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Aquatic exercise versus standard care on paraspinal muscle morphology and function in chronic low back pain patients: a randomized controlled trial

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Low back pain (LBP) is a disabling disease and a public health concern. Aquatic exercise is an alternative form of exercise with less spinal loading and difficulty performing movements, benefiting those with pain-related fear. This study aimed to investigate the effect of an aquatic exercise program (SwimEx) versus standard care (SC) on lumbar paraspinal muscle volume and composition, strength and patient outcomes in individuals with chronic LBP. This randomized controlled trial included 34 participants with chronic LBP. Participants were randomly allocated to each group (SwimEx, n = 18; SC, n = 16) and underwent a 10-week supervised intervention program twice per week. Magnetic resonance imaging was performed at baseline and 10-weeks to examine the impact of each intervention on multifidus (MF) and erector spinae (ES) muscle volume (cm^3) and fatty infiltration (% FI) at L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1. Mixed model repeated measures ANCOVA revealed no significant time*group interactions for MF and ES volume and %FI. SwimEX had significant increases in MF volume at L2-L3 and L3-L4, and ES volume at L1-L2. Furthermore, SwimEX also had a significant increase in MF %FI at L2-L3. Both groups displayed significant increases in lumbar strength. Correlations between muscle morphology and patient outcomes showed improvements in MF volume were moderately correlated with an increase in physical quality of life and decrease in anxiety/depression. Interestingly, improvements in MF volume, MF %FI, and ES %FI, were each moderately correlated with a decrease in sleep disturbance. In conclusion, aquatic therapy may help increase lumbar paraspinal muscle volume and strength in participants with chronic LBP. Our findings support the notion that improvements in paraspinal muscle health are related to improvements in patient-reported outcomes. More imaging studies are required to examine the impact of exercise on overall paraspinal muscle health in chronic LBP and investigate these associations.

Keywords Low back pain, Aquatic therapy, Paraspinal muscle, Magnetic resonance imaging, Patient reported outcomes, Quality of life

Low back pain (LBP) is the most common musculoskeletal disorder globally[1], as it affects all age groups[2], making it a known public health problem[3,4]. LBP is not only common, but it has serious social and healthcare related consequences[4]. In addition, LBP is significantly associated with high levels of disability, decreased participation in life activities as well as sleep quality and increased depressive symptoms[5–7]. Therefore, it is not surprising that it is a leading cause of disability and work absenteeism worldwide[4], carrying the largest socioeconomic burden[4], especially when it becomes chronic[8]. Presently, exercise is the most common type of conservative approach to treat chronic LBP, with recent reviews supporting its effectiveness[9,10], especially for pain, quality of life, depression and disability[11–14]. Due to the link between changes in paraspinal muscle morphology (e.g.,

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atrophy, fatty infiltration) and LBP[15,16], and spinal instability resulting from these muscle impairments[17], many exercise interventions specifically target paraspinal muscles[13,14].

It is sometimes difficult for those with LBP to perform strengthening exercises without avoiding the weight load on their spine[18], and many individuals with chronic LBP have fears of performing movements due to pain[9,10]. One promising form of exercise and treatment alternative for individuals with LBP is aquatic therapy, with less risk of injury and difficulty performing exercises[18–21]. Recently, water-based exercise has been shown to significantly reduce pain and fear avoidance behavior compared to land-based exercise in elderly chronic LBP patients[22]. Water immersion decreases axial loading of the spine and, through the effects of buoyancy, allows the execution of movements that are usually difficult to perform on land by reducing stress in joints[23–25]. These unique properties of water allow a water-based exercise program to be tailored to the needs of those suffering from LBP. Aquatic exercise may improve pain and disability, and maintain quality of life in individuals with LBP[24], especially in individuals with low levels of physical fitness[26,27]. Improvements in muscle strength[28] and cardiovascular fitness[29,30] through continuous limb movements against water resistance have been reported as well. These findings suggest the potential benefits of aquatic exercise for individuals with chronic LBP; however its effects on paraspinal muscle health are still unclear. To our knowledge, no imaging studies have assessed the effect of aquatic therapy on paraspinal muscle morphology and function. Therefore, the purpose of this study was to investigate the effect of an aquatic therapy exercise program versus standard care on 1) multifidus (MF) muscle size and composition (i.e., fatty infiltration) and 2) erector spinae (ES) muscle size and composition, and strength, and the association of these changes with pain, disability, quality of life, and psychosocial factors (e.g., kinesiophobia, catastrophizing, anxiety, depression, and sleep) in individuals with chronic LBP.

Methodology
Study design
This study was a two-arm prospective randomized controlled trial (RCT).

Study setting
This project was organized at the School of Health, Concordia University (registration trial NCT05823857 on 27/04/2023). The Central Ethics Research Committee of the Quebec Minister of Health and Social Services (# CCER-21–22-35) approved the project in March 2022, and the project protocol has been published[31]. All participants signed a written informed consent form prior to entering the study. All methods were performed in accordance with the relevant guidelines and regulations, and the study was reported using the CONSORT guidelines[32].

Participants
Participant recruitment was conducted through the School of Health Athletic Therapy clinic and through poster and media advertising (i.e., email blast) since this is an efficient participant recruitment method[33]. If potential participants communicated interest in joining the study, a research team member (B.R.) contacted them to further review the study information, interview them, confirm eligibility, and enroll them. Participant recruitment respected the following inclusion/exclusion criteria. *Inclusion*: (1) chronic non-specific LBP (> 3 months), described as pain in the area between the lower ribs and gluteal folds, with or without leg pain; (2) presently seeking care for LBP; (3) between the age of 18 to 65 years old; (4) English or French language proficiency; (5) obtain a “moderate” or “severe” disability score on the modified Oswestry Low Back Pain Questionnaire; (6) does not presently participate in sports or exercise training for the low back muscles specifically (3 months before beginning the trial). *Exclusion*: (1) indication of deficits in motor reflexes or nerve root compression (e.g., weakness, changes in reflex, or sensory loss); (2) past lumbar spinal surgeries or vertebral fractures; (3) structural abnormalities in the lumbar spine (e.g., spondylolysis, spondylolisthesis, or lumbar scoliosis > 10°); (4) comorbid health circumstance limiting participation in an exercise program (i.e., screened with Physical Activity Readiness Questionnaire). A physical exam was performed by a certified Athletic Therapist (AT) to rule out any neurological involvement, if needed. Participants were withdrawn from the intervention if they missed more than 7 sessions. Participant recruitment began October 2022 and data collection was complete by December 2023.

Randomization and blinding
Participants were randomly assigned to two treatment groups (1:1) using consecutively numbered sealed opaque envelopes (i.e., computer-simulated randomization sequence with permuted blocks) created by an individual not involved in the study. Eligible participants were randomized into an aquatic therapy group or a land-based standard care group. Only the assessor was blinded to the characteristics of the participants and their respective groups, as therapist and participant blinding is generally not possible in exercise trials[34].

Procedure
The intervention period lasted 10 weeks, with a frequency of 2 sessions a week for each group. This training frequency is in accordance with past related exercise intervention studies for individuals with chronic LBP[14]. The American College of Sports Medicine guidelines recommend 24–36 h of rest per week for light or aerobic exercises, and at least 48 h between resistance training sessions for the same muscle group[35]. Therefore, training sessions were separated by at least 48 h, with most participants having 1–2 days apart during the week. All training sessions (~ 60 min) were conducted by a certified Athletic Therapist and took place in the School of Health Athletic Therapy Clinic or Swim Ex pool. The duration of 10 weeks was chosen as training induced strength improvements largely occur within that period[36]. Information about pain medication and co-interventions were

collected for all participants throughout the study. Participants were requested to avoid other forms of treatment and exercise targeting the back (e.g., osteopath, physiotherapy, occupational therapy, chiropractor, massage).

Exercise interventions
Each exercise intervention has been explained in detail in a past publication[31]. Thus, only a summary of the interventions will be reported in the current study.

Swim ex water-based trunk stabilization group (Swim Ex)
Participants in this group received aquatic therapy in the School of Health Swim Ex pool. The following aquatic exercise program[31], was modified from a recent intervention in adults with chronic LBP[37]. Participants completed trunk stabilization, which was based on a variation of aquatic exercises in diverse positions, with the goal of engaging the deep trunk muscles (i.e., MF and transverse abdominis) in a co-contraction. Furthermore, in order to strengthen the gluteus maximus, gluteus medius, and gluteus minimus muscles, hip and gluteal specific exercises were performed. The overall aim of this program was to improve the stability and strength of the spine in a low weight-bearing but functional manner. Two sets of each exercise were completed 10–20 times or for 1–3 min, depending on the exercise. Exercises were regularly progressed for each participant by the addition of repetitions, dumbbells, steps of various heights, resistance bands at the knees or ankles, hand paddles of various sizes, water current, and by going into more challenging positions (not holding onto wall). The Borg Rating of Perceived Exertion Scale and the Category Ratio scale, both 1–10 scales, were used to progress level of difficulty[38].

Standard care group (SC)
Participants in this group underwent standard LBP treatment in the School of Health Athletic Therapy clinic. The ATs performed a comprehensive assessment of the participants and administered various interventions comprising stretching, strengthening and stabilization exercise, aerobic conditioning, and manual mobilization techniques. There were no efforts to standardize the treatment, though pain medication and co-intervention data were recorded during the study.

Data collection
At baseline, after randomization, participants' demographic characteristics were acquired with a self-reported questionnaire. All self-reported questionnaires were done in-person through paper forms. MRI muscle outcomes and lumbar extensor muscle strength assessments were then acquired for each group at the Concordia University School of Health. All baseline assessments (i.e. MRI, strength, questionnaires) were repeated at the 10-week follow-up (post-intervention).

Outcome measures
Primary outcome measures
(1) Multifidus muscle 3D volume and fatty infiltration (FI) at the L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1 levels.

Secondary outcome measures
(1) Erector spinae 3D volume and FI at the L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1 levels, (2) pain, (3) disability, (4) health related quality of life, (5) kinesiophobia, (6) catastrophizing, (7) depression/anxiety, (8) sleep quality, and (9) lumbar extensor strength.

Measurement tools
MRI assessment of paraspinal muscle morphology
At baseline, all participants had a lumbosacral MRI evaluation before beginning the exercise intervention using the School of Health's 3-T GE machine (standard phased-array body coil with 16 channels, 4-mm slice thickness, 180-mm^2 field of view, and 512 × 512 matrix). Axial T2-weighted (TR:3800, TE:98) and IDEAL (Lava-flex, 2 echo sequence, TE:4.5, TE: minimum full, flip angle:5) slices were acquired from L1 to L5 to measure the morphology and composition of the MF and ES paraspinal muscles. To compute the summative 3D volume of each side, bilateral manual segmentation of regions of interest (ROI) representing each muscle's cross-sectional area (CSA) were obtained on fat and water images at L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1. More specifically, at each level and each side, three CSA measurements were acquired on three different slices (i.e., lower endplate of the above vertebra, mid-disc, and the upper endplate of the below vertebra) to compute the 3D volume. The average measurements of the right and left volumes and %FIs were used in the analyses. Muscle measurements were performed by B.R. (PhD student), who was blinded to the group designations, and trained by a senior researcher (M.F.) with over 15 years of experience in spine imaging analysis. Prior to the beginning of this study, the reliability for MF and ES muscle measurements (Volume and %FI) was tested at each level from L1-L4. Images of 10 participants were randomly selected by the rater (B.R.) and measured independently. The same muscle measurements were repeated after at least 5 days. The reliability table is reported in a recent publication[39], which demonstrated excellent intra-rater reliability (ICCs > 0.90) for volume and %FI, except for left MF volume at L1-L2 (ICC = 0.874). IDEAL axial water and fat images were used to compute the percent fat-signal fraction, representing %FI: $\%FSF = (Signal_{fat}/[Signal_{water} + Signal_{Fat}] \times 100)$ of each muscle at each level. Imaging analysis was conducted via the Horos DICOM viewer software.

Segmentation Method: As seen in Fig. 1a, each muscle was segmented separately in two ROIs using the following segmentation method. The posterior MF border was along the epimysium, distinct from the thoracolumbar fascia and neighbouring adipose tissue. The medial MF border was outlined by the spinous process from its most superficial to deep part where it joins the lamina, including any fat within this area. The

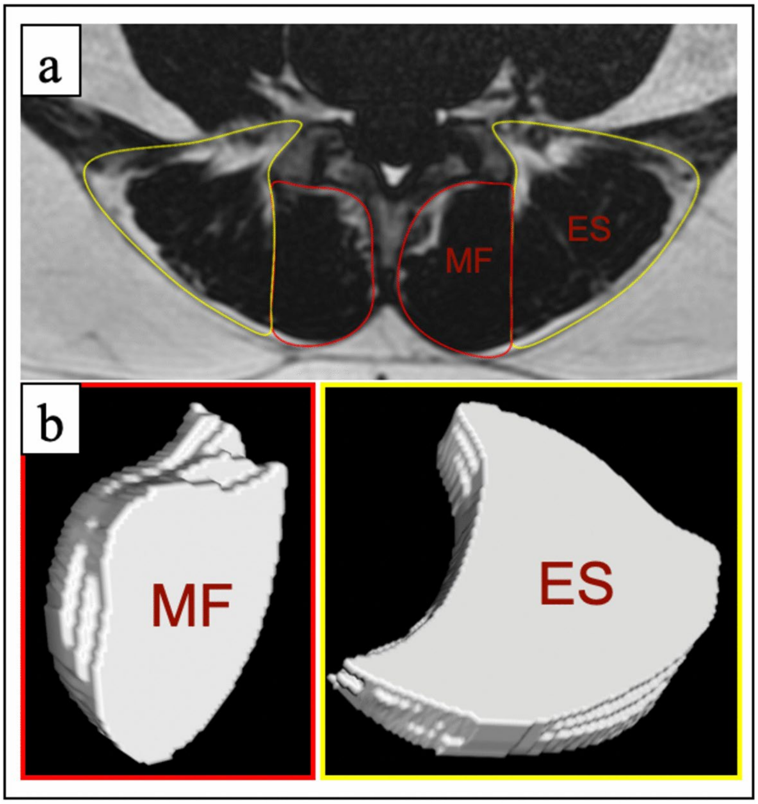

Fig. 1. Example of MF and ES muscle (**a**) ROI definition and (**b**) 3D volume computation.

anterior and deep MF border was outlined between the medial part of the lamina to the posterior feature of the mammillary process and zygapophyseal joint. These MF borders joined with the anterior and deep ES border where it continued along the lateral part of the transverse process. The separation between the lateral MF and medial ES, the intermuscular fascial border, was determined by a fatty streak in between the muscles from the mammillary process to the posterior border, which was included in the ES ROI. The anterior ES border was along the transverse process and intermuscular fascia between the ES and quadratus lumborum. The lateral ES border was outlined along the iliocostalis fascial border. The posterior ES border was outlined by using the fascial plane and *including* the epimuscular "fat tent" between the longissimus and iliocostalis if present. Additionally, epimuscular fat tents that were under the lumbosacral fascia and lateral to the iliocostalis were *included* in the ROI[40,41]. Once all three individual slice segmentations were completed per spinal level, 3D volume computations were performed (Fig. 1b).

Lumbar extensor muscle strength

Lumbar extension strength was assessed with the use of the MedX Lumbar Extension Isokinetic Dynamometer machine (MedX, Ocala, FL). This dynamometer ensured isolation of the lumbar extensor muscles during testing by securing participants' hips, knees, and pelvis to the machine and fixing the axis of movement between spinal levels L5-S1. By removing the activation of the gluteal and hamstrings muscles, this machine assesses isometric lumbar extension muscular strength (torque) in a seated position and accommodates the dynamic resistance through a full 72° range of motion. Further details of the procedure are explained in the published protocol[31].

Questionnaires

Self-reported questionnaires were used to measure pain, disability, quality of life, pain-related fear (catastrophizing and Kinesiophobia), depression, anxiety, and sleep quality. Participants' level of pain, disability/functional status and health related quality of life were assessed by the numerical pain rating scale, modified Oswestry Low Back Pain Disability Index (ODI) and Short-Form 12 Item Health Survey questionnaire (SF-12), respectively. For the numerical pain rating scale, participants were asked to give an average rating of their LBP in the past 7 days on a scale from 0 to 10. The SF-12 was divided into two subscales that represented a physical component summary and a mental component summary. Pain-related fear was assessed by The Pain Catastrophizing Scale (PCS) and the Tampa Scale of Kinesiophobia (TSK). Depression and anxiety were assessed by The Hospital Anxiety and Depression Scale (HADS), and sleep disturbance was assessed by the Insomnia Severity Index (ISI). All questionnaires have shown good test–retest reliability and have been validated in the chronic LBP population[42–50].

Sample size justification

Although the effect of aquatic therapy on paraspinal muscle morphology has not yet been investigated in chronic LBP, past studies[51–53] have shown a significant increase in MF muscle size from other exercise programs with medium to large effect sizes. Therefore, a mean effect size of 0.73 was used to determine the sample size at 80% power and a significance of alpha 0.05. This study served as a RCT, in which the goal was to recruit 34 participants (17 in each group) to investigate the effect of aquatic therapy on paraspinal muscle morphology and strength.

Statistical analysis

Primary and secondary outcomes were initially evaluated with descriptive statistics. Mixed repeated measures ANCOVA analyses were used to assessed variations in paraspinal muscle measurements and strength over time, adjusting for baseline paraspinal muscle measurements, BMI, disability level and LBP duration (i.e., entered as covariates). The normality, homogeneity of variance and sphericity assumptions were tenable and verified using the Kolmogorov–Smirnov and Shapiro–Wilk, Levene's Test and Mauchly's Test of Sphericity, respectively. Pearson correlations assessed the relationship between changes in paraspinal muscle morphology and changes in pain, disability, quality of life, pain related fear, depression, anxiety, and sleep quality. Crude Pearson correlations and non-parametric partial correlations adjusted for BMI assessed the relationship between changes in paraspinal muscle morphology and changes in strength. Associations between muscle morphology and patient outcomes were calculated for the combined lumbar levels (L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1). For the correlation analyses, the left and right 3D volumes and %FI for each muscle were averaged at each level and summed to reflect combined changes in paraspinal muscle volume and %FI. According to Cohen's guidelines, the strength of correlation coefficients (r) were described as 0.1 to 0.2, 0.3 to 0.5, and > 0.5 indicating small/weak, medium/moderate and large/strong correlations, respectively[54]. All analyses were performed using the intention-to-treat approach. All statistical analyses were completed with IBM SPSS version 28.0 (IBM Corp., Armonk, NY, USA); a p-value of < 0.05 was considered statistically significant.

Results

Participants

Participant's baseline characteristics are presented in Table 1. A total of 39 participants with LBP consented to participate at baseline, and 34 participated in the 10-week follow up. In the SC group, three participants were excluded after randomization due to abnormal baseline MRI findings, and one participant dropped out for time commitment issues (refer to Fig. 1 in the Appendix). In the Swim Ex group, one participant dropped out for time commitment issues. The Swim Ex and SC groups both had a mean attendance of 17.56 sessions out of 20 possible sessions, demonstrating a high level of participation. No participants reported using opioid medications during the intervention. In addition, co-interventions reported during the intervention included exercise

	Total (n = 34)	Swim Ex (n = 18)	SC (n = 16)	P-*Value*
Age (y)	36.9 ± 9.9	36.4 ± 10.4	37.4 ± 9.6	0.789[#]
Range	(23–59)	(23–55)	(25–59)	
Female, n (%)	19 (56)	9 (50)	10 (63)	0.464[†]
Height (cm)	171.5 ± 9.1	171.4 ± 7.4	171.6 ± 11.0	0.971[#]
Weight (kg)	75.3 ± 13.6	77.8 ± 13.1	72.6 ± 14.0	0.275[#]
BMI (kg/m^2)	25.5 ± 3.8	26.4 ± 3.8	24.6 ± 3.6	0.164[#]
*LBP Duration				
> 5 years	16	6	10	0.007[†]
1–5 years	13	11	2	
6–11 months	4	0	4	
3–5 months	1	1	0	
LBP NPRS (0–10)	5.5 ± 1.7	5.1 ± 1.7	5.9 ± 1.5	0.188[#]
*ODI	28.1 ± 8.8	31.7 ± 10.4	24.0 ± 3.5	0.008[#]
SF-12 Physical	37.4 ± 5.9	35.6 ± 6.3	39.5 ± 4.7	0.050[#]
SF-12 Mental	43.4 ± 12.2	41.0 ± 10.6	46.1 ± 13.7	0.231[#]
PCS[a]	18.8 ± 10.5	20.7 ± 10.0	16.8 ± 10.9	0.293[#]
TSK	24.1 ± 5.3	25.4 ± 5.2	22.6 ± 5.2	0.116[#]
HADS	13.2 ± 6.5	14.6 ± 6.0	11.6 ± 6.8	0.175[#]
ISI	12.0 ± 5.1	12.8 ± 3.7	11.1 ± 6.3	0.332[#]

Table 1. Participants' baseline characteristics. Values are presented as means ± standard deviations, unless otherwise denoted. BMI: body mass index; HADS: Hospital Anxiety and Depression Scale; ISI: Insomnia Severity Index; LBP: lower back pain; NPRS: Numerical Pain Rating Scale; ODI: Oswestry Disability Index; PCS: Pain Catastrophizing Scale; SF-12: 12-item Short Form Health Survey; TSK: Tampa Scale of Kinesiophobia. *$p < 0.05$, [#] Based on independent samples t-test. [†] Based on chi-square test. [a]1 missing data point from Swim Ex group.

(17.6%), massage therapy (5.9%), non-steroidal anti-inflammatory drugs (5.9%), cannabis (2.9%), chiropractor for neck (2.9%), and physiotherapy for elbow tendinopathy (2.9%). All characteristics were comparable between groups except for LBP duration and baseline self-reported disability (ODI). The Swim Ex group had a higher proportion of participants with an LBP duration of 1–5 years ($p = 0.007$). Additionally, self-reported disability was significantly higher in the Swim Ex group ($p = 0.008$), and notably physical quality of life (SF-12) was nearly significantly higher in the SC group ($p = 0.05$).

Effect of Swim Ex and SC on muscle volume

Table 2 shows the effect of Swim Ex and SC on muscle volume. There were no significant time*group interactions for MF and ES volume at L1-L2, L2-L3, L3-L4, L4-L5 or L5-S1 (all $p > 0.05$). Postintervention, a significant increase in MF volume was only seen in the Swim Ex group at L2-L3 (0.21 [0.06 to 0.36] cm^3) and L3-L4 (0.35 [0.06 to 0.64] cm^3). For the ES, at L1-L2, only the Swim Ex group had a significant increase in volume (0.59 [0.10 to 1.08] cm^3). No other significant changes were found for MF or ES volume at the other levels in either group.

Effect of Swim Ex and SC on fatty infiltration (% fat infiltration)

Table 3 shows the effect of Swim Ex and SC on FI. There were no significant time*group interactions for MF and ES %FI at L1-L2, L2-L3, L3-L4, L4-L5 or L5-S1 (all $p > 0.05$). Postintervention, at L2-L3, a significant increase in MF %FI was only seen in the Swim Ex group (0.80 [0.35 to 1.24]). No other significant changes were found for MF or ES %FI in either group.

Effect of Swim Ex and SC on lumbar extensor strength

Table 4 shows the effect of Swim Ex and SC on lumbar extensor strength. There were no significant time*group interactions (all $p > 0.05$). However, significant postintervention increases in mean and max strength were seen in both groups, with a higher increase in mean strength in SC and a higher increase in max strength in Swim Ex.

Correlation between changes in muscle morphology and self-reported patient outcomes

Table 5 shows the Pearson correlations between changes in muscle volume and %FI, and changes in pain, disability and quality of life from baseline to 10 weeks in all groups. A significant, moderate positive correlation was present between changes in MF volume (all levels combined) and physical quality of life SF-12 score (r = 0.39, $p = 0.03$).

Table 6 shows the Pearson correlations between changes in muscle volume and %FI, and changes in psychosocial factors (i.e., catastrophizing, Kinesiophobia, anxiety, depression, and sleep) from baseline to 10 weeks in all groups. A significant moderate negative correlation was present between changes in MF volume (all levels combined) and HADS score (r = -0.37, $p = 0.04$). Interestingly, sleep disturbance score had significant moderate negative correlations between changes in MF volume (r = -0.42, $p = 0.02$), MF %FI (r = -0.40, $p = 0.03$), and ES %FI (r = -0.37, $p = 0.04$).

Correlation between changes in muscle morphology and strength

Table 7 shows the crude Pearson and adjusted partial correlations between changes in muscle volume and %FI from L1-L2, L2-L3, L3-L4, L4-L5 and L5-S1 levels combined with changes in mean and max (36 degrees) strength from baseline to 10 weeks in all groups. In all analyses, no significant correlations were found.

Discussion

Our findings revealed a significant increase only in the aquatic therapy group in MF volume at L2-L3 and L3-L4, and in ES volume at L1-L2. While the relationship between exercise and paraspinal muscle size (CSA) has been examined, literature discussing the relationship between aquatic therapy and lumbar paraspinal muscle morphology in LBP has yet to be investigated. Therefore, our findings are difficult to directly compare to past studies. However, one recent study investigated patients with lumbar fusion, and found an increase in lumbar MF thickness and relative change in MF thickness after a 6-week aquatic exercise program compared to a home exercise program[55]. Our findings corroborate with the previous aquatic therapy study, as both studies have shown significant improvement in muscle size from aquatic exercise.

Participants in the aquatic therapy group performed trunk stabilization with a variety of exercises aimed to target the MF and transverse abdominis. One recent study investigated core stabilization exercises and strengthening exercises in people with LBP[56]. Core stabilization led to a significant improvement in percent change of muscle thickness in the lumbar MF compared to the strengthening group[56]. Another aspect of aquatic exercise is to enhance motor control (MC), which has shown promising results in improving MF size[57–60]. While land-based stabilization and MC exercise are not the same as aquatic therapy, they share similar aspects of training. Psych et al. compared trunk muscle activity during aquatic and land exercises in individuals with and without LBP[37], and reported that aquatic exercises produced comparable back muscle activation and intensity to similar land-based exercises in 71% of their comparisons. Accordingly, because Psych et al.'s aquatic exercises resulted in half the reported pain levels of the land exercises[37], and were mostly considered pain free in a follow-up study[61], we included many of these exercises into our aquatic intervention. The authors state that aquatic exercise should not be considered less sufficient in activating trunk muscles than land exercise, and is potentially more appropriate to avoid the adverse effects of exercise-related pain. Furthermore, activation levels of 25% or less have been found to be effective in improving MC and endurance properties of trunk muscles[62]. More specifically, aquatic squat exercises for back extensors (with shoulder flexion, and single-leg squats) were especially efficient at increasing ES and MF muscle activity[61]. In addition, balancing proprioception exercises generated high ES muscle activity, while the one-leg standing hip abduction and extension exercises generated high MF muscle activity. Therefore, the aquatic exercises used in our study and Psych et al.'s appear to generate efficient activation

Variables	Measurement period	Swim Ex n = 18	SC n = 16	Interaction effect between time and group
L1-L2 MF Volume (cm^3)	Baseline (Std. Error)	2.54 (0.00)	2.54 (0.00)	*p*-value = 0.526 F = 0.413 df = 1
	10-weeks (Std. Error)	2.54 (0.06)	2.60 (0.06)	
	MD (95% CI)	0.00 (−0.12 to 0.12)	0.06 (−0.07 to 0.19)	
	Main effect of time	*p*-value = 0.971 F = 0.001 df = 1	*p*-value = 0.362 F = 0.859 df = 1	
L1-L2 ES Volume (cm^3)	Baseline (Std. Error)	23.89 (0.00)	23.89 (0.00)	*p*-value = 0.240 F = 1.44 df = 1
	10-weeks (Std. Error)	24.48 (0.24)	24.04 (0.24)	
	MD (95% CI)	0.59 (0.10 to 1.08)*	0.15 (−0.38 to 0.67)	
	Main effect of time	*p*-value = 0.020 F = 6.14 df = 1	*p*-value = 0.568 F = 0.333 df = 1	
L2-L3 MF Volume (cm^3)	Baseline (Std. Error)	3.91 (0.00)	3.91 (0.00)	*p*-value = 0.496 F = 0.476 df = 1
	10-weeks (Std. Error)	4.12 (0.07)	4.04 (0.08)	
	MD (95% CI)	0.21 (0.06 to 0.36)*	0.13 (−0.03 to 0.29)	
	Main effect of time	*p*-value = 0.008 F = 8.13 df = 1	*p*-value = 0.111 F = 2.70 df = 1	
L2-L3 ES Volume (cm^3)	Baseline (Std. Error)	24.18 (0.00)	24.18 (0.00)	*p*-value = 0.684 F = 0.170 df = 1
	10-weeks (Std. Error)	24.33 (0.25)	24.49 (0.27)	
	MD (95% CI)	0.14 (−0.37 to 0.66)	0.30 (−0.25 to 0.85)	
	Main effect of time	*p*-value = 0.575 F = 0.321 df = 1	*p*-value = 0.269 F = 1.27 df = 1	
L3-L4 MF Volume (cm^3)	Baseline (Std. Error)	7.34 (0.00)	7.34 (0.00)	*p*-value = 0.082 F = 3.25 df = 1
	10-weeks (Std. Error)	7.69 (0.14)	7.29 (0.15)	
	MD (95% CI)	0.35 (0.06 to 0.64)*	−0.05 (−0.36 to 0.26)	
	Main effect of time	*p*-value = 0.019 F = 6.23 df = 1	*p*-value = 0.737 F = 0.115 df = 1	
L3-L4 ES Volume (cm^3)	Baseline (Std. Error)	22.05 (0.00)	22.05 (0.00)	*p*-value = 0.605 F = 0.274 df = 1
	10-weeks (Std. Error)	22.18 (0.24)	22.37 (0.26)	
	MD (95% CI)	0.13 (−0.37 to 0.63)	0.33 (−0.21 to 0.86)	
	Main effect of time	*p*-value = 0.603 F = 0.277 df = 1	*p*-value = 0.221 F = 1.57 df = 1	
L4-L5 MF Volume (cm^3)	Baseline (Std. Error)	10.56 (0.00)	10.56 (0.00)	*p*-value = 0.557 F = 0.353 df = 1
	10-weeks (Std. Error)	10.92 (0.19)	10.74 (0.21)	
	MD (95% CI)	0.36 (−0.03 to 0.76)	0.18 (−0.24 to 0.61)	
	Main effect of time	*p*-value = 0.070 F = 3.54 df = 1	*p*-value = 0.382 F = 0.788 df = 1	
L4-L5 ES Volume (cm^3)	Baseline (Std. Error)	19.87 (0.00)	19.87 (0.00)	*p*-value = 0.978 F = 0.001 df = 1
	10-weeks (Std. Error)	20.14 (0.33)	20.12 (0.36)	
	MD (95% CI)	0.27 (−0.41 to 0.95)	0.25 (−0.47 to 0.98)	
	Main effect of time	*p*-value = 0.425 F = 0.655 df = 1	*p*-value = 0.480 F = 0.513 df = 1	
L5-S1 MF Volume (cm^3)	Baseline (Std. Error)	12.81 (0.00)	12.81 (0.00)	*p*-value = 0.128 F = 2.46 df = 1
	10-weeks (Std. Error)	13.06 (0.17)	12.65 (0.18)	
	MD (95% CI)	0.25 (−0.09 to 0.59)	−0.16 (−0.52 to 0.20)	
	Main effect of time	*p*-value = 0.145 F = 2.24 df = 1	*p*-value = 0.367 F = 0.840 df = 1	
L5-S1 ES Volume (cm^3)	Baseline (Std. Error)	12.43 (0.00)	12.43 (0.00)	*p*-value = 0.177 F = 1.92 df = 1
	10-weeks (Std. Error)	12.63 (0.42)	11.72 (0.45)	
	MD (95% CI)	0.20 (−0.66 to 1.06)	−0.71 (−1.63 to 0.21)	
	Main effect of time	*p*-value = 0.640 F = 0.223 df = 1	*p*-value = 0.127 F = 2.47 df = 1	

Table 2. Adjusted multifidus and erector spinae muscle volume means in the Swim Ex and SC groups. CI: Confidence Interval; ES: Erector Spinae; MD: Mean Difference; MF: Multifidus; SC: Standard Care; Swim Ex: Aquatic Therapy. * The mean difference is significant at the 0.05 level.

Variables	Measurement period	Swim Ex n = 18	SC n = 16	Interaction effect between time and group
L1-L2 MF %FI	Baseline (Std. Error)	11.39 (0.00)	11.39 (0.00)	*p*-value = 0.519 F = 0.428 df = 1
	10-weeks (Std. Error)	12.15 (0.45)	11.69 (0.48)	
	MD (95% CI)	0.76 (− 0.16 to 1.68)	0.31 (− 0.68 to 1.29)	
	Main effect of time	*p*-value = 0.100 F = 2.90 df = 1	*p*-value = 0.527 F = 0.411 df = 1	
L1-L2 ES %FI	Baseline (Std. Error)	11.79 (0.00)	11.79 (0.00)	*p*-value = 0.620 F = 0.251 df = 1
	10-weeks (Std. Error)	12.30 (0.25)	12.10 (0.26)	
	MD (95% CI)	0.51 (0.00 to 1.01)	0.31 (− 0.23 to 0.85)	
	Main effect of time	*p*-value = 0.050 F = 4.19 df = 1	*p*-value = 0.246 F = 1.41 df = 1	
L2-L3 MF %FI	Baseline (Std. Error)	10.52 (0.00)	10.52 (0.00)	*p*-value = 0.165 F = 2.03 df = 1
	10-weeks (Std. Error)	11.32 (0.22)	10.83 (0.23)	
	MD (95% CI)	0.80 (0.35 to 1.24)*	0.31 (− 0.16 to 0.79)	
	Main effect of time	*p*-value = 0.001 F = 13.39 df = 1	*p*-value = 0.190 F = 1.81 df = 1	
L2-L3 ES %FI	Baseline (Std. Error)	14.75 (0.00)	14.75 (0.00)	*p*-value = 0.263 F = 1.30 df = 1
	10-weeks (Std. Error)	15.13 (0.38)	14.46 (0.40)	
	MD (95% CI)	0.37 (− 0.40 to 1.14)	− 0.30 (− 1.12 to 0.53)	
	Main effect of time	*p*-value = 0.332 F = 0.974 df = 1	*p*-value = 0.469 F = 0.538 df = 1	
L3-L4 MF %FI	Baseline (Std. Error)	11.83 (0.00)	11.83 (0.00)	*p*-value = 0.898 F = 0.017 df = 1
	10-weeks (Std. Error)	12.24 (0.42)	12.33 (0.45)	
	MD (95% CI)	0.41 (− 0.44 to 1.27)	0.50 (− 0.42 to 1.41)	
	Main effect of time	*p*-value = 0.331 F = 0.980 df = 1	*p*-value = 0.274 F = 1.24 df = 1	
L3-L4 ES %FI	Baseline (Std. Error)	21.10 (0.00)	21.10 (0.00)	*p*-value = 0.995 F = 0.00 df = 1
	10-weeks (Std. Error)	20.44 (0.47)	20.45 (0.50)	
	MD (95% CI)	− 0.65 (− 1.61 to 0.30)	− 0.65 (− 1.67 to 0.37)	
	Main effect of time	*p*-value = 0.172 F = 1.97 df = 1	*p*-value = 0.203 F = 1.70 df = 1	
L4-L5 MF %FI	Baseline (Std. Error)	18.74 (0.00)	18.74 (0.00)	*p*-value = 0.538 F = 0.390 df = 1
	10-weeks (Std. Error)	18.66 (0.37)	19.03 (0.40)	
	MD (95% CI)	− 0.07 (− 0.84 to 0.69)	0.29 (− 0.53 to 1.11)	
	Main effect of time	*p*-value = 0.846 F = 0.038 df = 1	*p*-value = 0.476 F = 0.523 df = 1	
L4-L5 ES %FI	Baseline (Std. Error)	29.01 (0.00)	29.01 (0.00)	*p*-value = 0.735 F = 0.117 df = 1
	10-weeks (Std. Error)	28.77 (0.52)	28.49 (0.56)	
	MD (95% CI)	− 0.24 (− 1.31 to 0.83)	− 0.52 (− 1.66 to 0.63)	
	Main effect of time	*p*-value = 0.652 F = 0.208 df = 1	*p*-value = 0.364 F = 0.853 df = 1	
L5-S1 MF %FI	Baseline (Std. Error)	23.90 (0.00)	23.90 (0.00)	*p*-value = 0.974 F = 0.001 df = 1
	10-weeks (Std. Error)	23.79 (0.37)	23.81 (0.39)	
	MD (95% CI)	− 0.11 (− 0.86 to 0.64)	− 0.09 (− 0.90 to 0.71)	
	Main effect of time	*p*-value = 0.762 F = 0.093 df = 1	*p*-value = 0.813 F = 0.057 df = 1	
L5-S1 ES %FI	Baseline (Std. Error)	36.76 (0.00)	36.76 (0.00)	*p*-value = 0.883 F = 0.022 df = 1
	10-weeks (Std. Error)	35.74 (0.64)	35.60 (0.69)	
	MD (95% CI)	− 1.02 (− 2.34 to 0.30)	− 1.17 (− 2.58 to 0.24)	
	Main effect of time	*p*-value = 0.125 F = 2.51 df = 1	*p*-value = 0.101 F = 2.88 df = 1	

Table 3. Adjusted multifidus and erector spinae muscle % fatty infiltration means in the Swim Ex and SC groups. CI: Confidence Interval; ES: Erector Spinae; MD: Mean Difference; MF: Multifidus; SC: Standard Care; Swim Ex: Aquatic Therapy. * The mean difference is significant at the 0.05 level.

Variables	Measurement period	Swim Ex n = 18	SC n = 16	Interaction effect between time and group
Mean Strength (Nm)	Baseline (Std. Error)	130.10 (0.00)	130.10 (0.00)	p-value = 0.60 F = 0.28 df = 1
	10-weeks (Std. Error)	156.72 (9.93)	164.87 (10.61)	
	MD (95% CI)	26.64 (6.31 to 46.98)*	34.79 (13.06 to 56.52)*	
	Main effect of time	p-value = 0.012 F = 7.20 df = 1	p-value = 0.003 F = 10.75 df = 1	
Max Strength (Nm)	Baseline (Std. Error)	124.82 (0.00)	124.82 (0.00)	p-value = 0.93 F = 0.01 df = 1
	10-weeks (Std. Error)	159.32 (10.68)	157.77 (11.41)	
	MD (95% CI)	34.50 (12.63 to 56.36)*	32.94 (9.58 to 56.30)*	
	Main effect of time	p-value = 0.003 F = 10.44 df = 1	p-value = 0.007 F = 8.34 df = 1	

Table 4. Comparison of lumbar extensor mean and max (36 degrees) strength in the Swim Ex and SC groups. CI: Confidence interval; MD: Mean Difference; SC: Standard Care; Swim Ex: Aquatic Therapy. *The mean difference is significant at the 0.05 level.

	ΔNPRS [95% CI]	ΔODI [95% CI]	ΔSF12-Physical [95% CI]	ΔSF12-Mental [95% CI]
ΔMF Vol	− 0.07 [− 0.37 to 0.19]	− 0.08 [− 0.45 to 0.23]	0.39* [0.04 to 0.66]	0.09 [− 0.23 to 0.38]
ΔES Vol	− 0.11 [− 0.50 to 0.25]	− 0.11 [− 0.60 to 0.32]	0.21 [− 0.19 to 0.59]	0.07 [− 0.24 to 0.39]
ΔMF FI	− 0.27 [− 0.56 to 0.09]	0.01 [− 0.37 to 0.34]	0.05 [− 0.23 to 0.33]	0.29 [0.03 to 0.53]
ΔES FI	− 0.03 [− 0.33 to 0.25]	− 0.03 [− 0.41 to 0.35]	0.07 [− 0.37 to 0.46]	0.17 [− 0.17 to 0.44]

Table 5. Correlations between changes in the muscle morphology (all spinal levels combined) and changes in pain, disability and quality of life in all groups. CI: Confidence Interval; ES: Erector Spinae; FI: Fatty Infiltration; MF: Multifidus; NPRS: Numerical Pain Rating Scale; ODI: Oswestry Disability Index; SF-12: 12-item Short Form Health Survey; Vol: Volume. *Indicates $p < 0.05$.

Variables	ΔPCS [95% CI]	ΔTSK [95% CI]	ΔHADS [95% CI]	ΔISI [95% CI]
ΔMF Vol	0.20 [− 0.13 to 0.46]	− 0.31 [− 0.58 to 0.01]	− 0.37* [− 0.63 to − 0.03]	− 0.42* [− 0.66 to − 0.14]
ΔES Vol	0.07 [− 0.31 to 0.38]	0.03 [− 0.32 to 0.35]	− 0.28 [− 0.61 to 0.05]	− 0.16 [− 0.39 to 0.15]
ΔMF FI	− 0.27 [− 0.55 to 0.12]	− 0.16 [− 0.52 to 0.26]	− 0.18 [− 0.49 to 0.15]	− 0.40* [− 0.70 to − 0.06]
ΔES FI	− 0.21 [− 0.51 to 0.14]	− 0.05 [− 0.46 to 0.41]	− 0.31 [− 0.65 to 0.12]	− 0.37* [− 0.67 to 0.07]

Table 6. Correlations between changes in the muscle morphology (all spinal levels combined) and changes in psychosocial factors (i.e., catastrophizing, Kinesiophobia, anxiety, depression, and sleep) in all groups. CI: Confidence Interval; ES: Erector Spinae; FI: Fatty Infiltration; HADS: Hospital Anxiety and Depression Scale; ISI: Insomnia Severity Index; MF: Multifidus; PCS: Pain Catastrophizing Scale; TSK: Tampa Scale of Kinesiophobia; Vol: Volume. *Indicates $p < 0.05$.

	ΔMean Strength [95% CI]	ΔMean Strength Adjusted (BMI)	ΔMax Strength [95% CI]	ΔMax Strength Adjusted (BMI)
L1-S1 combined, n = 34				
ΔMF Vol	− 0.04 [− 0.33 to 0.30]	− 0.05 (P = 0.780)	− 0.03 [− 0.31 to 0.39]	0.03 (P = 0.851)
ΔES Vol	0.09 [− 0.33 to 0.45]	0.11 (P = 0.532)	0.15 [− 0.22 to 0.47]	0.19 (P = 0.302)
ΔMF FI	− 0.17 [− 0.49 to 0.19]	− 0.18 (P = 0.310)	− 0.22 [− 0.46 to 0.13]	− 0.15 (P = 0.414)
ΔES FI	− 0.04 [− 0.35 to 0.26]	− 0.12 (P = 0.507)	0.02 [− 0.27 to 0.35]	− 0.01 (P = 0.942)

Table 7. Crude and adjusted partial correlations between changes in the muscle morphology (all spinal levels combined) and change in mean and max (36 degrees) strength in all groups. BMI: Body Mass Index; CI: Confidence Interval; ES: Erector Spinae; FI: Fatty Infiltration; MF: Multifidus; Vol: Volume. * Indicates $p < 0.05$.

levels to lead to muscle improvements coupled with less exercise-related pain and potentially pain-related fear. Furthermore, it is important to note that there is a greater amount of paraspinal muscle FI at the lower lumbar levels than at the upper levels in individuals with and without LBP[63,64]. Indeed, a longitudinal MRI study investigating the long-term progression of changes in paraspinal muscles found greater muscle atrophy and FI at L5-S1 than at L3-L4 over 15 years[65]. As most bodyweight is endured at the lower lumbar levels, provoking more stress[65], the lower levels have a higher incidence of spinal failure, pathology and degenerative changes[66,67]. As such, more targeted, intense and longer duration exercise interventions are likely needed to induce positive changes in paraspinal muscle quality at the lower lumbar levels[68,69]. Indeed, our group recently reported on the effect of a 12-week combined MC and isolated lumbar extension exercise program in patients with CLBP, and a decrease in FI was only observed at the upper lumbar levels[39,58]. The greater extent of paraspinal muscle degeneration (e.g., atrophy and higher FI) at the lower lumbar levels likely makes those levels more resistant to morphological changes[70], which may explain why our aquatic group demonstrated improvements in muscle size at the upper lumbar levels and not the lower levels.

Fear avoidance beliefs, which refer to fear of physical movement and work activities that may elicit pain, is common in individuals with chronic LBP[9,10]. Conversely, in people with chronic LBP, water-based exercise has significantly reduced pain-related fear and fear avoidance behavior compared to land-based exercise[22], and less reported anxiety after performing aquatic exercise[71]. An additional benefit of aquatic exercise is that it allows patients to exercise at greater intensities than would be possible on land[72]. The unique properties of water allow a water-based exercise program to be tailored to the needs of those with LBP, while activating targeted muscles similarly to land exercises, as mentioned previously[37]. Therefore, it is possible that participants in aquatic exercise group felt safer and more confident in a water setting, with less fear of falling and pain compared to similar land-based exercises[37]. Consequently, they were more able to overcome their pain-related fears than the land-based SC group, which led to a subsequent better response to the intervention through increased participation and confidence. The results for this study's self-reported outcomes, especially pain-related fear, will be published and discussed in further detail in another related manuscript.

Our study also revealed a significant increase in MF %FI at L2-L3 in the aquatic therapy group. Though, the increase in FI was less than %1, and below the standard error measurement and minimal detectable change according to a past reliability analysis performed by the same rater[39]. Unfortunately, there are limited imaging studies that have investigated the effectiveness of exercise on paraspinal muscle health, and they have been criticized for their poor quality and probable methodological bias[59]. Recently, a systematic review asked if exercise can reverse paraspinal muscle FI in people with LBP and gathered all available data on the topic[69]. Only six studies met the selection criteria, with a limitation to pool data due to large methodological and clinical heterogeneity across studies. The authors concluded that exercise may not reverse paraspinal muscle FI in chronic LBP, and that we need larger RCTs, with standardized imaging methodologies and extended intervention durations to generate firmer conclusions[69].

Presently, the ideal exercise program for reducing FI is undetermined[69,73]. A high-intensity resistance training program did not significantly improve paraspinal muscle composition (FI) in people with LBP[74]. Again, elevated levels of intramuscular FI, which is characteristic of LBP[63,75,76], may be more resistant to changes in morphology[70]. Therefore, reversing FI through exercise possibly warrants a greater exercise frequency, duration and intensity than our study's interventions. Though, 8 weeks of training have generated evident homeostatic myocellular changes[77]. In the few exercise studies investigating this, the programs were probably too brief and used inadequate intensity levels to produce any changes in muscle quality, and it is uncertain whether the paraspinal muscles were properly recruited during the training[68]. Successful attainment of compositional and morphological alterations in paraspinal muscles would probably require specific exercises to first confirm proper recruitment of the targeted muscles, followed by resistance training of adequate loads[68]. The aforementioned explanations are reasons we believe our interventions were not successful in improving muscle FI. Perhaps our aquatic therapy and SC intervention periods were not targeted, intense or frequent enough to elicit significant decreases in FI. It is also plausible that changes in strength and muscle size precede changes in muscle composition, and thus a longer intervention duration may have elicited changes in muscle composition[69]. Overall, the need for lengthier interventions and greater intensity exercise to improve paraspinal muscle quality in LBP has been highlighted in the literature[68,69].

With respect to lumbar extensor strength, both aquatic therapy and SC led to significant improvements in strength. Of note, the SC group had higher mean strength as compared to the aquatic therapy group at the end of the intervention. This finding may be partly explained by the fact that the SC group had significantly greater self-reported function at baseline, leading to a higher final mean strength. Recently, a systematic review and meta-analysis compared posterior chain resistance training, which targeted thoracic, lumbar and hip extensor muscles, to general exercise in people with chronic LBP[78]. In accordance with our findings, the analysis revealed that posterior chain resistance training resulted in significantly greater improvements in muscle strength, which included lumbar extension, lift capacity, knee extension and leg press. These findings corroborate with ours, as it shows the additional benefits of exercise interventions that specifically target trunk musculature in this population. More specifically, our aquatic therapy and SC interventions involved aspects of stabilization training, which have been shown to be more effective in improving trunk strength and trunk extensor endurance than conventional exercises in patients with LBP[79]. With respect to aquatic exercise, to our knowledge Han et al. are the only authors to investigate the effect of aquatic exercise on strength in people with LBP and similarly used a 10-week intervention targeting lumbar muscles[80]. Supporting our findings, their aquatic intervention similarly had significant improvements in lumbar extensor peak torque. Finally, another aquatic exercise program also led to significant improvements in trunk extensor strength, but in patients with lumbar fusion[55]. These studies demonstrate the benefits of exercise interventions specifically targeting lumbar muscles in the chronic LBP population.

Our findings between muscle morphology and self-reported patient outcomes revealed a significant moderate correlation between change in MF volume and several outcomes, including physical quality of life, anxiety/depression, and sleep quality. Furthermore, there were significant moderate correlations between change in sleep quality and the %FI of MF and ES. This supports the notion that changes in muscle morphology potentially relate to improvements in patient outcomes. While literature discussing correlations between exercise-induced muscle changes, especially in aquatic therapy, and patient outcomes is scarce, recent studies have investigated this. Pinto et al. found low-quality evidence that there is no relationship between changes in lumbar MF morphology from MC exercise and LBP-related disability[57]. The authors stated that MC exercise may improve MF morphology in individuals with chronic LBP, but these improvements may not be associated with patient outcomes. As mentioned previously, a resistance-based exercise intervention did not result in significant paraspinal muscle morphological changes in individuals with LBP[74]. However, in the patients that did show an improvement in muscle morphology, there was a correlation with their improvements in disability and anxiety/depression. This reveals an association between muscle morphological improvements and improvements in patient outcomes. It is proposed that depressive symptoms are significant moderators of the relationship between sensorimotor exercise training and improvement in pain in chronic LBP[81]. Additionally, further depressive mood and anxiety significantly moderated the effect of sensorimotor exercise on disability[81]. Therefore, psychosocial outcomes, such as depression and anxiety, could moderate the relationship between MC exercise-induced changes in chronic LBP. This could explain the inconsistent results seen in past literature investigating the benefits of different types of exercise in chronic LBP, and highlights the importance of identifying psychosocial risk factors to personalize treatments. Altogether, while the effectiveness of MC and strengthening exercises to improve patients' patient outcomes is supported in systematic reviews[13,59,82], it remains uncertain if the observed improvements are a direct result of the exercise-induced changes in muscle deficits. Regardless, it is suggested that exercise for chronic LBP should be tailored to the individual, due to personal paraspinal muscle morphological and functional changes[83]. This also stresses the importance of identifying subgroups of patients with LBP who could better respond to particular exercise programs[74,83].

Our study found no significant correlations between changes in muscle morphology (size and FI) and strength, and studies investigating this relationship are scarce and have mixed results. We have seen that paraspinal muscle morphological changes can impact muscle recruitment and result in LBP-related MC dysfunction[84–87]. In terms of muscle size, in people with LBP, a significant decrease in MF CSA was correlated with the capacity to produce a voluntary isometric contraction[84], while improvements in muscle size were correlated with improvements in strength after a resistance training intervention[74]. In contrast to our findings, the authors stated that muscle health improvements could lead to larger functional improvements[74]. Conversely, although Dahlqvist et al. did not specifically assess the relationship between changes in morphology and change in strength, they did test for a relationship between paraspinal muscle health and strength. Interestingly, the authors did not find a correlation between paraspinal muscle CSA and FI, and back extension strength[88]. In terms of muscle quality, LBP is correlated with lumbar MF FI, which may result in a reduced range of motion in lumbar flexion and lumbar dysfunction[89], and reduced muscle performance[90,91]. To our knowledge, only one study has found a correlation between ES %FI and relative back muscle extension strength[90], but this investigation was done with asymptomatic individuals (i.e., without LBP). More studies are needed to investigate the relationship between paraspinal muscle morphology and strength in chronic LBP.

Limitations

This study had limitations, including participants being aware of which treatment they were randomized in because of the type of interventions given. Therefore, true blinding was not achievable. In addition, the absence of a no-exercise or non-targeted exercise control group is also a limitation. Moreover, because only people with LBP were included in our study, our findings cannot be generalized to healthy asymptomatic individuals.

Conclusions

This study provided preliminary evidence to suggest that aquatic therapy may help increase lumbar paraspinal muscle volume and strength. Additionally, it further supported the theory that improvements in paraspinal muscle health are related to concomitant improvements in patient-reported outcomes. This highlights the importance of maintaining and improving paraspinal muscle quality in LBP. Future trials should further investigate the possible mechanisms underlying this relationship.

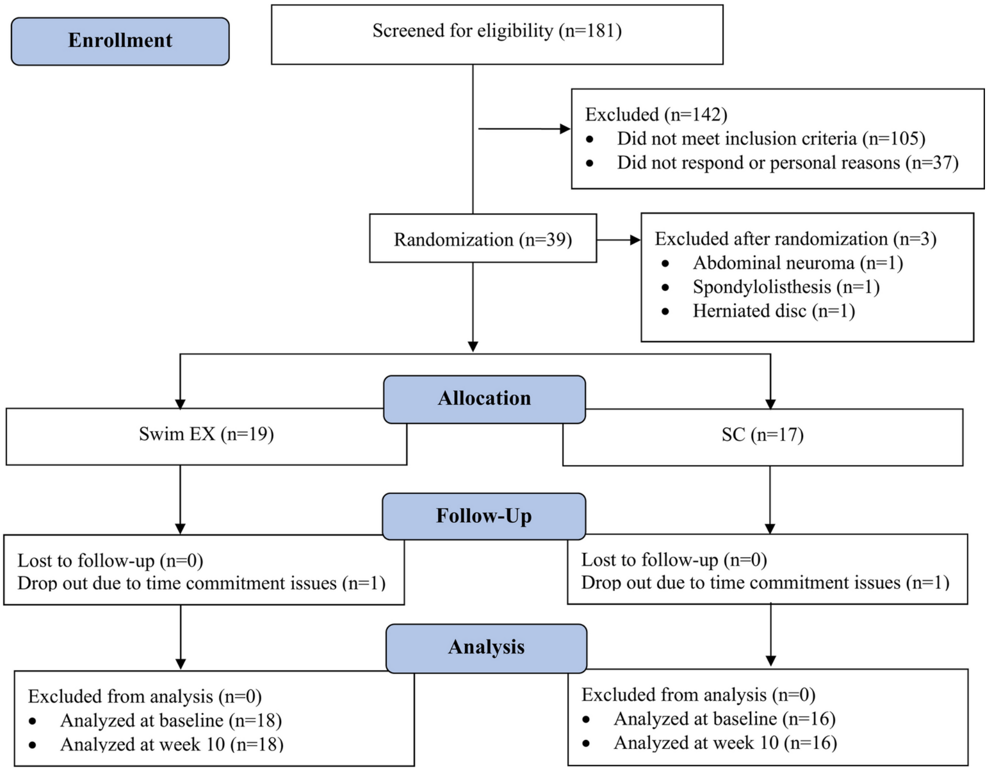

Fig. 2. Consort flow diagram.

Data availability
All data are available upon request from the corresponding author.

Appendix
See Fig. 2.

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Author contributions
M.F. was responsible for the conception and design of the study. M.F. was responsible for funding acquisition, and supervisor. A.M., B.R., C.M. and N.V. were responsible for the acquisition of data. B.R. was responsible for participant recruitment and data analysis. B.R. drafted the manuscript; all authors revised the draft, and read and approved the final version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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