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Original Article

Assessing the Impact of Closed and Open Kinetic Chain Hydrotherapy on Vertical Ground Reaction Force, Rate of Loading, Lumbo-Pelvic Stability, Pain Intensity, and Kinesiophobia in Men with Non-Specific Chronic Low Back Pain: A Randomized Clinical Trial

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ABSTRACT

Background: Chronic non-specific low back pain (CNSLBP) is a leading cause of work absenteeism and increased dependence on healthcare services and insurance. Despite its prevalence, limited research has explored the effects of open and closed kinetic chain (O/CKC) exercises performed in water on improving CNSLBP-related outcomes. This study aimed to assess the impact of hydrotherapy-based closed and open kinetic chain exercises on lumbo-pelvic stability, pain intensity, kinesiophobia, rate of loading (ROL), and vertical ground reaction force (vGRF) in men with CNSLBP.

Methods: The double-blind randomized controlled trial was designed with a pre-post test in men aged 40–60 (48.10 ± 5.97) with CNSLBP. Patients were randomly assigned to two hydrotherapy groups—CKCE and OKCE—and a control group. Pain intensity, kinesiophobia, lumbo-pelvic stability (LPS), rate of loading (ROL), and vertical ground reaction force (vGRF) were measured using the visual analog scale, Tampa Kinesiophobia Scale, biofeedback pressure device, and plantar pressure device. The intervention groups performed prescribed exercises for eight weeks, with three sessions per week. Covariance analysis was used to compare group differences.

Results: In the comparison within the OKCE and CKCE groups, significant differences were observed between the pre- and post-intervention measurements ($p < 0.05$). Moreover, statistically significant differences were found in pain ($p = 0.001$) and kinesiophobia scores ($p = 0.001$), both with a large effect size. Additionally, noteworthy differences were noted in vGRF ($p = 0.003$), ROL ($p = 0.012$), and LPS ($p = 0.022$).

Conclusion: The study results indicate that hydrotherapy exercises involving open and closed kinetic chains benefit individuals with CNSLBP. It is recommended that healthcare professionals, including physicians, physiotherapists, and occupational therapists, incorporate these exercises into comprehensive rehabilitation programs for such patients.

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Introduction

Low back pain (LBP) is a significant health concern that impacts daily activities and quality of life, potentially leading to serious consequences. The World Health Organization (WHO) has identified LBP as a significant global health issue [1]. In Iran, the prevalence of LBP ranges from 14.4% to 84.1% across various groups, including the workforce, expectant mothers, and students [2]. It ranks as the third leading cause of health issues and disabilities among Iranians aged 15 to 69 [2]. Reports indicate that approximately 65% of the Iranian population experiences LBP annually, affecting both genders equally [3]. Research also shows that around 27–28% of Iranian men suffer from LBP, with variations influenced by occupational factors and individual characteristics [4].

Kinetic chain exercises (open and closed) are now recognized as essential rehabilitation methods, particularly for the lower limbs [5]. A closed kinetic chain (CKC) exercise occurs when the foot is in contact with a surface, stabilizing the distal segment of the lower limb [6]. In contrast, an open kinetic chain (OKC) exercise allows for mobility of the distal segment without ground contact [7]. Various exercise modalities offer distinct advantages and limitations in rehabilitation settings. Specific treatment objectives typically influence the selection between OKC and CKC [8]. CKC exercises involving weight-bearing are beneficial as they enhance joint stability, increase compressive forces, and improve proprioceptive awareness [8]. Conversely, OKC exercises, often performed without weight-bearing on the feet, offer advantages such as greater acceleration forces and support for functional movements [8].

The Rate of Loading (ROL) is a crucial measure in biomechanics and sports science, reflecting the impact or pressure exerted on tissues during physical activity [9]. It indicates the progressive increase in loading on the body, highlighting the strain and stress placed on muscles, tendons, ligaments, and bones [9]. Low shock absorption indicates that high pressure is applied to the lower limbs over a short period [9]. The ROL during physical activities is influenced by various factors, including movement speed, shoe type, body weight, height, landing surface, and movement strategy [10]. Proper control and management of these forces are essential for injury prevention and optimal performance [10].

The formula for ROL indicates that the Vertical Ground Reaction Force (vGRF) directly correlates with ROL; therefore, an increase in vGRF leads to an increased ROL [11]. Individuals with low back pain (LBP) exhibit changes in motor control, characterized by a reduced range of pelvic motion, increased ground reaction forces, and altered walking speed and step length. Consequently, LBP and walking are closely interrelated [12]. Spinal proprioceptive deficits, aberrant muscle activation patterns, and impaired neuromuscular control often arise from pain [13]. This mechanism enhances the loading speed and ground reaction force while reducing the body's shock absorption capacity [14].

Individuals experiencing Chronic Non-Specific Low Back Pain (CNSLBP) may find it difficult to perform exercises on solid ground; however, they can participate effectively in aquatic exercises [15]. In hydrotherapy (HT) sessions, adjusting the level of water immersion can modulate spinal load and weight-bearing, allowing patients to begin rehabilitation earlier than land-based exercises [14]. HT's primary advantage in managing CNSLBP is its ability to initiate therapeutic activities sooner than traditional dry land methods, often without causing pain [16].

The higher water viscosity compared to air provides increased resistance, enhancing sensory feedback and proprioception. This increased resistance may improve stability and balance during aquatic activities [14]. Thus, HT serves as an active therapeutic approach for enhancing balance, as the unique properties of water reduce spinal pressure, increase spinal stability, and facilitate pain-free physical activity [6].

Lumbo-Pelvic Stability (LPS) is a vital movement variable in assessing individuals with LBP and plays a crucial role in both clinical evaluations and laboratory studies [17]. The ability to control the dynamic interactions between the lumbar spine and pelvic complex is essential for maintaining spinal stability [18]. Impairments in LPS can disrupt spinal support mechanisms, potentially leading to tissue damage and the persistence of chronic lumbar pain [19, 20].

Hydrotherapy (HT), a therapeutic approach involving exercises performed in water, significantly impacts gait kinetics [21]. The properties of water, such as buoyancy and resistance, create a unique environment that can enhance gait mechanics and efficiency [21]. By reducing joint impact and providing support, HT enables individuals to practice walking patterns with reduced pain and physical stress [22]. The resistance water offers also strengthens the muscles involved in gait, improving control and coordination during walking [6]. Moreover, the multidirectional resistance of water challenges balance and stability, further improving overall gait quality [23].

Incorporating HT into gait training can improve walking ability, increase muscle strength, and enhance overall mobility [22]. Through water resistance, individuals can perform controlled and stable movements, promoting improved muscle activation and coordination throughout the kinetic chain [24]. The reduced joint impact in water also allows for smoother and more fluid movements, facilitating proper alignment and biomechanics [24]. Incorporating HT into kinetic training can optimize muscle recruitment, movement efficiency, and overall functional performance, making it a valuable modality for improving movement patterns and enhancing rehabilitation outcomes [24].

Research on closed kinetic chain (CKC) and open kinetic chain (OKC) exercises has predominantly focused on their effects on the knee and hip joints in both land-based and aquatic settings [25]. However, the combined effects of these exercises on chronic lower back pain have not been thoroughly investigated. Therefore, we evaluated the impact of hydrotherapy-based CKC and OKC exercises on multiple variables, including lumbo-pelvic stability, pain intensity, kinesiophobia, rate of loading, and vertical ground reaction force, in a group of men with non-specific chronic low back pain.

Methods

Study Design

This study employed a quasi-experimental research design, incorporating pre- and post-testing within a double-blind randomized controlled trial involving patients with Chronic Non-Specific Low Back Pain (CNSLBP). Random Allocation Software version 1.0 was used to generate randomization codes in blocks 4 and 6. Allocation concealment was maintained using sequentially numbered sealed envelopes, which were opened and distributed by an unbiased, independent researcher.

Participants were randomly assigned to CKC, OKC, and control groups, with 20 patients in each group. Significantly, participants were blinded to their group assignments. Patients were instructed not to disclose their treatment group to the evaluators to maintain blinding.

In accordance with the Declaration of Helsinki, the aims and procedures of the study were explained to all participants, and informed consent was obtained from them or their legal guardians for participation and the potential open-access publication of identifying details or images [26]. The study was approved by the Bio-Medical Research Ethics Committee of Bu-Ali Sina University (Approval Number: IR.BASU.REC.1402.011) and registered with the Iranian Registry of Clinical Trials (IRCT Number: IRCT20190129042534N1). This research adhered to the principles of the 2008 Declaration of Helsinki.

Participants

This randomized controlled trial involved 60 male patients aged 40–60 years [48.10±5.97] who attended a specialized therapeutic clinic in Hamedan [27,19]. Patients with Chronic Non-Specific Low Back Pain (CNSLBP) were included after receiving approval from a neurosurgeon and meeting predefined inclusion criteria. Eligible participants were aged 40–60 years with a history of persistent low back pain lasting more than three months. Exclusion criteria included previous spinal or hip surgeries; pre-existing neurological, cardiovascular, respiratory, or neck conditions; and diabetes [22].

Participants were excluded for the following reasons: pain in other body regions; severe deformities in the upper or lower limbs; use of pain medication under a specialist physician's supervision within the last six months; physiotherapy within the past year; presence of sciatic pain, spondylolysis, neuromuscular disorders, respiratory issues, or vertebral fractures [22] [Figure 1].

The experimental groups underwent closed kinetic chain (CKC) and open kinetic chain (OKC) hydrotherapy exercises thrice weekly for eight weeks. The control group received no intervention. Measurements were taken before and after the eight-week intervention period across all three groups. Additionally, participants were asked to return for follow-up assessments, including evaluation of their satisfaction with treatment using the Global Rating of Change questionnaire.

G*Power software was used to estimate the sample size. Based on a previous study, the power, alpha, and effect size were set at 0.8, 0.5, and 0.5, respectively [22]. Initially, a sample size of 57 was calculated. Following recommendations from the advisor and specialist physician, three additional participants were included, resulting in 20 participants per group.

Assessments

ROL and vGRF: Before testing, participants engaged in a 6-minute warm-up consisting of 3 minutes of general warm-up followed by 3 minutes of stretching exercises [22]. Gait analysis was conducted using plantar pressure measurements obtained from a Foot Pressure Model (FDMeS, Zebris, Germany) and analyzed with Win FDM-S Stance software [version 01.02.09]. Participants were instructed to stand and walk normally over the pressure distribution device.

Data were collected from three successful walking trials, and the average values were used for analysis. The vertical Ground Reaction Force (vGRF) was calculated based on the heel impact on plantar pressure within the first 100 milliseconds after heel strike. The peak vertical force time was determined from initial foot contact on the plate until the point of maximum vertical force. This value was normalized by dividing it by the participant's body weight and was expressed as a multiple of body weight.

The time to peak force was calculated as the duration between the initial foot contact and the peak vertical force. The Rate of Loading (ROL) was derived by dividing the initial vGRF by the time elapsed to reach it, as shown in Formula 1 and Figure 2 [28–30].

$$\text{Loading of rate} = \left[\frac{\text{peak } F_Z + (N)\text{body weight}(N)}{\text{time to peak } F_Z}\right] = \frac{N}{S.w}$$

Formula_1. Calculating the Rate of Loading or ROL. Peak F_Z: The Maximum recorded force was normalized by dividing it by the participants' body weight. Time to Peak $F_{Z:}$ The time interval between the initial contact of the foot with the foot pressure and reaching the peak vertical force was considered the time to reach the maximum force.

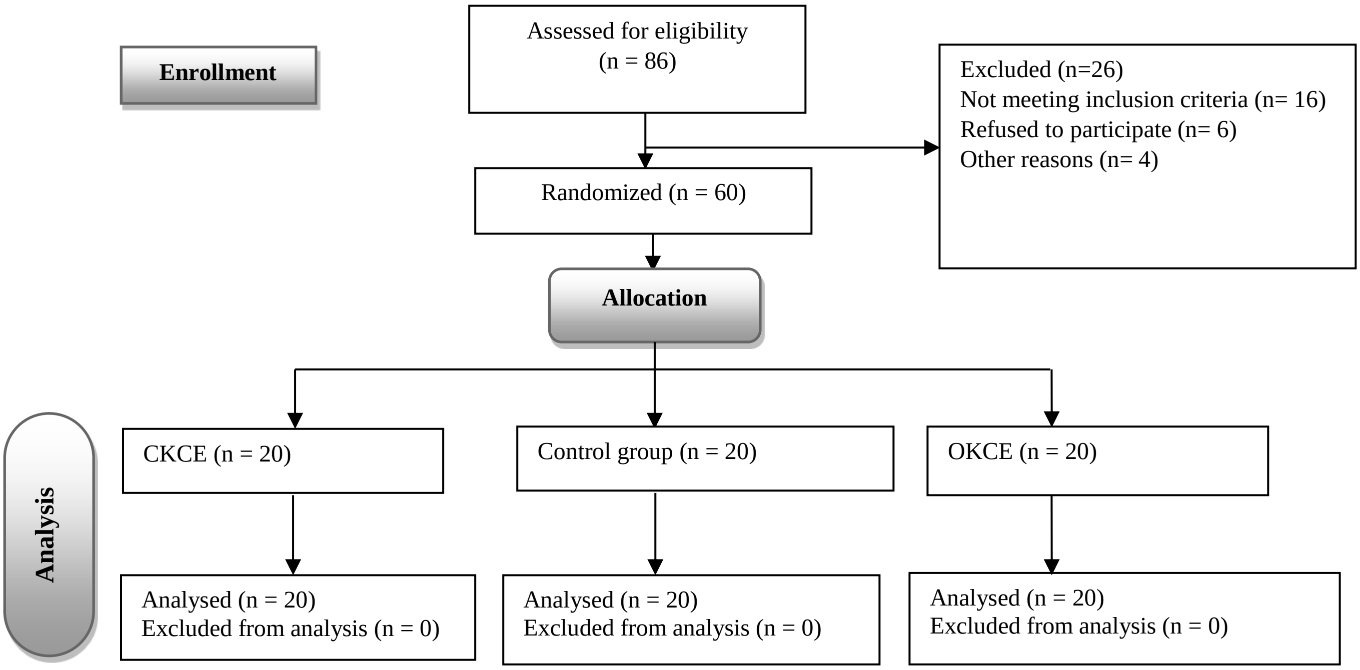

Figure 1: The subjects' CONSORT flow diagram

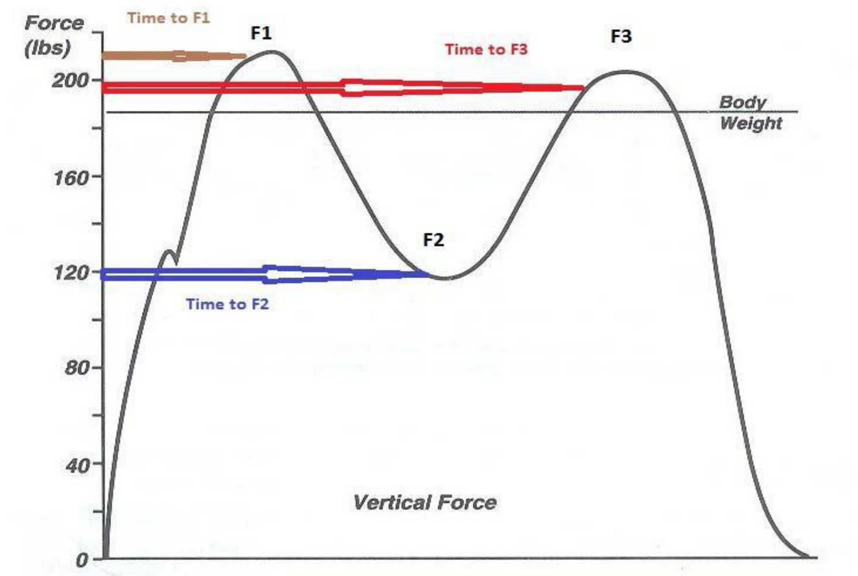

Figure 2: illustrates the calculation of the time required to reach vertical ground reaction force parameters with the corresponding diagram. Time to F1 represents the duration of ground reaction force during heel strike, Time to F2 signifies the duration of ground reaction force during foot flat, and Time to F1 defines the duration of ground reaction force during heel off.

Pain: The current study included individuals with pain scores greater than four. Pain perception was assessed using a 10-centimeter Visual Analog Scale (VAS). Participants were asked to mark their pain level on the scale within this range. [31].

The Tampa Scale, in its Persian version, was used to evaluate kinesiophobia. This scale consists of an 11-item questionnaire, with participants instructed to respond to each item based on their current emotional state. Responses were recorded using a four-point Likert scale ranging from "strongly disagree" [1] to "strongly agree" [4]. The scale demonstrated excellent reliability and validity, with internal consistency reliability reported at 86% [32].

Lumbo-Pelvic Stability [LPS], Pressure Biofeedback Units (PBUs) were used to evaluate the activation and stability of the core muscles and spine, ensuring appropriate support and protection of the spine, lower back, and neck during various movements [33]. The study utilized the PBU (Stabilizer®) device from Chattanooga Group, Inc. (Hixson, TN, USA) to assess LPS. This device was integral to conducting a comprehensive four-test evaluation [34]. The reliability coefficients for these evaluations ranged from 0.86 to 0.90 [34][34][34]. Participants' LPS status was determined by measuring pressure changes from baseline levels, 40 mmHg for the prone test and 70 mmHg for the supine test. The assessment involved administering four specific LPS tests, as described below [34].

1- Knee lifts abdominal [KLAT]. In the KLAT position, the participant lies supine with knees flexed and feet flat on the floor. The PBU is placed horizontally under the lower back, with its bottom aligned at the level of the posterior superior iliac spine. A baseline pressure of 40 mmHg is set for this evaluation. The participant then raises one leg, flexing the hip and knee to 90 degrees, and holds this position for 4–6 seconds [Figure 3], [33].

2- Bent knee fall-out [BKFO]: In a supine position, the participant had the PBU placed vertically beneath the lumbar spine, with the bottom edge of the unit positioned 2 cm above the caudal edge of the upper posterior cruciate ligament on the tested side. Following instructions, the participant slowly bent the knee on the PBU side to 120 degrees while simultaneously abducting and laterally rotating the hip approximately 45 degrees, then returned to the starting position. In contrast, the contralateral knee remained in a neutral position, with the foot flat on the floor [Figure 4], [33].

3- Active Straight Leg Raising [ASLR]: The participant lay on their back with the PBU positioned horizontally under the lumbar spine, its lower edge aligned with the posterior upper lumbar region. The PBU was calibrated to 40 mm Hg. Subsequently, the maximum pressure change was recorded [Figure 5], [33].

4- Prone Test: The PBU was positioned between the participant's upper anterior sacral spine and navel while lying supine. The device was calibrated to 70 mm Hg before each contraction. Participants were instructed to use diaphragmatic breathing. With the airbag set to 70 mm Hg, the participant, after taking two breaths, performed three contractions under verbal guidance. These contractions involved engaging the abdominal muscles without spinal or pelvic movement, specifically, drawing the navel toward the spine and maintaining the contraction for 10 seconds [Figure 6]. [17, 33].

Figure 3: Knee lifts abdominal [KLAT] Test

Figure 4: Bent knee fall-out [BKFO] Test

Figure 5: Active Straight Leg Raising [ASLR]

Figure 6: Prone Test

Experimental Intervention Protocol

An eight-week exercise program, divided into two phases, was implemented after assessing the specified variables. The first four-week phase focused on water familiarization, breathing pattern analysis and training, core muscle co-contraction, and integrating proper breathing and posture during daily activities and swimming in the pool (Table 1). The second phase, also four weeks long, emphasized functionality and progression. Building on the foundations established in the first phase, this stage aimed to enhance endurance and muscle strength through resistance training (red threshold; see Table 2). A hydrotherapy specialist and a researcher supervised three 60-minute exercise sessions each week. Each session comprised a five-minute warm-up, 50 minutes of hydrotherapy kinetic chain exercises, and a five-minute cool-down involving stretching. At Bu-Ali Sina University, the OKCE group used pool noodles in deep water under lifeguard supervision, while the CKCE group performed exercises in chest-deep water. Throughout the intervention, the volume, intensity, duration, and repetitions of the training program were progressively increased for both groups [Tables 1 and 2] [22,35].

Table 1: Initial Exercises [Weeks 1-4]

Exercise Type	**Hydrotherapy Closed Kinetic Chain Exercise Group**	**Hydrotherapy Open Kinetic Chain Exercise Group**	**Duration, Repetitions, Time**
Warm-Up	Three minutes of shallow-water exercises including walking, stepping, and arm movements.		3 min
Stretching	Perform two sets of 15-second stretches, targeting the quadratus lumborum, hamstrings, iliopsoas, piriformis, gastrocnemius, and soleus.		5 min
Breathing Exercises	Breathing exercises and training in shallow water.	Evaluating and practicing deep breathing Techniques with the help of pool noodles.	5 min
Core Activation	Transverse abdominis and multifidus muscle activation is achieved via semi-squat exercises while supported against the pool wall.	Core activation is achieved through noodle usage in a semi-squat position, positioned against the pool wall in the deep section of the pool.	10 sec x 3
Leg Movements	Forward movement with extended knee, bending, and opening.	Equivalent to a closed chain structure in deep water using a noodle.	12 m x 3
Backward Walking	Long steps backward.	Executing a cycling-like motion in reverse while utilizing noodles in the deep end.	12 m x 3
Side Steps	Step sideways for a long distance.	Using buoyant noodles facilitates deep water exercises involving leg adduction and abduction with extended knees.	12 m x 3
Single-Leg Movement	Flexion and extension of the thigh in a flat knee position.	Deep water exercises, utilizing flotation devices, were performed to target thigh flexion and extension	10 sec x 3
Cooling Down	Utilizing shallow water to stretch the muscles of the upper and lower body.		5 min

R = Repeat, S = Secon, M = Meter, Min =Mintues

Table 2: Exercises for the Progression Phase [Weeks 5-8]

Exercise Type	**Hydrotherapy Closed Chain Exercise Group**	**Hydrotherapy Open Chain Exercise Group**	**Duration, Repetitions, Time**
Warm-Up	Three minutes of shallow-water exercises including walking, stepping, and arm movements.		3 min
Stretching	Perform two sets of 15-second stretches, targeting the quadratus lumborum, hamstrings, iliopsoas,piriformis, gastrocnemius, and soleus.		3 x 15 sec
Core Activation	Perform extensions and flexions of the thighs, keeping knees extended, using a red TheraBand.	Do core exercises using noodles while in a semi-squat against the pool wall in the deep end.	3 x 15 sec
Leg Flexion/Extension	Shoulder movements—flexing and extending—while in a half-squat.	Use noodles in the pool's deep end with a red TheraBand like a closed-chain exercise.	4 x 12 m
Shoulder Movement	Employing a red TheraBand for backward ambulation.	It's like doing a closed-chain exercise but using noodles in the deep end.	4 x 12 r
Backward Movement	Backward walking with a red TheraBand.	I'm using noodles and a red TheraBand to swim backward in the deep end.	4 x 15 sec
Leg Adduction/Abduction	With knees extended, adduct and abduct your legs while using a red TheraBand.	Comparable to a closed chain, using noodles in the deep end.	4 x 12 m
Horizontal Movements	Using a red TheraBand, perform horizontal leg movements while in a semi-squat.	Like the closed chain exercise, use two noodles in the pool's deep end with a red TheraBand.	3 x 12 r
Cooling Down	Utilizing shallow water to stretch the muscles of the upper and lower body.		5 min

R = Repeat, S = Secon, M = Meter, Min =Mintues

Statistical Analysis

Data were analyzed using SPSS version 26. The Shapiro-Wilk test was applied to assess the normality of the data. Since the data followed a normal distribution, ANOVA was used to compare the groups' pre-test scores. Paired t-tests were employed to compare individual variables within each group. Additionally, analysis of variance (ANOVA) was performed to examine the main effects of the hydrotherapy intervention on the measured variables. A significance level of $p < 0.05$ was considered statistically significant. Eta-squared coefficients (η^2) were calculated to evaluate the effect size of the intervention [36].

Results

Mean and standard deviation values were calculated for demographic characteristics and baseline variables (Table 3). No statistically significant differences were found among the groups regarding age, weight, height, BMI, KLAT, BKFO, ASLR, PT, pain, ROL, vGRF, or kinesiophobia ($p > 0.05$) (Table 3).

Pain and Kinesiophobia

A significant difference ($p < 0.05$) in pain and kinesiophobia scores was observed between the CKC and OKC groups, based on paired t-test results, indicating a meaningful treatment effect. As shown in Table 4, the control group's scores remained unchanged before and after the intervention, demonstrating no significant difference ($p > 0.05$). Furthermore, ANOVA results confirmed a statistically significant reduction in reported pain levels ($F_2 = 112.386$) [Table 5].

LPS Variables

Significant improvements in LPS variables were found in both the CKCE and OKCE groups ($p < 0.05$). In contrast, the control group showed no significant changes ($p > 0.05$), according to paired t-test analyses [Table 4]. ANOVA results further supported these findings, with the following significant outcomes: [F2=6.158, P=0.004, η2=0.207], BFKO [F2=3.198, P=0.048, η2=0.102], ASLR [F2=3.568, P=0.035, η2=0.113], and PT [F2=22.327, P=0.001, η2=0.444], [Table 5].

ROL and vGRF

The results of the paired t-test analysis revealed significant differences in LPS variables among participants in the CKCE and OKCE intervention groups ($p < 0.05$) [Table 4]. Similarly, analysis of variance (ANOVA) indicated statistically significant differences in vertical ground reaction force (vGRF) and rate of loading (ROL) across the groups, with the following results: vGRF [F2=6.384, P=0.003, η2=0.183], ROL [F2=4.80, P=0.012, η2=0.144], [Table 5].

Table 3: Descriptive statistics of participants and the one-way analysis of variance findings at the baseline.

Groups Variable	HCKC group [n= 20]	HOKC group [n= 20]	Control group [n= 20]	F	P- value
	Mean ± SD	Mean ± SD	Mean ± SD		
Age[year]	46.10 ± 6.06	47.806 ± 5.43	46.10 ± 6.06	2.791	**0.070**
Height[cm]	174.98 ± 6.47	172.12 ± 8.34	174.98 ± 6.47	3.93	**0.065**
Weight[kg]	78.70 ± 11.61	84.83 ± 10.21	78.70 ± 11.61	0.176	**0.839**
BMI [kg/m2]	28.32 ± 11.4726	28.24 ± 3.46	28.32 ± 11.4726	1.61	**0.208**
KLAT	5.30 ± 8.15	9.40 ± 6.76	9.45 ± 3.59	1.833	**0.162**
BKFO	-13.30 ± 8.15	-10.05 ± 8.53	-10.50 ± 15.28	2.66	**0.078**
ASLR	7.90 ± 8.56	7.60 ± 8.58	10.40 ± 9.16	0.597	**0.554**
PT	5.30 ± 8.15	9.40 ± 6.76	9.45 ± 3.59	0.920	**0.405**
Pain	14.20 ± 6.12	15.85 ± 4.28	16.30 ± 6.75	1.60	**0.209**
ROL	3.19±0.59	3.19±0.59	3.61±0.56	2.041	**0.139**
vGRF	101.77± 13.48	3.19±0.59	109.96±12.39	2.66	**0.078**
Kinesiophobia	28.30±3.67	29.65±3.61	28.45±3.61	0.828	**0.442**

Groups differed significantly [P < 0.05]. Hydrotherapy Closed Kinetic Chain [HCKC], Hydrotherapy Open Kinetic Chain [HOKC], Body Mass Index [BMI], Knee Lift Abdominal Test [KLAT], Bent-Knee Fall-Out [BKFO], Active Straight Leg Raise [ASLR], Prone Test [PT], Rate of Loading [ROL], and Vertical Ground Reaction Force [vGRF].

Table 4: The results of the dependent t-test between the measured variables [Mean ± SD].

Variable	Control group [N= 20]			HOKC group [N= 20			HCKCgroup [N= 20]		
	Pre-test	**Post-test**	**P- value**	**Pre-test**	**Post-test**	**P- value**	**Pre-test**	**Post-test**	**P- value**
PAIN	6.30 ± 0.978	6.50 ± 1.00	0.214	5.95 ± 0.60	1.65 ± 1.22	0.001*	6.50 ± 1.46	2.07 ± 1.23	0.001*
Kinesiophobia	28.45±3.61	28.30±4.15	0.905	29.65±3.61	15.75±2.29	0.001*	28.30±3.67	17.10±3.85	0.0001*
KLAT	9.45 ± 3.59	6.55 ± 10.32	0.273	9.40 ± 6.76	2.60 ± 4.00	0.001*	5.30 ± 8.15	1.300 ± 1.28	0.044*
BKFO	-10.50 ± 15.28	-± 14.85 20.00	0.273	-10.05 ± 8.53	-2.30 ± 4.47	0.001*	-13.30 ± 8.15	1.70 ± 1.78	0.184
ASLR	10.40 ± 9.16	10.55 ± 9.07	0.330	7.60 ± 8.58	2.35 ± 5.87	0.029*	7.90 ± 7.86	2.50 ± 1.41	0.015*
PRONE	9.45 ± 3.59	15.25 ± 5.72	0.128	15.85 ± 4.28	5.30 ± 4.60	0.001*	14.20 ± 6.12	6.90 ± 4.70	.0.001*
vGRF	109.96 ± 12.39	114.17 ± 18.04	0.108	102.20 ± 11.97	97.35 ± 14.34	0.05*	101.77 ± 13.48	88.52 ± 16.76	0.008*
ROL	3.61 ± 0.56	3.51 ± 1.17	1.0	3.38 ± 0.80	2.87 ± 0.32	0.013*	3.19 ± 0.59	2.79 ± 0.54	0.003*

Groups differed significantly [P < 0.05]. Closed Kinetic Chain Exercise [CKCE], Hydrotherapy Open Kinetic Chain Exercise [OKCE], Knee Lift Abdominal Test [KLAT], Bent-Knee Fall-Out [BKFO], Active Straight Leg Raise [ASLR], Prone Test [PT], Rate of Loading [ROL], and Vertical Ground Reaction Force [vGRF].

Table 5: Outcome measurements analyzed using ANCOVA.

Variable	F	DF	Men Squares	Sum of Squares	Power	Partial eta squared	P- value
PAIN	112.386	2	132.386	264.013	1	0.801	0.001*
kensiophobia	110.700	2	32.658	65.317	1	0.798	0.001*
vGRF	6.384	2	191775.101	383550.202	0.984	0.183	0.003*
ROL	4.80	2	11.169	22.338	0.886	0.144	0.012*
KLAT	6.158	2	346.278	692.556	0.874	0.207	0.004*
BKFO	3.198	2	151.224	302.448	1	0.102	0.048*
SLR	3.568	2	118.414	236.829	0.639	0.113	0.035*
PRONE	79.757	2	963.702	1927.404	1	0.740	0.001*

Groups differed significantly [P < 0.05]. Knee Lift Abdominal Test [KLAT], Bent-Knee Fall-Out [BKFO], Active Straight Leg Raise [ASLR], Prone Test [PT], Rate of Loading [ROL], and Vertical Ground Reaction Force [vGRF].

Discussion

This randomized controlled trial examined the effects of closed and open kinetic chain (CKC and OKC) hydrotherapy on various factors, including loading rate (ROL), vertical ground reaction force (vGRF), lumbo-pelvic stability (LPS), pain intensity, and kinesiophobia in men suffering from non-specific chronic low back pain (CNSLBP). Our findings revealed significant improvements in ROL and vGRF in the hydrotherapy groups compared to the control group, confirming our initial hypothesis.

The formula for ROL suggests that an increase in vGRF corresponds with a rise in ROL [28]. This relationship indicates a direct correlation between these two factors, emphasizing that as the ground reaction force increases, so does the rate at which the load is applied [29]. Previous research has demonstrated that individuals with low back pain (LBP) may experience motor dysfunctions elsewhere in their body during motor tasks [37]. Specifically, LBP can reduce muscle activity intensity in the lower extremities during walking and standing and decrease vGRF and ROL [38]. This observation underscores the potential movement pattern differences between individuals with LBP and those without, particularly in the lower extremities, which may increase the risk of lower extremity injuries [39].

Several studies have indicated that a lack of coordination in the lumbar region, especially during sudden movements, can result in musculoskeletal injury [22, 46]. Postural compensatory strategies may be employed to understand better spinal movement patterns and the connection between kinetic and kinematic changes in individuals with LBP [22]. It is plausible that individuals with LBP improve their movement control by walking more slowly and carefully to reduce the risk of misalignments or deviations [22]. Research into the standing posture of patients with CNSLBP has shown an increase in the activity of the vertebral column extensor muscles and a decrease in the reverse rotation between the pelvis, lower back, and thoracic spine [41]. Additionally, when asked to increase their walking speed, individuals with LBP tend to increase their stride rate rather than stride length, in contrast to those without pain [42].

The findings of this study align with previous research by Delitto et al. [43], Alaca et al. [44], Pires et al. [46], Roussel et al. [17], and Khojastehpour et al. [47], suggesting that maintaining a stable spine improves body mechanics, particularly for individuals with LBP, especially during standing. When the hip, knee, and ankle joints deviate from their normal positions, it can lead to uneven force distribution, affecting daily functioning. Weakness or improper muscle function can cause instability, resulting in excessive pressure on the joints and further irritation [37]. In individuals with CNSLBP, plantar pressure distribution is often higher in the forefoot than in the hindfoot [40]. Typically, patients with CNSLBP use ankle strategies for postural control, which increases the deflection of the center of pressure forward, further loading the forefoot [22].

In OKC hydrotherapy sessions, patients can freely move their hands and feet during water-based exercises, benefiting from the buoyant support of water. In contrast, CKC hydrotherapy involves exercises where the distal part of the limb is fixed, such as weight-bearing or standing exercises. Both forms of hydrotherapy are effective in reducing ROL and peak vGRF in individuals with chronic low back pain. OKC exercises help improve joint mobility and muscle strength, while CKC exercises enhance proprioception and stability. These hydrotherapy interventions can be tailored to individual needs and are often recommended as part of a comprehensive treatment plan for chronic back pain.

Significant differences in pain levels, kinesiophobia, and disability index scores were observed between the experimental and control groups. Patients with chronic low back pain (CLBP) who underwent exercise showed marked reductions in pain, fear of movement, and disability index scores, aligning with findings from studies by Monticone et al. [49], Tavakoli et al. [50], and Yalfani et al. [22]. These results corroborate previous research, which suggests that exercise positively influences pain, kinesiophobia, and disability reduction in individuals with CLBP [22, 44, 49, 50].

Studies have indicated that CLBP is often associated with abdominal muscle dysfunction, weakness, and alterations in walking mechanics [42]. For instance, Carayannopoulos et al. [51] reported that therapeutic exercises in water resulted in significant reductions in pain and disability, along with marked improvements in walking parameters. Hydrotherapy has proven to be an effective treatment for CLBP, alleviating muscle tension, reducing pain, and improving flexibility in the back [45]. The buoyancy of water plays a key role in decreasing pressure on the joints and spine, allowing patients to perform exercises that may otherwise be difficult or painful on land [46]. Many patients experience relief and enhanced mobility through regular hydrotherapy sessions [47].

Furthermore, Baena et al. concluded that the aquatic environment provides pain relief, increases blood flow, and blocks pain receptors while stimulating endorphin secretion. These mechanisms contribute to pain reduction in individuals with CLBP [48]. The severity of pain is a primary determinant of disability in CLBP patients, suggesting that reducing pain can concurrently lessen disability [45]. In this context, Cuesta-Vargas et al. [52] and Khojastepour et al. [47] demonstrated that practicing in a water environment led to significant pain reduction, which, in turn, decreased the severity of disability in individuals with CLBP [42, 47, 52].

The experimental groups (OKC and CKC) performing water exercises exhibited significantly different lumbo-pelvic stability (LPS) measurements compared to the control group ($p < 0.05$). Maintaining pelvic and lumbar stability is crucial for balancing forces in the vertebrae, pelvis, and motor chains, ultimately enabling proper limb movement [42]. Weakness or improper muscle function can lead to instability, placing excessive pressure on the joints and causing further irritation [42]. Proper control and absorption of these forces during physical activities are essential for preventing injuries [49].

A review of studies in this area confirmed the relationship between chronic low back pain (CLBP) and instability in the lumbo-pelvic region [50]. Maintaining stability in the lower back and pelvis during leg movements is vital to ensure proper coordination between muscle contractions. This coordination prevents the pelvis and trunk from rotating in undesired ways, which can otherwise disrupt movement and reduce stability [50]. Lack of coordination and stability can cause muscles to fail to generate sufficient force to prevent uncoordinated movements, leading to further instability [40].

The results of this study align with previous findings by Dehcheshmeh et al. [20], Asar et al. [18], Hodges et al. [19], and Roussel et al. [17], supporting the relationship between chronic low back pain and lumbo-pelvic instability. This understanding can be applied to therapeutic and rehabilitation management strategies in clinical practice for patients with chronic low back pain [51]. Hydrotherapy is an effective treatment for facilitating a safe return to full function in individuals suffering from chronic lower back pain [51].

The groups engaged in OKC and CKC water-based exercises demonstrated improved neuromuscular control of the lumbar and pelvic areas. This enhanced control helps distribute forces to the lower limbs, reducing pressure on both the lumbar region and lower limbs. Consequently, this results in lower vertical ground reaction force (vGRF) and reduced load levels during movement. Hydrotherapy, therefore, can be an effective treatment option for individuals with CLBP, as it promotes increased LPS and reduces load on the lower limbs and vertical reaction force. These exercises play a significant role in the recovery process for individuals with CLBP by potentially decreasing the reaction force and load during walking.

However, the study had several limitations that future research should address. First, it focused exclusively on men with central nervous system-related low back pain (CNSLBP), limiting its generalizability. Second, it primarily concentrated on the effects of OKCE and CKCE programs on vertical vGRF, ROL, and LPS in CNSLBP without considering other variables related to walking in this condition. Lastly, there was no long-term follow-up to assess the sustained impact of the hydrotherapy intervention.

Conclusion

The findings of our study indicate that hydrotherapy is an effective intervention for reducing pain and kinesiophobia in individuals with chronic low back pain (CLBP). Additionally, hydrotherapy was shown to enhance key factors such as loading rate (ROL), vertical ground reaction force (vGRF), and lumbo-pelvic stability (LPS). These results underscore hydrotherapy's beneficial impact on the physical health and functional recovery of individuals suffering from CLBP. Given its positive outcomes, hydrotherapy may be a valuable component of comprehensive rehabilitation plans for CLBP patients, supported by healthcare professionals, physiotherapists, and occupational therapists.

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References

1. Phattharasupharerk S, Purepong N, Eksakulkla S, Siriphorn A. Effects of Qigong practice in office workers with chronic non-specific low back pain: a randomized control trial. Journal of bodywork and movement therapies. 2019;23[2]:375-81.
2. Mousavi SJ, Akbari ME, Mehdian H, Mobini B, Montazeri A, Akbarnia B, et al. Low back pain in Iran: a growing need to adapt and implement evidence-based practice in developing countries. Spine. 2011;36(10):E638–46.
3. Yalfani A, Ahmadnezhad L, Gholami Borujeni B, Khoshnamvand Z. The effect of six weeks core stability exercise training on balance, pain and function in women with chronic low back pain. Journal of Health and Care. 2017;10;18[4]:336-46.
4. Alexander IJ, Chao EY, Johnson KA. The assessment of dynamic foot-to-ground contact forces and plantar pressure distribution: a review of the evolution of current techniques and clinical applications. Foot & ankle. 1990;
5. Baena-Beato PÁ, Artero EG, Arroyo-Morales M, Robles-Fuentes A, Gatto-Cardia MC, Delgado-Fernández M. Aquatic therapy improves pain, disability, quality of life, body composition and fitness in sedentary adults with chronic low back pain. A controlled clinical trial. Clinical Rehabilitation. 2014;
6. Kwon YJ, Park SJ, Jefferson J, Kim K. The effect of open and closed kinetic chain exercises on dynamic balance ability of normal healthy adults. Journal of physical therapy science. 2013 Jun 25;
7. Sciascia A, Cromwell R. Kinetic chain rehabilitation: a theoretical framework. Rehabilitation research and practice. 2012;2012.
8. Lephart SM, Henry TJ. The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. Journal of Sport Rehabilitation [Internet]. 1996;1;5[1]:71-87. Available from: https://journals.humankinetics.com/view/journals/jsr/5/1/article-p71.xml
9. Ghafouri M, Teymourzadeh A, Nakhostin-Ansari A, Sepanlou SG, Dalvand S, Moradpour F, et al. Prevalence and predictors of low back pain among the Iranian population: Results from the Persian cohort study. Annals of Medicine and Surgery. 2022;74(103243).
10. Dufek JS, Bates BT. Biomechanical factors associated with injury during landing in jump sports. Sports medicine. 1991;(v;12:326-37. DOI):10 2165 00007256-199112050–00005.
11. FATOLLAHİ A, BARGHAMADİ M, DARVİSHANİ MA. Effect of Hydrotherapy on Muscle Activities and Running Kinetics in Adult Males with Pronated Foot: A Randomized Clinical Trial. Pamukkale Journal of Sport Sciences. 2023 Dec;313(..\GRF).
12. Lee H, Hübscher M, Moseley GL, Kamper SJ, Traeger AC, Mansell G. How does pain lead to disability? A systematic review and meta-analysis of mediation studies in people with back and neck pain. Pain. 2015;156[6]:988-97.
13. Rum L, Brasiliano P, Vannozzi G, Laudani L, Macaluso A. Non-specific chronic low back pain elicits kinematic and neuromuscular changes in walking and gait termination. Gait & Posture. 2021;84:238–44.
14. Bento PC, Pereira G, Ugrinowitsch C, Rodacki AL. The effects of a water-based exercise program on strength and functionality of older adults. Journal of aging and physical activity. 2012 Oct;1;20[4]:469-70.
15. Christakou A, Boulnta F. The effectiveness of hydrotherapy in patients with chronic low back pain. Physiotherapy Quarterly [Internet]. 2020;1;28[3]:32-8. Available from: Rate\DOI\20.pdf
16. Hewett, T. E., et al. (2005). "Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study." The American journal of sports medicine 33(4): 492-501.

17. Roussel N, Nijs J, Truijen S, Vervecken L, Mottram S, Stassijns G. Altered breathing patterns during lumbopelvic motor control tests in chronic low back pain: a case–control study. European Spine Journal. 2009;18:1066–73.
18. Asar S, Gandomi F, Dehcheshmeh PF, Kermanshah I. Relationship between LumboPelvic Motor Control Deficiency and Non-Specific Chronic Low Back Pain: A Systematic Review. The Scientific Journal of Rehabilitation Medicine. 2019 Dec;15;8[4]:311-9.
19. Grosdent S, Demoulin C, Cruz C, Giop R, Tomasella M, Crielaard JM, et al. Lumbopelvic motor control and low back pain in elite socer players: a cross-sectional study. Journal of sports sciences. 2016;2;34[11]:1021-9.
20. Fadaei Dehcheshmeh, P., et al. (2021). "Effect of lumbopelvic control on landing mechanics and lower extremity muscles' activities in female professional athletes: implications for injury prevention." BMC Sports Science, Medicine and Rehabilitation **13**(1): 101.
21. Ariyoshi M, SONODA K, NAGATA K, MASHIMA T, ZENMYO M, PAKU C, et al. Efficacy of aquatic exercises for patients with low-back pain. The Kurume medical journal. 1999 Jun 14;
22. Yalfani A, Raeisi Z, Koumasian Z. Effects of eight-week water versus mat pilates on female patients with chronic nonspecific low back pain: double-blind randomized clinical trial. Journal of Bodywork and Movement Therapies. 2020;5(DOI).
23. Brody LT, Geigle PR, Geigle P, editors. Aquatic exercise for rehabilitation and training. Human Kinetics [Internet]. 2009; Available from: https://us.humankinetics.com/products/aquatic-exercise-for-rehabilitation-and-training
24. Gomes Neto, M., et al. (2020). "Effects of water-based exercise on functioning and quality of life in people with Parkinson's disease: a systematic review and meta-analysis." Clinical Rehabilitation **34**(12): 1425-1435.
25. Tagesson S, Öberg B, Good L, Kvist J. A comprehensive rehabilitation program with quadriceps strengthening in closed versus open kinetic chain exercise in patients with anterior cruciate ligament deficiency: a randomized clinical trial evaluating dynamic tibial translation and muscle function. The American journal of sports medicine. 2008;Feb;36[2]:298-307:17-.
26. Boutron I, Moher D, Altman DG, Schulz KF, Ravaud P, Group CONSORT. Extending the CONSORT statement to randomized trials of nonpharmacologic treatment: explanation and elaboration. Annals of internal medicine. 2008;19;148[4]:295-309. DOI:10 7326 0003-4819-148-4-200802190–00008.
27. Wong CK, Mak RY, Kwok TS, Tsang JS, Leung MY, Funabashi M, et al. Prevalence, incidence, and factors associated with non-specific chronic low back pain in community-dwelling older adults aged 60 years and older: a systematic review and meta-analysis. The journal of pain. 2022;1;23[4]:509-34.
28. Rustøen T, Wahl AK, Hanestad BR, Lerdal A, Paul S, Miaskowski C. Age and the experience of chronic pain: differences in health and quality of life among younger, middle-aged, and older adults. The Clinical journal of pain. 2005 Nov;1;21[6]:513-23.
29. Hüllemann, P., et al. (2018). "Clinical manifestation of acute, subacute, and chronic low back pain in different age groups: low back pain in 35,446 patients." Pain Practice **18**(8): 1011-1023.
30. Kim Y, Vakula MN, Waller B, Bressel E. A systematic review and meta-analysis comparing the effect of aquatic and land exercise on dynamic balance in older adults. BMC geriatrics. 2020;
31. Wearing SC, Urry S SR, J.E. Ground reaction forces at discrete sites of the foot derived from pressure plate measurements. Foot & Ankle International. 2001;
32. Zulkifli SS, Loh WP. A state-of-the-art review of foot pressure. Foot and Ankle Surgery. 2020 Jan;1;26[1]:25-32.
33. Kovács, I., et al. (1999). "Foot placement modifies kinematics and kinetics during drop jumping." Medicine and Science in Sports and Exercise 31(5): 708-716.
34. Bijur PE, Silver W, Gallagher EJ. Reliability of the visual analog scale for measurement of acute pain. Academic emergency medicine. 2001;
35. Jafari, H., et al. (2010). "Psychometric properties of Iranian version of Tampa Scale for Kinesiophobia in low back pain patients." Archives of Rehabilitation 11(1): 0-0.
36. Hosseinifar M, Akbari M, Akbari A, Ghiasi F. Comparison of Lumbo-Pelvic Stability between Patients with Chronic Low Back Pain and Healthy Subjects. International Journal of Medical Research & Health Sciences. 2016 Jan;1;5[10]:122-7.
37. Beyranvand R, Sahebozamani M, Daneshjoo A, Seyedjafari E. Assessment and comparison the effect of exercise in different depth of water on postural stability and balance recovery strategies of older people: a clinical trial.
38. Olkoski MM, Silva MF, Guenka LC, Pelegrinelli AR, LF DB, Dias JM, et al. Comparing the effects of aquatic exercises with or without high intensity on the functional status, muscular endurance, and performance of patients with chronic low back pain. The Journal of Sports Medicine and Physical Fitness. 2020 Dec;14;61[5]:699-706. DOI:10 23736 0022-4707 20 11265-9.
39. Dundar U, Solak O, Yigit I, Evcik D, Kavuncu V. Clinical effectiveness of aquatic exercise to treat chronic low back pain: a randomized controlled trial.
40. Richardson JT. Eta squared and partial eta squared as measures of effect size in educational research. Educational research review. 2011;Jan;1;6[2]:135-47.
41. Lamoth, C. J., et al. (2006). "Effects of chronic low back pain on trunk coordination and back muscle activity during walking: changes in motor control." European Spine Journal **15**: 23-40.
42. Heywood S, McClelland J, Mentiplay B, Geigle P, Rahmann A, Clark R. Effectiveness of aquatic exercise in improving lower limb strength in musculoskeletal conditions: a systematic review and meta-analysis. Archives of physical medicine and rehabilitation. 2017;
43. Delitto A, George SZ, Dillen L, Whitman JM, Sowa G, Shekelle P, et al. Low back pain: clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopaedic Section of the American Physical Therapy Association. Journal of orthopaedic & sports physical therapy [Internet]. 2012; Available from: https://www.jospt.org/doi/10.2519/jospt.2012.42.4.A
44. Alaca N, Kaba H, Atalay A. Associations between the severity of disability level and fear of movement and pain beliefs in patients with chronic low back pain. Journal of Back and Musculoskeletal Rehabilitation. 2020 Jan;1;33[5]:785-91. DOI:10 3233-171039.
45. Pires D, Cruz EB, Caeiro C. Aquatic exercise and pain neurophysiology education versus aquatic exercise alone for patients with chronic low back pain: a randomized controlled trial. Clinical rehabilitation. 2015 Jun 29;
46. Irandoust, K. and M. Taheri (2019). "The effect of aquatic training on kinematic walking patterns of elderly women." International Archives of Health Sciences **6**(1): 1-5.
47. Khojastehpour B, Atri AE, Javaheri SA. Comparison the effect of core stabilization training in water and on land on pain and dynamic postural stability in women with chronic non-specific low back pain. J Anesth Pain. 2019;10[2]:75-90.
48. Borujeni BG, Yalfani A. Reduction of postural sway in athletes with chronic low back pain through eight weeks of inspiratory muscle training: a randomized controlled trial. Clinical Biomechanics. 2019;69(215–20):10 1016 2019 09 006.

49. Monticone M, Ferrante S, Rocca B, Baiardi P, Dal Farra F, Foti C. Effect of a long-lasting multidisciplinary program on disability and fear-avoidance behaviors in patients with chronic low back pain: results of a randomized controlled trial. The Clinical journal of pain. 2013;(v 1;29[11]:929-38).
50. Tavakoli MN, Mirghaemi TS. The Effectiveness of Cognitive-Behavioral Group Therapy Anger and Assertiveness of Adolescents. International Journal of Education and Applied Sciences [Internet]. 2023 Jan;1;3[4]:20-8. Available from: Rate\DOI\47.pdf
51. Carayannopoulos AG, Han A, Burdenko IN. The benefits of combining water and land-based therapy. Journal of exercise rehabilitation. 2020;Feb;16[1]:20.
52. Cuesta-Vargas AI, Adams N, Salazar JA, Belles A, Hazañas S, Arroyo-Morales M. Deep water running and general practice in primary care for non-specific low back pain versus general practice alone: randomized controlled trial. Clinical rheumatology. 2012;31:1073–8.
53. Baena-Beato PÁ, Artero EG, Arroyo-Morales M, Robles-Fuentes A, Gatto-Cardia MC, Delgado-Fernández M. Aquatic therapy improves pain, disability, quality of life, body composition and fitness in sedentary adults with chronic low back pain. A controlled clinical trial. Clinical Rehabilitation. 2014;
54. Rahimi A, Arab AM, Nourbakhsh MR, Hosseini SM, Forghany S. Lower limb kinematics in individuals with chronic low back pain during walking. Journal of Electromyography and Kinesiology. 2020;51(102404).
55. Solana-Tramunt M, Ortegón A, Morales J, Nieto A, Nishishinya MB, Villafañe JH. Diagnostic accuracy of lumbopelvic motor control tests using pressure biofeedback unit in professional swimmers: A cross-sectional study. Journal of orthopaedics. 2019 Nov;1;16[6]:590-5.
56. Becker BE. Aquatic therapy: scientific foundations and clinical rehabilitation applications. Pm&r. 2009 Sep;1;1[9]:859-72.
57. Wu CY, Yang CL, Chuang LL, Lin KC, Chen HC, Chen MD, et al. Effect of therapist-based versus robot-assisted bilateral arm training on motor control, functional performance, and quality of life after chronic stroke: a clinical trial. Physical Therapy. 2012 Jul;1;92[8]:1006-16.