the other groups ($p < 0.05$). Post-intervention median VAS and ODI scores were measured as group 1 = 3 (2–4) and 17 (14–26); group 2 = 3 (2–4) and 24 (16–26); control group = 4 (3–5) and 28 (20–36). The difference between the means between groups 1 and 2 was 0.63 for VAS and 7.61 for ODI. These differences were smaller than the minimal clinically important difference value. VAS was statistically lower in groups 1 and 2 than in the control group ($p < 0.001$). There was no statistical difference in VAS between groups 1 and 2 ($p = 0.668$). Group 1 improved ODI statistically more than group 2 ($p = 0.002$). Supervised SSE performed four days a week is statistically more effective in increasing muscle stiffness and reducing disability than exercises performed two days a week.

Trial registration This study was registered in Clinical Trials on 22.04.2024 with the reference number NCT06227767. https://clinicaltrials.gov/NCT06227767.

Keywords Elasticity imaging techniques · Rehabilitation · Stiffness · Shear wave elastography · Transversus abdominis

✉ Esin Akbaş
eakbas@adiyaman.edu.tr

Mustafa Özdemir
itf212@hotmail.com

Abuzer Akbaş
akbas.abuzer@gmail.com

Serkan Usgu
serkan.usgu@hku.edu.tr

Hacı Taner Bulut
taner.bulut02@gmail.com

[1] Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Adıyaman University, Adıyaman, Turkey

[2] Department of Radiology, Faculty of Medicine, Adiyaman University, Turkey

[3] Adıyaman Training and Research Hospital, Adıyaman, Turkey

[4] Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Hasan Kalyoncu University, Gaziantep, Turkey

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Introduction

Low back pain is a symptom caused by various diseases or anomalies [1]. Most individuals experience at least one episode of low back pain during their lifetime [2]. The number of low back pain cases globally was reported to be 619 million in 2020 [3]. Low back pain is one of the most common causes of disability and loss of work. Therefore, the treatment of low back pain is an important issue for clinicians.

Non-pharmacological treatments such as patient education, exercise, manual therapy, massage, and cognitive behavioral therapy are recommended for the treatment of chronic low back pain (CLBP) [4]. Spinal stabilization exercises (SSE) are one of the most commonly used exercise methods in CLBP rehabilitation. These exercises have been shown to reduce pain and disability and increase muscle strength and balance in CLBP [5–8].

Passive mechanical properties of skeletal muscle, such as elasticity, viscosity, and stiffness, represent the properties of the muscle at rest without voluntary contraction [9, 10]. Passive mechanical properties are determined by the extracellular matrix (mostly Type 1 and 3 collagen) and titin protein [11, 12]. Passive mechanical properties of lumbar stabilizer muscles in CLBP have been investigated in various studies. Brown et al. reported a 34% increase in muscle fiber stiffness and a 107% increase in fiber bundle stiffness in the multifidus muscle compared with controls at 12 weeks of intervertebral disc degeneration in rabbits, suggesting that the muscle became stiffer due to proliferation and/or rearrangement of collagen content within the muscle [13]. Koppenhaver et al. evaluated the stiffness of the erector spinae and multifidus muscles using shear wave elastography (SWE) and reported that muscle stiffness increased in individuals with CLBP [14]. However, skeletal muscle connective tissue is known to respond to changing levels of physical activity. Miller et al. reported that muscle collagen and muscle myofibrillar proteins peaked at 24 h after exercise in biopsies taken from the quadriceps muscle and slowly decreased towards resting values 72 h after exercise [15]. Yu et al. evaluated the effect of isotonic exercise program on the stiffness of the infraspinatus tendon using SWE and reported that the exercises increased the stiffness of the infraspinatus tendon [16].

It is important to determine the most effective exercise intensity for CLBP in order not to waste the time and resources of health professionals, to achieve the purpose of exercise, to prevent sports injuries, not to impose unnecessary stress on individuals and to prevent work losses. To our knowledge, there are no studies comparing the effectiveness of exercises of different intensities in CLBP. In addition, the effect of SSE on the stiffness of transversus abdominis (TrA) muscle is unknown. Our aim is to investigate the effects of different intensities of SSE on the mechanical properties of core muscles and pain in CLBP. We hypothesized that muscle stiffness would increase due to an increase in collagen synthesis as exercise intensity increases.

Materials and methods

Trial design

The study was planned as a randomized controlled, single-blind, parallel group and was approved by the Hasan Kalyoncu University Non-Interventional Ethics Committee (decision number: 2024/7; decision date:10.01.2024). It was registered in Clinical Trials on 22.04.2024 with the reference number NCT06227767. The 1964 Helsinki Declaration was followed throughout the study. All participants were informed about the study in advance and written informed consent was obtained from each participant. CONSORT 2010 statement were followed in the analysis and reporting of study results [17].

Participants

This study was conducted in a tertiary hospital between April 2024 and March 2025. Patients who applied to the physical medicine and rehabilitation outpatient clinic due to low back pain were evaluated by a physical medicine and rehabilitation specialist in terms of eligibility criteria. Low back pain was defined as pain that caused activity limitation for at least one day in the last 4 weeks, localized between the lower edge of the 12th rib and the lower gluteal folds, and with or without radiating pain to the leg [18]. Inclusion criteria are as follows: volunteer to participate in the study; symptom duration longer than 3 months; being between the ages of 18–50; not having received physical therapy or an exercise program for low back pain in the last month. The exclusion criteria are as follows: lumbar and lower extremity surgery; radicular pain; severe/progressive scoliosis; spondylolisthesis; spinal stenosis; vertebral fracture; osteoporosis; neurological disease; pregnancy; diabetes mellitus; inflammatory disease; malignancy.

Randomization and blinding

Participants were assigned to 3 groups using the six-block randomization method. Randomization was performed by the last author, who was not involved in data collection. Participants were numbered according to the order of inclusion in the study. No concealed allocation method was used. Group 1 was the 4 days a week exercise group (n = 18); group 2 was the 2 days a week exercise group (n = 18); and

the group 3 was the control group (n = 18). Due to the nature of the study, patients were aware of the treatment they were receiving. The radiologist and physical medicine and rehabilitation specialist performing the outcome measurements were blinded.

Sample size

There is no study in the literature investigating the effect of SSE on TrA muscle stiffness. We conducted a pilot study (n = 24) to estimate the sample size. After treatment, a statistical difference was found between the groups in the stiffness of the right TrA muscle, and a large effect size was found (mean TrA muscle stiffness: group 1 = 34.08 ± 1.6, group 2 = 29.3 ± 3.7, group 3 = 20.5 ± 3.9). Therefore, we assumed a large effect size for the power analysis. G*Power® 3.1.9.7 software was used to calculate the sample size [19], applying the "ANOVA: Fixed effects, omnibus, one way" test. Using a power of 0.95, an alpha of 0.05, an effect size of 0.6, and group number 3, the total sample size was calculated as 48. Considering the 10% drop out rate, 54 participants were included in the study.

Interventions

The study period was planned as 12 weeks. Group 1 received supervised SSE 4 days a week (Monday, Tuesday, Thursday and Friday); group 2 received supervised SSE 2 days a week (Monday and Thursday); and the control group received a home exercise program. The exercise programs of group 1 and group 2 were supervised by a physiotherapist with ten years of experience in orthopedic rehabilitation.

SSE

Exercises were applied individually under the supervision of a physiotherapist. The first 5 min of the exercise program consisted of warm-up, and the last five minutes consisted of cool-down and breathing exercises. The total treatment time was 40–60 min. The exercises were applied in 3 phases with gradual progression and were performed in three sets and 15 repetitions. In phase 1 (1–4 weeks), activation of the TrA and multifidus muscles and diaphragmatic breathing were taught using the abdominal hallowing maneuver. After successfully implementing these movements, upper and lower extremity movements were added and phase 2 (5–8 weeks) exercises were started. In the last phase of the exercise program, phase 3 (9–12 weeks), functional movement exercises were applied to improve balance and coordination along with trunk stabilization [20, 21]. The exercise program applied is included in Appendix 1.

Home exercise program

Participants were informed about the causes of low back pain, prognosis, anatomical structure of the low back region, movements that increase or decrease low back pain, and hot/cold applications that can be done for pain management. The exercises were demonstrated to the participants in practice by the physiotherapist who had done the exercises for the other groups. The exercise program included strengthening and stretching exercises. Stretching exercises were performed for the iliopsoas, gluteal muscles and hamstrings. Strengthening exercises consisted of pelvic tilt, bridge and crunches [22]. The exercises were performed twice a week, with 15 repetitions and 3 sets per day. Participants were encouraged to keep an exercise diary. In order to increase patient compliance, patients were called by a physiotherapist once a week.

Outcome measurements

Demographic and clinical characteristics of the patients were recorded at the baseline. The primary outcome was mechanical properties of core muscles and secondary outcomes were pain and disability. For mechanical properties of the core muscles, the stiffness of the TrA muscle was measured. Stiffness was assessed at baseline and after treatment (week 12); pain and disability were assessed at the baseline, 6 weeks and 12 weeks.

Stiffness

SWE is an ultrasonography technique that examines the propagation speed of shear waves within tissue using the principle of acoustic radiation force. With this technique, shear wave speed (m/s) and Young's modulus (kPa) values are obtained [23]. Young's modulus is known as the modulus of elasticity and also indicates stiffness.

In this study, the evaluation of the TrA muscle was performed by a radiologist with thirteen years of experience in musculoskeletal radiology who was blinded to the group allocation. Measurements were made using the Samsung RS85 Prestige ultrasonography device and the LA2-14A linear probe. Before the measurement, the patients rested for five minutes and the measurement was performed in the supine position, with the legs extended and the abdominal muscles at rest. In B-mode ultrasonography, the TrA muscle was visualized in the transverse plane at the level of the anterior axillary line and umbilicus, with minimal pressure applied to the probe. In SWE mode, color maps were created to visualize shear wave velocities by means of a rectangular measurement box superimposed on grayscale images. On the elastographic color maps, four circular regions of

interest with a diameter of 3 mm were positioned on the TrA muscle. Shear wave velocities (m/s) and Young's modulus (k/Pa) were measured quantitatively in these regions. These measurements were repeated three times. The mean of the Young's modulus values obtained was recorded. The same procedure was performed for the contralateral TrA muscle.

Pain and disability

Pain and disability were assessed by a physical medicine and rehabilitation specialist with ten years of experience who was blinded to the group allocation. Pain was determined with visual analog scale (VAS). Pain level was scored from 0 (no pain) to 10 (unbearable pain) [24]. The minimal clinically important difference (MCID) for VAS in CLBP has been reported as 2 [25]. Disability was determined with Oswestry Disability Index (ODI). ODI score varies between 0 and 100, and higher scores indicate higher levels of disability [26]. Yakut et al. evaluated the reliability and validity of the Turkish version of the ODI [27]. The MCID for ODI in CLBP has been reported as 10 [25].

Statistical analysis

Statistical analysis was completed using the IBM SPSS 22.0 (IBM Corp., Armonk, NY, USA) program. Gender and work status were given as percentage (%) and number (n). The differences between these data were compared using the chi-square test. Non-parametric tests were preferred because the sample size was small. Continuous variables are given as median (min–max) and 95% confidence interval. Kruskal Wallis test (post hoc:Mann Wittney U test) was used to compare continuous variables between groups. Wilcoxon signed-rank test was used to compare TrA muscle stiffness within groups. Friedman test (post hoc: Wilcoxon signed-rank test) was used to compare VAS and ODI within the group. The r value was calculated for the effect size. The r value 0.1 represents a small effect, 0.3 represents a moderate effect, and 0.5 represents a large effect. [28]. MCID values for VAS and ODI were compared with values reported in the literature [25]. $P<0.05$ was considered sufficient to achieve statistical significance.

Results

Fifty-four patients were included in the study. Two patients in 4 days a week exercise group and one patient in each of the other groups were excluded from the study because they requested to leave the study. No side effects (such as muscle pain or increased back pain) were observed in either group during the study. The study was terminated after the pre-study targeted sample size was reached. The flow chart of the study is given in Fig. 1.

Demographic characteristics and baseline measurements of the groups are given in Table 1. There was no difference in baseline measurements and demographic characteristics between the groups ($p>0.05$). The control group's compliance rate with home exercises was determined as 60.7 ± 9.99.

Post-treatment TrA muscle stiffness measurements of the groups are given in Table 2. A statistically significant increase was found in the 4 days a week ($p=0.001$) and 2 days a week exercise groups ($p<0.001$). The effect size showed a large difference. There was no statistically significant difference in the control group ($p=0.331$ and $p=0.052$). Multiple comparisons between groups are given in Table 3. Left and right TrA muscle stiffness showed a statistically significant difference between the groups ($p<0.001$). Left and right TrA muscle stiffness was found to be statistically higher in the 4 days a week exercise group than the 2 days a week and control groups ($p=0.002$; $p<0.001$; $p=0.001$; $p<0.001$, respectively).

Comparison of post-treatment pain measurements is given in Table 4. In all three groups, a statistically and clinically significant difference was observed in VAS at 6 and 12 weeks compared to the baseline ($p<0.001$). In group comparisons, a statistical difference was found between the groups in the 6th week measurements ($p<0.001$). In multiple comparisons, no difference was found between 4 days a week and 2 days a week groups ($p=0.536$). There was a statistically significant difference between 4 days a week group and control group ($p=0.001$) and between 2 days a week group and control group ($p<0.001$). In group comparisons, a statistical difference was found between the groups in the 12th week measurements ($p<0.001$). Multiple comparison results are given in Table 3. The VAS of groups 4 days a week and 2 days a week were both statistically and clinically lower than the control group (differences of 4.5 points and 4.4 points, respectively).

Comparison of disability measurements after treatment is given in Table 4. A statistically significant decrease in ODI score was found in all 3 groups at the end of treatment compared to baseline. The difference in 4 days a week and 2 days a week groups was found to be clinically significant (mean difference 14.93 points and 11 points, respectively). However, the difference in control group was not found to be clinically significant. In the 6th week measurements, a statistical difference was found in the comparisons between the groups ($p<0.001$). There was no statistical difference between 4 days a week and 2 days a week groups ($p=0.095$). The ODI scores of groups 4 days a week and 2 days a week were statistically lower than control group ($p<0.001$, $p=0.003$, respectively). In the 12th week measurements, a statistical difference was found between the

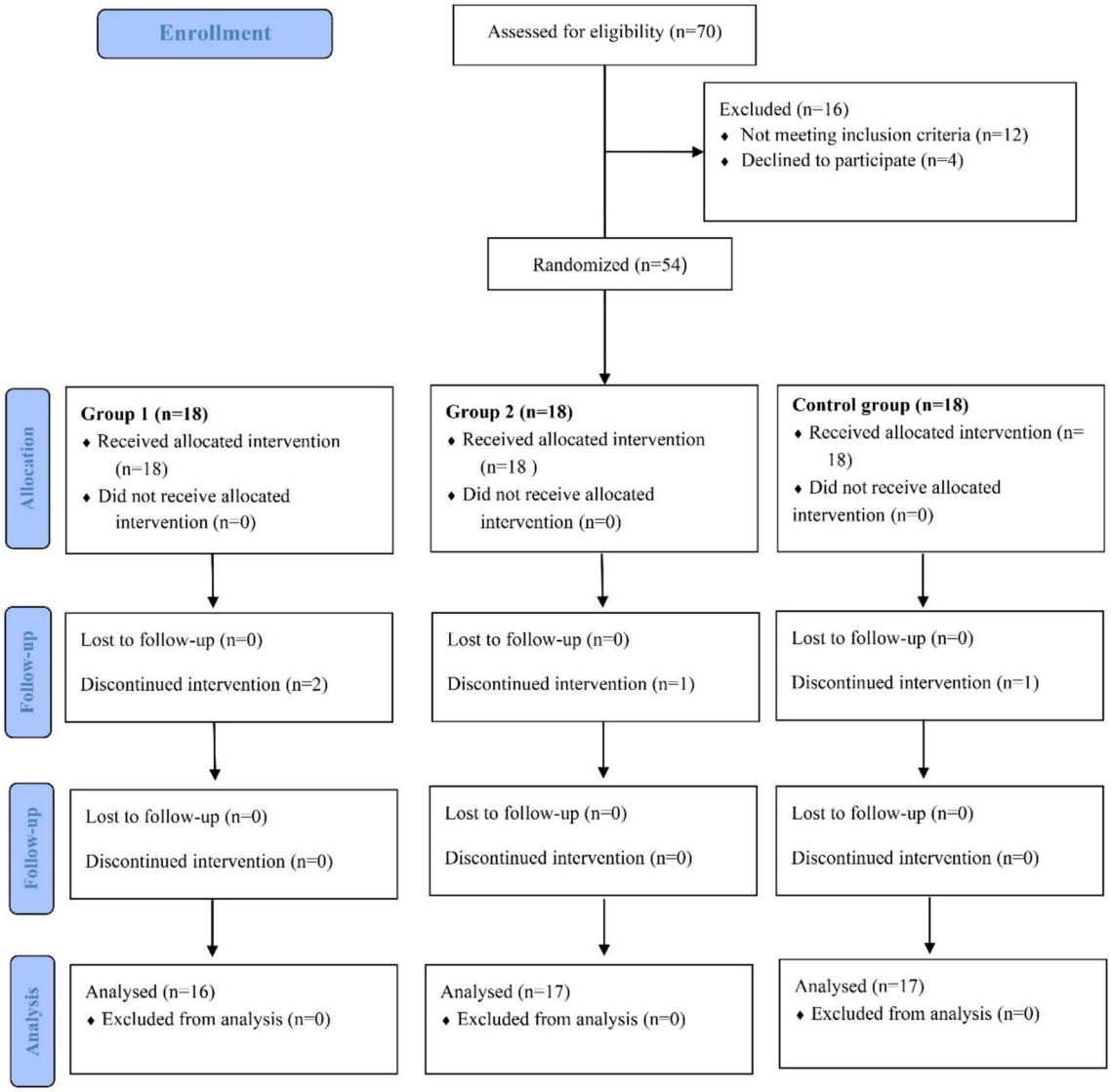

Fig. 1 Study flow chart

groups ($p<0.001$). Multiple comparison results are given in Table 3. Differences between groups were statistically significant but not clinically significant. The line graph of the muscle stiffness, pain and disability results of the groups is given in Fig. 2.

Discussion

The global epidemic of low back pain is increasing rapidly. It is important to develop rehabilitation programs to minimize absenteeism and disability [3]. For this purpose, it is necessary to determine the most effective exercise intensity for individuals with CLBP. Therefore, we compared the effectiveness of different intensity SSE programs in CLBP. Unlike previous studies [29, 30], we determined the effectiveness of the exercises with an objective method, SWE, in addition to self-reported scales. Our main finding was that exercises performed 4 days a week were more effective than other treatments in increasing muscle stiffness and reducing disability.

Previous studies have shown that erector spinae and multifidus muscles stiffness increase in CLBP [13, 14]. Therefore, treatments that reduce muscle stiffness can be harmful and lead to instability. It is also known that muscle stiffness increases with collagen synthesis after exercise. For these reasons, SSE are expected to increase the stiffness of the lumbar stabilizer muscles in CLBP. Tornblom et al. applied motor control and isolated lumbar extension exercises to 25 participants aged 18–65 years with CLBP twice a week for 12 weeks. They reported that there was no statistical difference in multifidus stiffness assessed by SWE after treatment

Table 1 Clinical and demographic features

		Median (min–max)	95% CI upper-lower values	*p*
Age, *y*	Group 1	37 (28–45)	33.81–36.69	0.907
	Group 2	35 (25–47)	31.81–40.07	
	Group 3	36 (25–47)	32.26–39.03	
BMI, kg/m^2	Group 1	24.5 (20.2–32.3)	23.01–26.85	0.633
	Group 2	23.3 (21.6–29.2)	22.75–25.01	
	Group 3	24.4 (17.3–28.4)	22.71–25.9	
Gender	Group 1	12 (75%)		0.863*
	Group 2	13 (76.5%)		
	Group 3	14 (82.4%)		
Symptom duration, *w*	Group 1	24 (15–44)	20.73–30.01	0.862
	Group 2	26 (16–48)	20.08–29.46	
	Group 3	22 (14–52)	19.79–28.44	
Work status	Group 1	11 (68.7%)		0.836*
	Group 2	10 (58.8%)		
	Group 3	11 (64.7%)		
Left TrA stiffness, kPa	Group 1	21.5 (14.8–29.1)	19.05–23.29	0.613
	Group 2	19.4 (14.8–27.8)	18.03–22.27	
	Group 3	18.6 (14.8–27.6)	17.52–22.10	
Right TrA stiffness, kPa	Group 1	21.3 (13.9–32.6)	18.75–23.89	0.969
	Group 2	19.4 (14.6–30.8)	18.57–23.32	
	Group 3	19.8 (16.2–29.5)	18.71–22.84	
VAS	Group 1	7 (5–8)	6.33–7.3	0.805
	Group 2	7 (6–8)	6.35–7.06	
	Group 3	7 (6–8)	6.48–7.28	
ODI	Group 1	34.5 (22–40)	30.52–35.86	0.969
	Group 2	35 (26–40)	31.41– 36	
	Group 3	35 (27–42)	30.76–36.19	

The proportions of female gender and working patients are given. Group 1: 4 days a week exercise group; Group 2: 2 days a week exercise group; Group 3: Control group; BMI: Body mass index; TrA: Transversus abdominis; VAS: Visual analog scale; ODI: Oswestry disability index; * p: Chi square test; p: Kruskal Wallis test

[31]. The reason why Tornblom et al. failed to show the expected increase in muscle stiffness may be due to the age range of the participants. Because it has been reported that stiffness changes with age [32]. Kwak et al. evaluated the effects of lumbar stabilization exercises on quadratus lumborum muscle stiffness in CLBP using the Myoton PRO device and reported that quadratus lumborum muscle stiffness decreased [33]. In our study, we found that SSE increased TrA stiffness. Studies with larger sample sizes are needed to explain these differences in the literature. To our knowledge, the effects of different intensity exercise on muscle stiffness in CLBP have not been investigated. Our study found that supervised SSE increased TrA muscle stiffness more than a home exercise program. This difference may be due to the control group's low compliance with the home exercise program and the exercises not being done in the correct posture. Besides, the 4 days a week group had higher muscle stiffness than the 2 days a week group. This result can be explained by the collagen response that occurs in the muscle as a result of exercise, as reported by Miller et al. [15]. In CLBP rehabilitation, we recommend planning exercise programs that will increase the stiffness of the lumbar stabilizer muscles.

Recent meta-analysis reported that stabilization exercises showed moderate to large effect sizes in reducing pain and improving disability in CLBP, with supervised and long-term (8–12 weeks) exercise programs providing the best results [34]. It is difficult to compare our study with other studies due to differences in treatment duration, exercise intensity, and measurement methods in studies investigating the effectiveness of SSE in CLBP. The most comparable studies include that of Bronfort et al. In this study, the effectiveness of supervised SSE, spinal manipulation and home exercise program in individuals with CLBP was compared. Supervised exercises were applied 2 days a week for 12 weeks. At the end of treatment, statistically significant improvements in patient-reported pain and disability scores were reported in all three groups. Pain and disability scores were lower in the supervised exercise group, although not statistically significant [35]. The findings of our study showed that there was a statistically significant improvement in pain and disability in all groups. Unlike the previous study, in our study, the 2 days exercise group reduced pain and disability statistically more than the home exercise group. This difference

Table 2 Intragroup comparison of muscle stiffness after treatment

		T0 Med (min–max)	T2 Med (min–max)	Means Difference 95% CI upper-lower values	z	r	*p*
Left TrA stiffness, kPa	Group 1	21.5 (14.8–29.1)	31.4 (25.6–37.8)	−10.5 (−12.7–−8.25)	−3.464	0.6	0.001
	Group 2	19.4 (14.8–27.8)	27.8 (21.6–34.8)	−7.30 (−8.80–−5.80)	−3.622	0.6	<0.001
	Group 3	18.6 (14.8–27.6)	19.4 (14.8–28.2)	−0.6 (−1.5–0.36)	−0.971	0.1	0.331
	p **	0.613	<0.001				
Right TrA stiffness, kPa	Group 1	21.3 (13.9–32.6)	33.3 (27.6–36.2)	−11.6 (−14.1–−9.07)	−3.465	0.6	0.001
	Group 2	19.4 (14.6–30.8)	28.2 (21.9–35.6)	−8.01 (−9.44–−6.58)	−3.622	0.6	<0.001
	Group 3	19.8 (16.2–29.5)	20.6 (15.2–30.2)	−0.5 (−1.07–0.07)	−1.943	0.3	0.052
	p **	0.969	<0.001				

Group 1: 4 days a week exercise group; Group 2: 2 days a week exercise group; Group 3: Control group; Med (min–max): Median (minimum–maximum); TrA: Transversus abdominis; T0: Baseline; T2: 12 weeks, p: Wilcoxon signed-rank test; *p* **: Kruskal–Wallis test

Table 3 Multiple comparisons of week 12 measurements between groups

	Differences between groups								
	Group 1–Group 2			Group 1–Group 3			Group 2–Group 3		
	MD	z	*p*	MD	z	*p*	MD	z	*p*
Left TrA	4.22 (1.19–7.2)	−3.064	0.002	11.27 (8.24 –14.31)	−4.864	<0.001	7.04 (4.05–10.03)	−3.945	<0.001
Right TrA	4 (1.01–6.09)	−3.352	0.001	11.68 (8.7–14.67)	−4.828	<0.001	7.68 (4.74–10.62)	−4.255	<0.001
VAS	−0.08 (−0.63–0.47)	−0.429	0.668	−1.55 (−2.10–−1.01)	−4,375	<0.001	−1.47 (−2.01–−0.93)	−4,410	<0.001
ODI	−4.45 (−7.61–−1.3)	−3.116	0.002	10.27 (−13.44–−1.12)	−4.504	<0.001	−5.82 (−8.93–−2.7)	−3.839	<0.001

Group 1: 4 days a week exercise group; Group 2: 2 days a week exercise group; Group 3: Control group; TrA: Transversus abdominis; VAS: Visual analog scale; ODI: Oswestry disability index; MD: Means Difference. The means difference was given at a 95% confidence interval. p: Mann Wittney u test (post hoc)

Table 4 Intragroup comparison of pain and disability

		T0	T1	T2	*p*	*Post hoc analysis		
						T0 vs T1	T0 vs T2	T1 vs T2
VAS	Group 1	7 (5–8)	3 (2–6)	3 (2–4)	<0.001	<0.001	<0.001	0.002
	Group 2	7 (6–8)	3 (2–4)	3 (2–4)	<0.001	<0.001	<0.001	0.005
	Group 3	7 (6–8)	5 (3–6)	4 (3–5)	<0.001	0.001	<0.001	0.003
	*p***	0.805	<0.001	<0.001				
ODI	Group 1	34.5 (22–40)	21 (15–28)	17 (14–26)	<0.001	<0.001	<0.001	0.007
	Group 2	35 (26–40)	25 (18–30)	24 (16–26)	<0.001	<0.001	<0.001	0.006
	Group 3	35 (27–42)	29 (22–35)	28 (20–36)	<0.001	<0.001	<0.001	0.127
	*p***	0.969	<0.001	<0.001				

Group 1: 4 days a week exercise group; Group 2: 2 days a week exercise group; Group 3: Control group; SD: Standard deviation; VAS: Visual analog scale; ODI: Oswestry disability index; T0: Baseline; T1: 6 weeks; T2: 12 weeks; p: Friedman test; *Post hoc analysis: Wilcoxon signed ranks test; p**: Kruskal–Wallis test

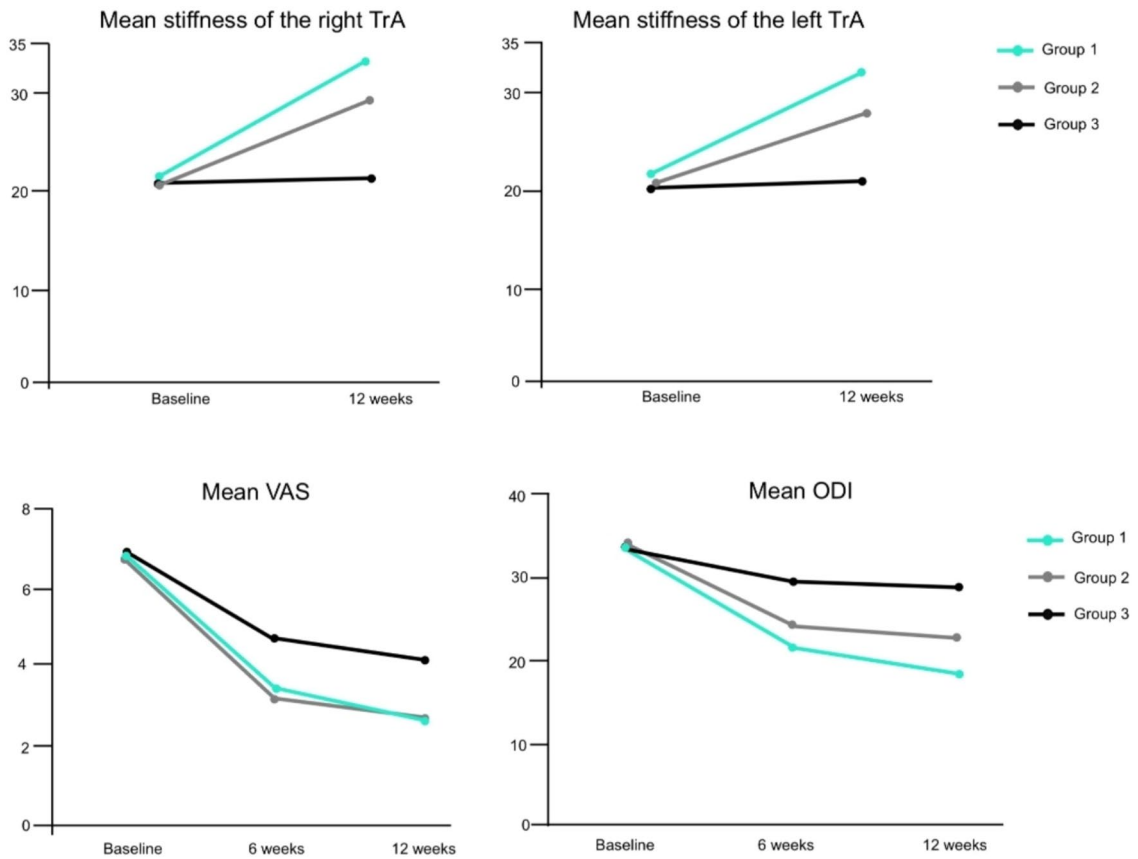

Fig. 2 Line chart of results of muscle stiffness, pain, and disability

may be due to our small sample size. The 4 days a week exercise group showed clinically significant improvement in disability compared to the other groups, but there was a statistically significant difference in pain only compared to the home exercise group. Since the relationship between TrA muscle dysfunction and low back pain is known [36], a correlation between changes in the structure of the muscle and pain was expected. Despite the difference in muscle mechanical structure and disability, the lack of a difference in pain may be explained by the presence of psychological and social factors contributing to pain.

Our study contributes to the literature in several aspects. Firstly, previous RHEI publications evaluated the effectiveness of physical therapy, pulsed electromagnetic field therapy, and balneotherapy in CLBP rehabilitation using patient-reported outcome measures [37, 38]. Unlike previous RHEI publications that focused on clinical outcomes of CLBP rehabilitation, in our study we evaluated the effectiveness of SSE by measuring muscle stiffness with SWE in addition to patient-reported outcome measures. Thus, we have presented a biomechanical perspective on rehabilitation outcomes that has not been previously addressed in this journal. Secondly, previous RHEI publications have investigated the use of SWE in the evaluation of liver fibrosis, in identifying parotid lymphoma, and as a diagnostic tool in Sjögren syndrome [39–41], and also assessed the elasticity of the quadriceps and patellar tendons by strain sonoelastography [42]. We believe that we contributed to the use of SWE in musculoskeletal system research by measuring the passive mechanical properties of the TrA muscle with SWE.

Our study has some limitations. The first is that due to the nature of exercise therapy, blinding is not possible. Secondly, only short-term follow-ups were made. Finally, the psychological status of the participants was not assessed, which may have affected the pain and disability results.

Conclusion

SSE performed 4 days a week under the supervision of a physiotherapist increase TrA muscle stiffness and improve pain and function statistically and clinically. It is statistically more effective in increasing muscle stiffness and reducing disability than exercises performed twice a week. We believe that the findings obtained in our study will contribute to the development of rehabilitation protocols for individuals with CLBP. Long-term follow-up studies investigating the relationship between increases in muscle stiffness and pain, disability, and time to return to work are recommended.

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Data availability Data available upon reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Consent to participate Participants were given comprehensive information about the study and written informed consent was obtained from the participants.

Ethical approval This study approved by the Hasan Kalyoncu University Non-Interventional Ethics Committee with the decision number 2024/7 and decision date 10.01.2024. Written informed consent was obtained from the all participants.

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