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The Role of Water Kinetic Chain Exercises in Maximum Voluntary Isometric Contraction of Gluteus Medius and Quadratus Lumborum Muscles in Chronic Low Back Pain Patients: A Randomized Clinical Trial

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ABSTRACT

Background: The gluteus medius (GMed) and quadratus lumborum (QL) muscles play crucial roles in stabilizing the pelvis and spine, yet their activation may be compromised in individuals with low back pain. Water exercises have shown promise in enhancing muscle function and coordination.

Objectives: This study aimed to investigate the effectiveness of water kinetic chain exercises in improving maximum voluntary isometric contraction (MVIC) of the targeted muscles in patients with chronic non-specific low back pain (CNSLBP).

Methods: A double-blind randomized controlled trial enrolled sixty men aged 40–60 years with CNSLBP. Participants were randomly assigned to three groups: water-based open kinetic chain exercises (WOKCe), water-based closed kinetic chain exercises (WCKCe), and a no-intervention control group. Surface EMG assessed MVIC, with electrodes positioned over the QL (about 2–3 cm lateral toward the L3 spinous process) during lateral trunk flexion and over the GMed (at the midpoint between the greater trochanter and the iliac crest) during hip abduction. Between-group differences were assessed using analysis of covariance (ANCOVA) after eight weeks of intervention (three sessions per week).

Results: ANCOVA revealed significant improvements in MVIC for both experimental groups compared to controls ($P<0.05$). For GMed MVIC, both aquatic exercise groups demonstrated significant improvements ($F=7.08$, $P=0.002$, $\eta^2=0.212$) with high statistical power (0.917). Similarly, for QL MVIC, both intervention groups showed substantial enhancements ($F=12.94$, $P=0.001$, $\eta^2=0.316$) with excellent statistical power (0.996). Post-hoc analyses confirmed that both WCKCe and WOKCe groups achieved comparable improvements in both muscle groups, with no significant differential effects between the two intervention modalities.

Conclusion: Both the WOKCe and WCKCe interventions resulted in significant enhancements in MVIC of the GMed QL muscles. These results suggest that either intervention can be effectively integrated into clinical and rehabilitation practices to improve muscle function and stability in individuals with chronic low back pain. This underscores the potential for tailored therapeutic strategies to optimize patient outcomes in musculoskeletal rehabilitation.

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Introduction

Chronic low back pain (CLBP) is a widespread condition that significantly impacts the lives of millions of individuals worldwide, often leading to physical limitations and diminished quality of life (QoL) [1-5]. It is characterized by persistent discomfort in the lower back that lasts for more than three months and can arise from various factors, including muscular imbalances, poor posture, and previous injuries [6-8]. The maximum voluntary isometric contraction (MVIC) is the peak force or torque a muscle group can generate in a single maximal effort against an immovable resistance [9-11]. It is a key measure in strength and conditioning, used to assess muscle function and track progress in training or rehabilitation [9, 12]. Studies suggest that weakened stabilizing muscles' MVIC may contribute to instability and discomfort in individuals with CLBP [13-15]. Evaluating MVIC in the lumbar region helps identify deficits that may exacerbate CLBP and guide targeted rehabilitation strategies [12-15]. For instance, when larger and stronger muscles are activated first without proper assistance from smaller stabilizing muscles, this disparity may overload the lumbar structures and ultimately cause discomfort or pain [16]. Additionally, the regular application of an unsuitable activation sequence can lead to muscle fatigue, weakness, and a heightened injury risk, underscoring the necessity for correct movement mechanics and muscle coordination in averting CLBP [17]. Among the key contributors to CLBP are dysfunctions in the stabilizing muscles of the lumbar and pelvic regions, particularly the gluteus medius (GMed) and quadratus lumborum (QL) [18-20]. Impairments in the strength and coordination of these muscles can lead to altered biomechanics [21, 22], resulting in increased stress on the lumbar spine and contributing to the persistence of CLBP [23-28]. Their synergistic activation is essential for maintaining optimal pelvic alignment and spinal integrity during dynamic activities, thereby preventing compensatory movement patterns and reducing the risk of musculoskeletal injuries [22, 29]. Function coordination of these muscles is essential for maintaining pelvic stability and proper spinal alignment during movement [10, 24-26]. In general, adequate strengthening and coordination of the QL and GMed muscles can enhance muscular health and establish a stable base for the lower back, assisting in the prevention of CLBP [30].

Conventional rehabilitation methods typically emphasize the importance of strengthening essential muscles [19, 31]. However, numerous patients find it challenging to consistently engage in land-based exercise programs, often due to discomfort or concerns about worsening their condition [32-34]. Water-based exercise programs have emerged as a promising solution, leveraging the unique properties of water to create a supportive environment that reduces joint stress while providing resistance for muscle strengthening [6, 32, 35-42]. he human body should not be viewed as a collection of isolated muscles, bones, connective tissues, and ligaments; rather, it is an integrated system where each component influences the others, and this interaction can yield either beneficial or detrimental effects [43-50]. Ideally, when the motor chain is engaged, the body operates as a cohesive unit, facilitating smooth and efficient movements [50-54].

Water kinetic chain exercises (WKCe) utilize the buoyancy and resistance of water to facilitate movement patterns that mimic functional activities, allowing individuals to engage in exercises with reduced pain and increased range of motion [45, 47, 55- 58]. Despite the potential advantages of aquatic therapy, there remains a significant gap in the literature regarding its specific effects on muscle activation in patients with CLBP [59-62].

The lack of research underscores the necessity for systematic investigation into the efficacy of WKCe on performance. The present study aimed to explore the impact of WKCe on MVIC of the GMed and QL muscles in individuals suffering from chronic non-specific low back pain (CNSLBP). By comparing the outcomes of both intervention groups, this research sought to determine whether WKCe can provide superior benefits in enhancing muscle function and alleviating pain levels. The findings from this investigation could significantly inform clinical practice, encouraging the integration of aquatic exercise into treatment plans for CNSLBP. Ultimately, this research aspires to contribute to the growing body of evidence supporting innovative rehabilitation strategies, offering hope for improved recovery and enhanced QoL for individuals affected by CNSLBP. By addressing this significant health issue, the study aimed to pave the way for more effective, patient-centered rehabilitation approaches that meet the needs of those suffering from this debilitating condition.

Methods

The present study employed a double-blind, randomized controlled pilot design to examine the effects of an intervention on individuals suffering from CNSLBP. To ensure reliable outcome assessments, comprehensive data collection was conducted both before and after the trial, incorporating subjective feedback and physiological evaluations [57]. Randomization was achieved by generating codes in blocks of four and six using Random Allocation Software, version 1.0 [63]. The allocation process was concealed with sequentially numbered, opaque, sealed envelopes, which were intentionally substantial to highlight their importance [64]. An orthopedic specialist diagnosed participants with CNSLBP following MRI scans and physical examinations. Sixty participants were randomly assigned to three groups of twenty to maintain balance within the study. One group served as the control, while another group engaged in weight-bearing water-based closed kinetic chain exercises (WCKCe), and the third group participated in non-weight-bearing water-based open kinetic chain exercises (WOKCe). To uphold the integrity of the blinding process and minimize potential bias in evaluations, participants were explicitly instructed not to reveal their group assignments to the assessors [57, 65, 66].

Before the study began, all participants received a thorough briefing outlining the research objectives and methodologies, which included a section to ensure complete understanding. Consent forms were voluntarily signed by participants and/or their legal guardians in accordance with the Helsinki Declaration [67-69]. Prior to signing, the forms were reviewed to guarantee clarity and comprehension. This trial received approval from the Ethics Committee for Human Research at Bu-Ali Sina University and was registered under Iranian Registry of Clinical Trials (IRCT).

Participants

To achieve an effect size of 0.25, with a significance level of 0.05 and a statistical power of 0.8 for accurate sample size calculations, the study utilized G*Power software [70]. Previous research that employed analysis of covariance (ANCOVA), analyzing both within-group and between-group variables, guided the selection of these parameters [70-72]. The study took into account the interactions of various factors and their impacts on the outcomes. The statistical analysis, which included a power calculation of 80% and an alpha level of 0.05, indicated that a minimum of 42 patients was required to obtain reliable results [25, 73]. In consultation with a medical expert, the researcher concluded that an optimal sample size of 60 participants would be ideal to minimize potential dropout [25].

The subjects in this randomized controlled trial comprised 60 men aged between 40 and 60 years (mean age: 48.1±5.97 years). The experimental groups participated in WOKCe and WCKCe three times a week for eight weeks, in contrast to the control group, which received no intervention (Figure 1). Eligibility criteria required participants to be aged 40 to 60 years, have experienced CLBP for over 12 weeks, and have no prior surgeries on the hip or spine. Exclusion criteria included discomfort in various regions, irregularities in the lower and upper limbs, spondylolysis, neuromuscular disorders, and respiratory conditions [44, 74].

Intervention: Water kinetic chain exercises

Over an eight-week period, the techniques of non-weight-bearing WOKCe and weight-bearing WCKCe were implemented in water, with participants attending three sessions per week, each lasting 60 minutes. The sessions were conducted under the supervision of the researcher and an aquatic therapy specialist. Each session commenced with a 5-minute warm-up, followed by 50 minutes dedicated to kinetic chain exercises, and concluded with a 5-minute cool-down stretching routine. Participants in the HOKCe group engaged in deep-water exercises utilizing flotation noodles, while the WCKCe group performed exercises in the shallow end of the pool, where the water level reached their xiphoid process. Aquatic therapy sessions for both groups were held at the pool of Bu-Ali Sina University in Hamadan, led by a qualified expert. The development of a phased training program for these groups was informed by previous research on volume, intensity, duration, and repetitions, with a systematic increase in exercise load implemented each week. The arrangement of WOKCe and WCKCe in the aquatic environment followed a phased approach, shaped by prior studies and the investigator's design (Tables 1) [44, 75, 76].

MVIC

Muscle electromyographic activity measurements were obtained using Megawin's (Finland) model ME6000, an 8-channel electromyography device (1000 Hz sampling rate) [77]. Muscle electrical activity was recorded using silver chloride passive electrodes [78]. Following skin preparation with medical alcohol, electrodes were positioned according to the SENIAM protocol on the GMed muscle, placed at the midpoint between the greater trochanter of the femur and the outermost aspect of the iliac crest after hair removal (Figure 2) [57, 79]. MVIC of the QL muscle was positioned at the midpoint between the twelfth rib and the iliac crest [57, 80]. The MVIC for the GMed muscle involved an abduction movement of the thigh against the resistance of the examiner. Following the placement of electrodes at the site of the GMed muscle, the participant lay in a prone position on the examina-

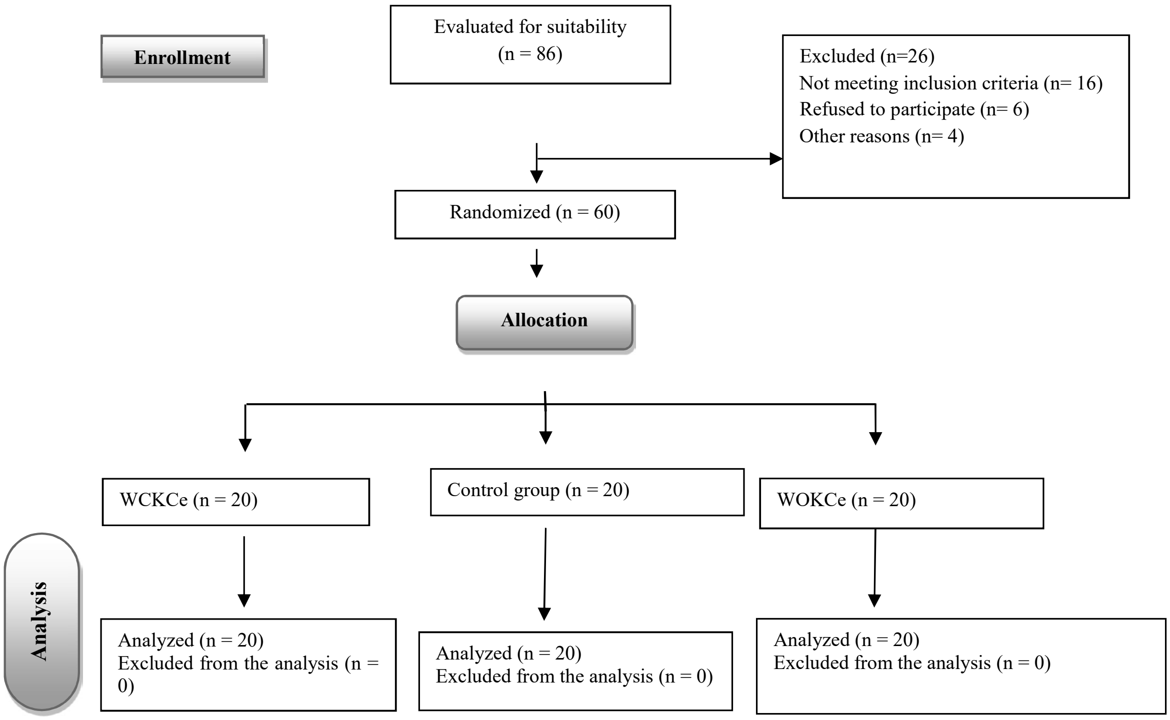

Figure 1. The CONSORT flow diagram

tion table. Upon command, the participant performed the abduction movement of the leg toward the side (abduction) without bending the knee, as illustrated in Figure 2. The duration of this test was 5 seconds, during which three maximum isometric contractions were executed, with one-minute rest intervals between each contraction for the dominant side [57, 80-82]. The MVIC for the QL muscle involved a lateral flexion movement against the resistance of the examiner. Following the placement of electrodes at the site of the muscle, the participant lay on his side on the examination table. Upon command, the participant performed the movement against the examiner's resistance, as illustrated in Figure 3. The duration of this test was 5 seconds, during which three maximum isometric contractions were repeated, with one-minute rest intervals between each contraction for the dominant side [57, 80-82]. Each of the MVIC movements was repeated three times, and the greatest electrical activity recorded for each muscle during the various contractions was considered the MVIC of that muscle [83, 84]. To calculate the MVIC, the muscle coactivation formula (EMGs / EMGL (EMGs + EMGL) was used [85, 86]. EMGs represent the level of activity of the muscle with lower activity, while EMGL denotes the level of activity of the muscle with higher activity during the side plank exercise [85, 86].


[redacted]

Figure 2. MVIC for the GMed during hip abduction against the resistance of the examiner

Figure 3. MVIC for the quadratus lumborum during lateral flexion trunk against the resistance of the examiner

Statistical analyses

To evaluate the effects of the interventions on MVIC, ANCOVA was utilized, with eta-squared (η^2) employed as a measure of effect size [87]. Pairwise comparisons were performed using the Bonferroni correction to control for type I error [88]. Additionally, the percentage of change (POC) from pre-test to post-test scores was calculated according to the formula established by Soufivand et al., with statistical significance set at $P<0.05$ [89] (Equation 1).

$$1.\quad \%{*}\mathbf{Difference} = \frac{\mathbf{Post - Pre}}{\mathbf{Pre}} * \mathbf{100}$$

E1 is the first experimental measurement.

E2 is the second experimental measurement.

Results

Table 2 displays the mean demographic characteristics, including age, height, weight, and body mass index (BMI) of participants. Furthermore, the results of the Shapiro-Wilk test are presented in Table 2. These results indicated that the data from the three groups—WOKCe, WCKCe, and control—were normally distributed, as demonstrated by P-values exceeding 0.05 for the research variables.

MVIC

In the WCKCe group, MVIC of the GMed muscle showed a significant improvement of 13.01% (P=0.009), indicating a positive effect of the intervention (P=0.007), suggesting effective intervention outcomes. The WOKCe group exhibited a notable improvement of 23.18% in MVIC of the QL muscle (P=0.028), indicating a strong positive effect of the treatment. Finally, the WCKCe group showed a significant improvement of 13.01% in MVIC of the QL muscle (P=0.003). In the control group, MVIC of the GMed decreased from pre-test to post-test by 5.63%; however, this change was not statistically significant (P=0.372). A similar non-significant decrease of 5.51% was observed in MVIC of the QL (P=0.186) (Table 3).

Table 4 presents the ANCOVA results, which revealed a statistically significant difference among the groups regarding the MVIC of the GMed muscle (F=7.08, P=0.002). The effect size, indicated by eta-squared (η^2=0.212), suggested a moderate effect, meaning that group membership accounted for a substantial portion of the variance in the MVIC of the GMed muscle. Additionally, the analysis demonstrated high statistical power (0.968), indicating a strong likelihood of detecting a true effect if one exists. Also, the ANCOVA results for the MVIC the QL muscle showed statistically significant group differences (F=12.94, P=0.001, η^2=0.996). These results indicate that there is sufficient evidence to conclude significant differences in the MVIC of the GMed and QL muscles among the WCKCe, WOKCe, and control groups.

Table 5 presents a comparative analysis of the study variables across the groups, revealing several important findings. Notably, a statistically significant difference in MVIC of the GMed muscle was observed between the WCKCe group and the control group (P=0.04), as well as between the WOKCe group and the control group (P=0.001). This statistically significant result indicates a possible influence of the WCKCe and WOKCe interventions on MVIC of the GMed muscle. Furthermore, the analysis revealed that there was no statistically significant difference observed between the two experimental groups (P=0.895), suggesting that these two interventions had similar effects on this particular muscle parameter. The analysis of the MVIC of the QL muscle revealed that both the WCKCe and WOKCe groups exhibited statistically significant differences compared to the control group (P=0.02 and P=0.001, respectively).

Table 1. The exercises protocol (weeks 1-8)

Exercise	Water Closed Kinetic Chain Exercise Group	Water Open Kinetic Chain Exercise Group	Duration, Repetition, Time
Familiarization	Introduction to the pool environment, rules, and regulations	Introduction to the pool environment, rules, and regulations	10 minutes
Warm-up	Walking back and forth, side stepping with arm movements in shallow water	Walking back and forth, side stepping with arm movements in shallow water	3 minutes
Stretching exercises	Stretching large muscles (hamstrings, iliopsoas, piriformis, and QL)	Stretching large muscles (hamstrings, iliopsoas, piriformis, and QL)	Each stretch: 15 seconds, 2 repetitions
Breathing patterns	Examination and training of proper breathing patterns	Examination and training of proper breathing patterns using noodles	5 minutes
Activation exercises	Activating transverse abdominal muscles and multifidus in the semi-squat position against the pool wall	Activating transverse abdominal muscles and multifidus using noodles in the semi-squat position	10 seconds, 3 repetitions
Forward movement	Walking forward with extended knee	Bending and opening thighs with extended knee using noodles in deep water	3×12 meters
Backward movement	Walking backwards with long steps	Racing backwards (similar to cycling) using noodles in deep water	3×12 meters
Lateral movement	Walking side by side with long steps	Adduction and abduction of legs with extended knee using noodles in deep water	3×12 meters
Single leg position	Flexion and extension of the thigh in a single leg position with flat knee	Flexion and extension of the thigh in floating position using noodles in deep water	10 seconds, 3 repetitions
Cooling down	Walking in shallow water and stretching upper and lower torso muscles	Walking in shallow water and stretching upper and lower torso muscles	5 minutes

This finding suggests that the interventions had a meaningful impact on the QL muscle strength. However, there was no statistically significant difference between the WCKCe and WOKCe groups regarding the MVIC of the QL muscle (P=0.07).

Discussion

The primary objective of this study was to assess the effects of WCKCe and WOKCe on the MVIC of the gluteus GMed and QL muscles. The results demonstrated a statistically significant and positive effect of the intervention on MVIC GMed and QL muscles in the

Table 2. Demographic characteristics of the participants (n=60)

Variables	Mean±SD			F	P
	WCKCe (n=20)	WOKCe (n=20)	Control (n=20)		
Age (y)	46.1±6.06	47.806±5.43	50.4±5.87	2.791	0.070
Height (cm)	174.98±6.47	172.12±8.34	188.26±5.76	3.93	0.065
Weight (kg)	78.7±11.61	84.83±10.21	76.7±5.4	0.176	0.839
BMI (kg/m^2)	28.32±3.72	28.24±3.46	27.78±2.82	1.61	0.208

Abbreviations: WCKCe: Water closed kinetic chain exercise, WCKCe: Water open kinetic chain exercise, BMI: Body mass index.

*Significant difference between groups (P<0.0 5).

Table 3. Results of the paired-samples t-test for the study variables and their percentage of change

Variables	Group	Pre-test	Post-test	Percentage of Change	P
MVIC of the GMed	Control	284.42±135.4	268.7±142.42	-5.63	0.372
	WCKCe	430.42±126.58	454.37±126.48	5.58↑	0.007*
	WOKCe	294.26±132.86	385.65±142.2	15.85↑	0.001*
MVIC of the QL	Control	272.55±46.04	257.55±75.82	-5.51	0.186
	WCKCe	269.98±107.48	304.5±111.49	13.01↑	0.009*
	WOKCe	220.93±79.90	271.76±200.29	23.18↑	0.004*

WCKCe: Water closed kinetic chain exercise, WCKCe: Water open kinetic chain exercise.

*Significant difference between groups (P<0.05).

Table 4. Results of the ANCOVA for the study variables

Variables	Group	Sum of Squares	Mean Square	Degree of Freedom	F	P	η²	Power
MVIC of the GMed	Control WCKCe WOKCe	57016.85	28508.429	2	7.08	0.002*	0.212	0.917
MVIC of the QL	Control WCKCe WOKCe	117488.58	58744.29	2	12.94	0.001*	0.316	0.996

*Significant difference between groups (P<0.05).

Table 5. Comparison of the study variables between groups

Variables	Group	Group	Mean Difference	Std. Error	P
MVIC of the GMed	WCKCe	WOKCe	-21.52	20.5	0.895
		Control	55.28	22.06	0.04*
	WOKCe	WCKCe	21.52	20.5	0.895
		Control	76.8	29.65	0.001*
	Control	WCKCe	-55.28	22.06	0.04*
		WOKCe	-76.8	29.65	0.001*
MVIC of the QL	WCKCe	WOKCe	-59.44	21.41	0.07
		Control	49.24	21.3	0.02*
	HOKCe	WCKCe	59.44	21.41	0.022*
		Control	108.69	21.38	0.001*
	Control	WCKCe	-49.24	21.3	0.07
		WOKCe	-108.69	21.38	0.001*

*Significant difference between groups (P<0.05).

experimental groups, with improvements ranging from 5.58% to 23.18%. Consequently, the findings confirmed the efficacy of the specific training protocol in enhancing MVIC GMed and QL muscles in experimental groups. This observed enhancement in muscular strength corroborates existing literature, which attributes the efficacy of aquatic therapy to the distinct hydrodynamic properties of water, namely buoyancy and omnidirectional resistance [33, 37, 70, 76, 89- 91]. The scientific rationale for these results becomes highly specific when considering the intervention as a form of water-based resistance exercise; the unique properties of water provide a distinct physiological stimulus compared to land-based training [33, 74, 76, 92, 93]. Water provides resistance in all planes of movement, unlike gravity, which is primarily vertical [33, 61, 94-96]. This constant, multi-directional load requires sustained stabilization from the deep core muscles, particularly the quadratus QL and GMed, to maintain a neutral pelvis and spine [19, 97, 98]. Furthermore, the viscosity of water generates a velocity-dependent resistance that imposes a substantial eccentric load during movement deceleration, a potent stimulus for neuromuscular adaptation and strength gain [76, 99, 100]. This environment of turbulence and omnidirectional perturbation constantly challenges postural control, thereby heightening proprioceptive input to the central nervous system [40, 61, 76, 95, 101]. In response to this heightened demand, the body augments motor unit recruitment to key lumbo-pelvic stabilizers, such as the GMed for hip and pelvic control, and the QL for lumbar stabilization directly resulting in the observed significant improvements in maximum voluntary contraction [90, 97, 102-105]. The buoyancy of water significantly reduces compressive forces on the spine and joints that this character allows for a higher training volume and greater range of motion with less pain or fatigue [32, 40, 59, 70, 91, 96, 97]. In summary, the combination of multi-directional resistance, enhanced proprioceptive challenge, and a low-impact environment created an ideal stimulus for neuromuscular adaptation in the lumbo-pelvic stabilizers, resulting in the significant strength gains observed in the intervention groups [61, 76, 97, 100, 106].

The implementation of WCKCe has been shown to significantly enhance proprioceptive input and neuromuscular control, which likely contributed to the observed strength gains in muscles of GMed and QL. Research by Bunton et al., Irish et al., Sciascia and Cromwell, and Tang et al. supports this assertion, indicating that closed-chain movements engage multiple muscle groups and joint stabilizers, thereby fostering a more integrated neuromuscular response [48, 53, 56, 107]. This type of exercise promotes dynamic stability and coordination, which are critical for effective movement patterns and injury prevention [48, 53, 56, 107]. In contrast, WOKCe have their own unique benefits, particularly in terms of facilitating a greater range of motion and promoting isolated muscle activation. Studies conducted by Lephart and Henry, Lust, Öberg et al., and Sciascia and Cromwell highlight that open chain exercises allow for targeted strengthening of specific muscles without the influence of surrounding muscle groups [50, 52, 53, 108]. This isolation can be particularly beneficial for rehabilitation purposes, where focused muscle activation is necessary to restore function and strength [28]. Enhancing the MVIC of the GMed and QL muscles is essential for improving overall lower limb function and preventing injuries [22, 24, 29]. One effective method for achieving this is through resistance exercises utilizing a theraband resistance bands (TRB) in water [57]. Resistance training, particularly when incorporating tools such as the TRB, provides a unique approach to muscle activation [109, 110]. The TRB offers variable resistance that can be adjusted according to the individual's strength level and rehabilitation needs [102]. This synergy is particularly advantageous for targeting the GMed and QL muscles due to a dual-mechanism approach. First, buoyancy mitigates joint compressive and gravitational forces, permitting greater range of motion and training volume with reduced pain and inhibitory feedback [58, 102, 111]. Second, the TRB provides targeted, elastic resistance in specific planes of movement (e.g. hip abduction), which directly and intensively engages the GMed without placing the joints under high axial loads [104, 112]. This combination creates an ideal high-stimulus, low-stress environment for neuromuscular adaptation [33, 60, 90, 97].

Studies have shown that performing resistance exercises in water can lead to increased MVIC levels due to the unique resistance properties of water [32, 70], which challenge the muscle fibers differently compared to land-based exercises [95, 96]. The inherent instability of the aquatic environment provides a continuous challenge to postural control, which heightens proprioceptive feedback to the central nervous system [103, 105]. This enhanced sensory input is essential for refining the neuromuscular control and coordination of movements involving the GMed, thereby increasing the overall effectiveness of the training regimen [58, 113]. To optimize increases in the MVIC of the GMed using TRB resistance in an aquatic environment, specific exercise prescriptions are fundamental [33, 60, 103]. A primary example involves performing standing lateral leg raises with a TRB secured around the ankles [102, 103, 109, 114]. This configuration effectively targets the GMed by superimposing the elastic resistance of the band onto the hydrodynamic resistance of water, thereby creating a compounded stimulus for muscle engagement [57, 102, 103, 109, 114]. This synergistic loading mechanism directly facilitates significant improvements in both GMed strength and lumbo-pelvic stability [104, 105, 110, 111]. Enhanced strength in the GMed and QL is foundational for improved balance, stability, and overall physical performance, which are critical for individuals in rehabilitation [29].

The ANCOVA results indicate no significant differential effect of exercise type on MVIC of the GMed between the WCKCe and WOKCe groups (P=0.895), demonstrating that both modalities were equally effective in improving GMed MVIC. This finding supports the concept that the distinction between closed and open kinetic chain exercises may not substantially influence strength outcomes in this population. Regarding MVIC of the QL muscle, both interventions again produced significant improvements relative to the control group, with the WCKCe group achieving a 13.01% increase (P=0.009) and the WOKCe group a 23.18% gain (P=0.004), confirming the efficacy of both modalities for targeting this crucial core stabilizer. Consistent with the GMed findings, no statistically significant difference emerged between the two intervention groups for MVIC of the QL (P=0.07). This consistent pattern across both muscles reinforces that WCKCe and WOKCe provide comparable benefits for enhancing lumbo-pelvic stabilizer strength, offering clinicians flexibility in exercise selection.

The underlying mechanisms for strength improvement in both muscles may involve similar neuromuscular adaptations, as both exercise types engage overlapping muscle groups and movement patterns [26, 29, 79, 103]. The comparative analysis of WCKCe and WOKCe reveals important implications for rehabilitation practices. Both exercise modalities leverage the unique properties of water to enhance muscle strength while minimizing the risk of injury associated with traditional land-based exercises [32, 33, 70]. Moreover, the findings suggest that clinicians can confidently implement either WCKCe or WOKCe in rehabilitation programs, depending on individual patient needs and preferences. For instance, WCKCe may be more suitable for patients requiring stability and support [44, 49, 50, 56, 108], while WOKCe could be advantageous for those aiming to enhance functional mobility and strength through a broader range of motion [53, 58]. The implications of these findings extend beyond immediate muscle strength improvements. Enhanced strength in the GMed and QL muscles is associated with improved functional outcomes, including better balance, stability, and overall physical performance. These factors are critical for athletes returning to sport and for individuals seeking to maintain an active lifestyle post-rehabilitation. The combination of TRB with hydrodynamic loading is particularly effective. Clinicians may freely choose between WCKCe and WOKCe for improving GMed and QL strength, as both yield comparable results. This provides flexibility to tailor programs to individual patient preferences and functional goals. This approach is especially beneficial for patients requiring low-impact training, such as those with LBP, hip pathologies, or during post-operative rehabilitation. Aquatic exercise offers an effective, flexible, and joint-protective approach to enhancing lumbo-pelvic stability and function.

This study has several limitations that should be addressed in future research. First, the long-term efficacy of both WCKCe and WOKCe on maintained strength improvements and functional outcomes remains unexplored. Second, the underlying neuromuscular adaptations, such as changes in motor unit recruitment patterns and muscle activation timing were not investigated. Additionally, the impact of these interventions on quality-of-life measures across diverse clinical populations warrants examination. Future studies should also establish optimal rehabilitation parameters by examining dose-response relationships through varied exercise intensities, durations, and frequencies. These investigations would substantiate the implementation of aquatic exercises as a primary strengthening modality rather than solely an initial rehabilitation approach.

Conclusion

Our study highlights the effectiveness of an 8-week aquatic exercise program in strengthening core muscles among men with CNSLBP. For clinicians, this underscores the importance of integrating aquatic therapy into rehabilitation strategies to enhance patient outcomes, including pain reduction and improved functional mobility. It is crucial for healthcare providers to tailor these interventions to individual patient needs and consider the study's limitations when applying the findings. Future investigations should focus on the long-term effects and broader applicability of aquatic exercises in diverse patient populations to optimize low back pain management. Clinicians can select WCKCe or WOKCe considering patient mobility and preference without compromising strength gains.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Research Ethics Committee for Human Research at Bu-Ali Sina University, Hamadan, Iran (Code: IR.BASU.REC.1402.011). This study was registered by the Iranian Registry of Clinical Trials (IRCT) (Code: IRCT.20190129042534N1). Before experimental procedures began, all the participants reviewed and voluntarily signed an informed written consent form.

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Authors' contributions

Conceptualization, study design, and writing: Ali Yalfani; Data interpretation: Hossien Ashoury; Data acquisition, and final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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