SPORTLOGIA
Scientific-Expert Journal of Anthropological Aspects of Sports, Physical Education and Recreation

Submitted: 09/09/2025
Accepted: 10/10/2025
Online first: 06/11/2025
UDK: to be registered

Original article

Effects of Aquatic therapy in the rehabilitation of spinal cord injury: A systematic review

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Abstract

Spinal cord injury (SCI) is a complex neurological condition that results in persistent physical, neurological, and physiological impairments, with secondary complications, particularly respiratory and cardiovascular, significantly contributing to morbidity and mortality. Integrated rehabilitation enables simultaneous improvements across multiple functional domains. Aquatic therapy, utilizing buoyancy, viscosity, and hydrostatic pressure, provides a unique environment to enhance motor, sensorimotor, and cardiorespiratory functions. This systematic review was conducted according to guidelines for transparent reporting of systematic reviews and meta-analyses (PRISMA). Included studies comprised randomized and non-randomized controlled trials, quasi-experimental studies, and case-control studies, involving over 300 adult participants of both sexes with complete or incomplete traumatic or non-traumatic SCI at all lesion levels according to the ASIA classification. Only studies with clearly defined primary outcomes of aquatic therapy were included, without restriction by publication date. Outcomes were analyzed using the International Classification of Functioning, Disability, and Health framework. Only primary outcomes were included in the meta-analysis, while other outcomes were presented narratively. Results demonstrated improvements in muscle strength, balance, and cardiorespiratory function, as well as enhancements in coordination, endurance, and quality of life. Aquatic therapy shows potential as an effective complementary rehabilitation method for adults with SCI, supporting the standardization of clinical practice and informing future evidence-based research.

Keywords: aquatic exercise, aquatics, aquatic therapy, aquatic physiotherapy, hydrotherapy

Citation: Omodoyinsola, A., Milić, O., Vukićević, V., Kukić, O. (2025). Effects of Aquatic therapy in the rehabilitation of spinal cord injury: A systematic review. *SportLogia 21(*2), 24-41
https://doi.org/10.63356/spl.2025.010

Introduction

Spinal cord injury (SCI) has an estimated global incidence of about 10.4 and 83 million inhabitants per year (Wyndaele & Wyndaele, 2006). Clinically, damage to the spinal cord may be complete or incomplete depending on the extent of damage to the cord. A complete injury generally means that both motor and sensory functions are completely lost at the lowest sacral segments, while incomplete spinal cord injury means a partial preservation of sensory or motor functions below the neurological level of injury, including the lowest sacral segments (Kirshblum et al., 2011). In clinical practice, completeness of injury is defined according to the American Spinal Injury Association (ASIA) rehabilitation and treatment guides, which is based on a classification ranging from A to D. A refers to complete injury with no motor or sensory skills preserved; B is an incomplete injury where sensory but not motor functions are preserved; C is an incomplete injury where motor functions are preserved below the neurological level and more than half of key muscles below the neurological level have a muscle power grade less than 3; D is an incomplete injury where motor function is preserved below the neurological level and at least half of key muscles below the neurological level have a muscle power grade of 3 or more; and E refers to normal preservation of motor and sensory functions (Kirshblum et al., 2011).

The resulting disability is defined as paraplegia or tetraplegia, referring to the number of limbs involved. Tetraplegia refers to damage at the cervical segment of the cord, resulting in an impairment in the function of the arms, trunk, legs, and pelvic organs, whereas paraplegia refers to damage in the thoracic, lumbar, or sacral segments of the cord, resulting in an impairment of the lower limbs while the upper limb is spared; trunk and pelvic organs may or may not be involved depending on the level of injury (Jacobs & Nash, 2004). Following a spinal cord injury, several health complications develop, beginning from the acute to the chronic phase of injury. Individuals experience complications and impairment in their physical, neuro-muscular, musculoskeletal, cardiovascular, respiratory, physiological functions, and other co-morbidities, which increase morbidity, mortality, and decrease quality of life (Jacobs & Nash, 2004; McKinley et al., 1999; McKinley et al., 2002). Pulmonary and cardiovascular complications are cited as a major cause of death in chronic SCI (Jacobs & Nash, 2004; McKinley et al., 2002; West et al., 2013) and have become a main focus during rehabilitation.

Management of resulting impairments is based on the clinical presentation of each individual (Gittler, 2003). These typically include improvement of spasticity, cardiovascular function, respiratory function, gait, muscle weakness, joint range of motion, impaired coordination, postural problems, and sensory dysfunction (Nas et al., 2015). Rehabilitation of specific goals are often separated and worked on one at a time. In a systematic review on non-pharmacological and pharmacological interventions for spasticity management, a non-pharmacological approach (TENS) was supported by Level 1 evidence and hydrotherapy by Level 2 evidence (Hsieh et al., 2007). Two reviews of strategies for gait rehabilitation indicated that approaches promoting repeated practice offer the highest benefit, including over-ground training and bodyweight-supported treadmill training, Locomat, and functional electrical stimulation (Lam et al., 2007; Wessels et al., 2010). Improvement in cardiovascular health through resistance training and arm ergometry has been shown to decrease the risk for cardiovascular disease in SCI (Warburton et al., 2007), whereas respiratory goals in the acute phase are achieved by mechanical ventilation with the aim to optimize respiratory status (Wong et al., 2012), and in the chronic phase, respiratory strengthening is recommended for optimization (Mueller et al., 2012). A systematic review showed respiratory training may improve respiratory function in SCI (Van Houtte et al., 2006).

As is evident, individual goals are often separated and require specific interventions, locations, and clinicians to be achieved. Therefore, an approach that offers an environment where treatment goals can be achieved simultaneously may be of benefit to optimize the duration of SCI rehabilitation. Aquatic therapy also offers such an environment by using warm water for healing and rehabilitation purposes (Hall et al., 2008), utilizing the physical properties of water (buoyancy, density, hydrostatic pressure, thermodynamics, and viscosity) to effect performance, responses, as well as changes in body structure and function (Becker, 2009). A systematic review on the effects of aquatic therapy in 2008 showed its effectiveness in several domains such as muscle strengthening, balance, gait, and cardiovascular and respiratory functions across a wide range of conditions, including stroke, rheumatoid arthritis, spinal cord injury, and many more (Geytenbeek, 2002). In recent years, aquatic therapy has become more popular, and more evidence has surfaced. Hence, the aim of this review is to quantify the evidence on aquatic therapy in the rehabilitation of SCI in adults, and categorize outcomes where its effects are demonstrated or yet to be demonstrated within the domains of the International Classification of Functioning, Disability and Health (ICF) for individuals with SCI, through a systematic review and meta-analysis in an attempt to guide clinical practice, future research, and health care policy.

The aim of this research is to systematically evaluate and quantify the existing scientific evidence on the effectiveness of aquatic therapy in the rehabilitation of adults with spinal cord injury (SCI). The research aims to identify, analyze and categorize the outcomes of the application of aquatic therapy according to the framework of the ICF, with special reference to its effects on muscle strength, balance, and cardiorespiratory functions. In addition, the aim is to use the obtained findings to formulate recommendations for clinical practice, future research and health policy, considering that until now no systematic review of the literature focusing exclusively on the application of aquatic therapy in people with SCI has been conducted.

Methods

Protocol and Registration

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to report this systematic review in a transparent and clear manner. PRISMA is a statement of evidence-based minimum collection of 27 items developed for reporting systematic reviews and meta-analyses (Moher et al., 2010).

Eligibility Criteria

The following eligibility criteria were used:

Study Characteristics: Randomized controlled trials (RCTs), controlled trials without randomization, case-control studies, and quasi-experimental studies. Only studies with participants from an adult population (18 years and above), male and/or female, were included. This allows for generalizability of the results of this review to the injury-prone demographic as described by the World Health Organization (2013): males (20-70 years), females (15-60). Complete or incomplete injuries of traumatic or non-traumatic etiology were included. SCI of all lesion levels classified according to the ASIA classification (A to D), regardless of the duration of the trauma, were included (American Spinal Injury Association, 2015). Studies with clearly defined primary outcomes for aquatic therapy interventions were included. Being the first review of SCI and aquatic therapy, inclusion of studies irrespective of their publication date was done to have a broader selection of studies and to document historically the empirical evidence for the effectiveness of aquatic therapy in SCI, as in previous studies (Lam et al., 2007; Tamburella et al., 2013). All studies considered eligible were those reported in English Language.

Intervention Protocol: Exclusively, only studies with a clearly defined protocol of aquatic therapy were deemed eligible to be included – partial or complete immersion in water, single or group activities, swimming, and all methods of aquatic therapy. Intervention protocols that combined land and aquatic therapy without control or underwater treadmill and body weight support techniques were not considered eligible for this review.

Report Characteristics: Studies were considered eligible if the intervention reported was clearly described by its total length, duration of each session, and type of activity performed.

Information Sources

Information sources used for the search include databases and a manual hand search of references in selected articles and relevant journals. An electronic search of publications was done by two independent researchers, also referred to in this study as reviewers (A and B), using the following databases: EMBASE, CINAHL, Cochrane, SPORTDiscus, Web of Science, and PubMed from inception to the last day of the search. The aim of the search was to find as many potentially relevant works as possible. The electronic search took place on January 8, 2015. The search strategy contained concepts directly related to aquatic therapy and SCI using the following keywords: "aquatic exercise," "aquatics," "aquatic therapy," "aquatic physiotherapy," "hydrotherapy," "underwater exercise," and "spinal cord injury." Keywords were combined to foster maximal retrieval of literature. The search was not limited to publications in English language nor to any publication date. Below is an example of the search strategy used in one of the databases:

EMBASE: "aquatic exercise" or "aquatics" or "aquatic therapy" or "aquatic physiotherapy" or "hydrotherapy" or "underwater exercise" AND "spinal cord injury." The same input was made in the same order by two researchers in each database.

Study Selection

Titles retrieved from the search of the database were compiled and duplicates eliminated by reviewer A. Titles and abstracts of the residual studies were then read and assessed by reviewer B for relevance. Titles and abstracts were considered relevant if any of the concepts of aquatic therapy, hydrotherapy, aquatics, underwater exercise, water, aquatic physiotherapy, aquatic exercise, immersion, and spinal cord injury, cervical injury, thoracic injury, lumbar injury, neurologic disease, neurologic injury, were addressed, and irrelevant titles and abstracts were eliminated. The resulting studies were then examined by reviewer B for confirmation. Full texts of the articles were then obtained, and two reviewers proceeded to independently evaluate if the eligibility criteria described previously were met. A manual search of the reference list of selected articles, relevant peer-review journals, and conference proceedings was done by reviewer B to identify potential studies that fit the eligibility criteria. Additional studies were identified and screened similarly to the electronically retrieved articles. Any disagreement on selection was resolved by discussion between both reviewers.

Statistical analyses

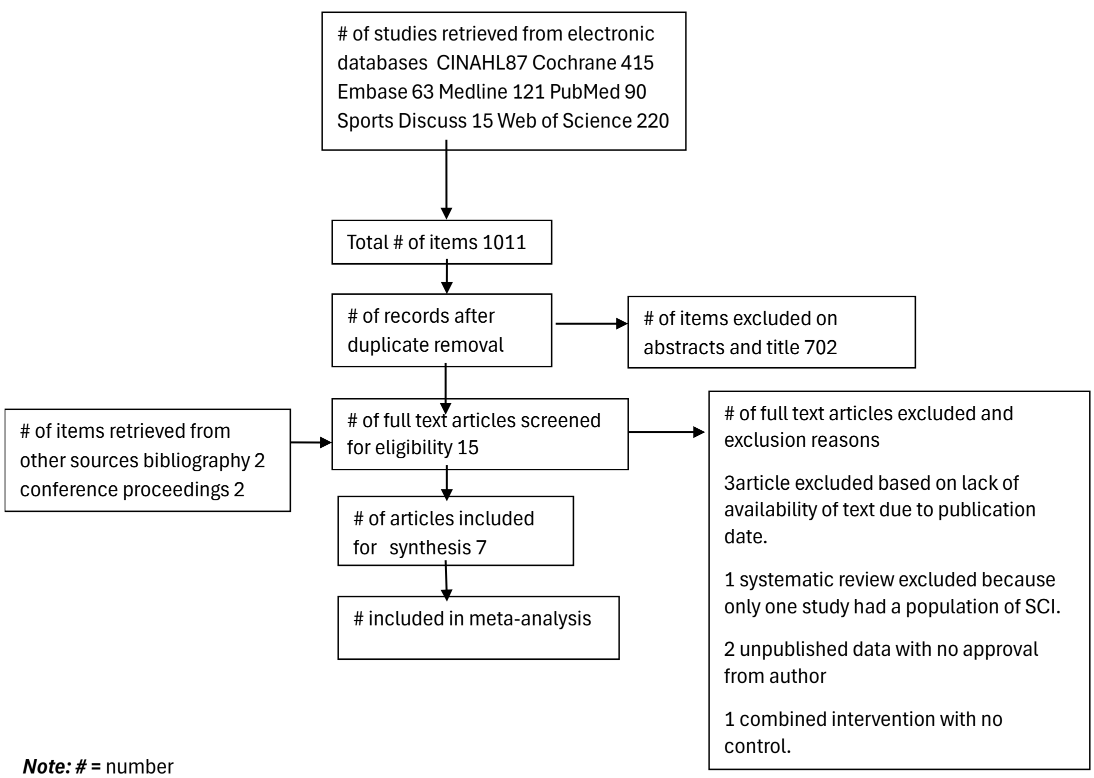
A data extraction sheet developed by reviewer A, based on the template of the Cochrane Consumers and Communication Review Group data extraction template (Moher et al., 2009), was used. The extraction sheet was pilot-tested independently by both reviewers on 3 randomly selected studies; any disagreement was resolved by a discussion between both parties, and the sheet modified accordingly. Reviewer A independently extracted data from the articles included in the review. No authors were contacted for additional raw data of their study. Variables for which data were sought were: (1) characteristics of the participants (age, sex, height, weight, ASIA classification, level of paralysis, and onset) (2) inclusion and exclusion criteria of individual studies (Table 1), (3) type of aquatic therapy (type, water temperature, intensity and frequency, administrator and comparator) (4) outcomes (mobility, cardiovascular, respiratory, hematological, participation, self-efficacy) (Table 2).

Assessment for Bias in Individual Studies

The Scottish Intercollegiate Guidelines Network (SIGN) checklist was used to assess risk of bias (network Sig., 2001). Any bias, if encountered, is reported descriptively (Table 3).

Summary Measures
The means as reported in each study are used to assess and describe the summary effect measure for each outcome. Standardized differences in means and confidence interval were calculated from reported means.
Synthesis of Results
The ICF framework was used to guide the syntheses of the various outcomes assessed across studies for a standard description of health-related states and outcomes (World Health Organisation, 2001). Due to the large variation in study designs, interventions, and reported outcome measures, not all outcomes were included in the meta-analysis. Primary outcomes (Thomaz et al., 2005; Leal et al., 2010; Jung et al., 2014; Kesiktas et al., 2004; Silva et al., 2005) were reported in a meta-analysis (Fig 2, Fig 3) to estimate overall effect size of the intervention in studies with identical outcome measures. Effect size is calculated using standardized difference in means. All statistical analysis was conducted using Comprehensive Meta-Analysis software (meta-analysis C., 2015). Other outcomes are reported in a narrative manner (Tamburella et al., 2013; Bosch & Wells, 1991), similar to the approach in previous reviews (West et al., 2013). Risk of bias across studies was assessed by testing for heterogeneity.

Results
The PRISMA flow diagram illustrates the process of literature search and study selection. A total of 1,011 records were identified through searches of relevant electronic databases, along with four additional records retrieved from other sources. After removing duplicates and screening titles and abstracts, 15 studies were assessed in full text, of which seven met the inclusion criteria for the synthesis. The remaining studies were excluded due to unavailability of full text, inadequate population, unpublished data, or lack of a control group. Part of the included studies was incorporated into the meta-analysis.



Note: # = number

Figure 1. PRISMA Flow Diagram of Study Selection for Aquatic Therapy in Spinal Cord Injury Rehabilitation.

Table 1. Study characteristics.

Study	Outcome investigated	Purpose	No	Mean age	Gender	Asia impairment / Level of injury	Post injury months	Exclusion criteria	Mean height(cm)/weight(Kg)
Bosch et al 1991	Pulmonary function	Effect of immersion on residual volume of SCI and able-bodied	24	28.5	M	C4-C7, T3-T12	>6	medically unstable, onset <6months	67.7kg
Kesiktas et al. 2004	Mobility function	Effect of hydrotherapy on spasticity in SCI	20	32.13	M,F	A-D	8.6	Outpatient of rehab facility, no spasticity	-
Thomaz et al 2005	Pulmonary function	Effect of immersion on spirometry parameters of SCI and able bodied	23	27 median	M	A or B C4-C8	9	Prior tracheostomy, active pulmonary complications, clinical instability	-
DaSilva et al. 2005	Mobility, Selfcare	Effect of swimming on functional independence of SCI	16	25.75	M, F	A C5 L3	14-40	Contra indication to swimming, post injury >4yrs, ASIA >A, participation in rehab program <4weeks	-
Leal et al 2009	Pulmonary function, Hematologic function	Effect of graded immersion on VC in SCI	23	30.4	M	A or B / C4-C7	2-15	Clinical instability, history of tracheostomy, active respiratory disorder, conditions that prevent form partaking in water activities (skin infection and incontinence)	-
Tamburella et al 2013	Mobility	Walking in water VS Walking on land after SCI	30	43.5	M,F	D C4-T12		Cardiac or respiratory failure infective skin, excessively low, high or uncontrolled blood pressure, urinary tract infection, incontinence, morbid hydrophobia.	173.93cm 66.6Kg
Jung et al. 2014	Pulmonary function	Effect of aquatic exercise on pulmonary function in SCI	20	47.1	M,F	B-D	4-12	ASIA A, injury level <C8 >L5, outpatient of the rehab facility.	170cm/ 64Kg

Note*:* no= Number, M =Male, F =Female, cm =Centimeters, Kg= Kilograms

A total of 121 SCI individuals were investigated across all studies with no dropouts reported. Studies investigating pulmonary functions recruited 52 SCI participants in total. Two studies investigated only males (Thomaz et al., 2005; Leal et al., 2010), two investigated both males and females with mean age ranging from 27 to 51 years (Bosch & Wells, 1991; Jung et al., 2014). Severity of injury ranged from ASIA A-B in two studies (Thomaz et al., 2005; Leal et al., 2010), unspecified in one (Bosch & Wells, 1991), and ASIA A-D in one (Jung et al., 2014). Injury level ranged from C4-T12 across all four studies, with post-injury duration between 2 to 89 months. Two studies reported height and weight (Jung et al., 2014; Bosch & Wells, 1991), one reported weight only (Leal et al., 2010), and one reported neither (Thomaz et al., 2005). Exclusion criteria were not described in one study (Jung et al., 2014), while inclusion criteria were described in all four studies.

In the analyzed studies, aquatic interventions, including immersion (Bosch et al., 1990; Thomaz et al., 2005; Leal et al., 2009), swimming (DaSilva et al., 2009), water walking (Tamburella et al., 2013), and structured aquatic exercises (Jung et al., 2014), were conducted in water temperatures of 33–35°C. Session duration ranged from 5 to 60 minutes, with a frequency of 2–3 times per week over periods of 8 weeks to 4 months. Most interventions required assistance or the use of aids (e.g., wheelchairs, flotation devices, parallel bars, mechanical lifts), whereas activities in the control groups were performed on land (Kesiktas et al., 2004; DaSilva et al., 2009; Jung et al., 2014). A detailed overview of the interventions, including protocols, temperature, duration, frequency, administrators, and aids, is presented in Table 2**.** These protocols demonstrate that aquatic activities can be successfully adapted to meet different functional and respiratory needs of participants.

Table 2. Summary of interventions in individual studies.

Study	Intervention	Protocol	Temp(°C)	Intensity	Frequency	Administrator	Aids
Bosch et al. 1990	Immersion EG and CG	Spirometry measurement of residual volume in water in an upright seated position in an underwater weight tank. Spirometry measurement of residual volume on land in a seated position leaning forward from the waist, hydrostatic weighing, dry weight measurement first on land followed by underwater weighing in the tank in a seated position.	34	5 trials	-	Author	Wheelchair for transfers.
Thomaz et al 2005	Immersion	Immersion to shoulder level in an upright seated position, followed by spirometry in the water	33.5- 34.5	5-15mins	shoulder	Author	-
Kesiktas et al. 2004	(EG) CG	Underwater exercise, oral baclofen, PROM on land and psychotherapy Oral baclofen, PROM on land and psychotherapy	21	20mins 3Xweekly X10weeks	1.7m	-	Flotation devices, paddles, parallel bars, weighted stools or chairs
DaSilva et al. 2009	Swimming (EG) (CG)	Warm up: muscular stretching, transference training from wheelchair to the ground to swimming pool tested using different techniques. Main part: exercises aimed at independence change on the balance point and movement referential, crawl back and breast stroke exercises. Cool down: relaxation, fluctuation and respiration, techniques to exit the pool and transference from ground to wheelchair were trained. Locomotion training in wheelchair or gait training and sportive physical activities on land	-	2Xweekly 45mins 4months	-	prof. physical education	-

Leal et al 2009	Immersion EG (a) CG(a) EG (b) CG (b)	Spirometry performance at pool side followed by spirometry during graded immersion in an upright seated position in the pool to the pelvis, xiphoid and neck Spirometry on land with pressure cuffs around legs and groin deflated on land, then inflated to one-half of the pulse pressure followed by a repeat during graded immersion in water.	33.5- 34.5	5mins at each depth of immersion	pelvis, xiphoid and neck	Author	Mechanical crane
Tamburella et al 2013	Walking in water EG CG	Land walking at self- selected speed in a walkway. Walking at self- selected speed in the water with both arms placed above the surface of the water	35		xiphoid	-	-
Jung et al. 2014	Aquatic exercise (EG) CG	Warm up: ROM and breathing exercise, upper extremity exercises for function and weight bearing to left and right with arms at 90° in sitting, forward and backward movements in sitting position, with clasped hands, moving a heavy sensory ball forward, backward, side. Cool down: ROM, flexibility and breathing Same activities and protocol on land.	-	10min each phase, total 60min 3Xweekly for 8 weeks	-	-	-

Note: EG= experimental group, CG = control group

In a meta-analysis, the effects of aquatic therapy on respiratory functions in adults with spinal cord injury (SCI) were evaluated, through the four most frequently investigated parameters: forced vital capacity (FVC), vital capacity (VC), expiratory reserve volume (ERV) and inspiratory capacity (IC). Analysis of the combined results of two studies examining FVC (Thomaz et al., 2005; Jung et al., 2014) showed a statistically significant advantage of aquatic therapy compared to control interventions ($Z = 4.255$, $p < 0.001$), with complete homogeneity of results ($I^2 = 0\%$). A similar trend was observed in VC, where the results of two studies (Thomaz et al., 2005; Leal et al., 2010) indicated a significant increase in vital capacity after the application of aquatic therapy ($Z = 4.004$, $p < 0.001$, $I^2 = 0\%$).For ERV (Leal et al., 2010; Thomaz et al., 2005) a positive effect in favor of aquatic therapy was also recorded ($Z = 2.831$, $p = 0.005$), with moderate heterogeneity ($I^2 = 34.83\%$). In contrast, the results for IC (Leal et al., 2010; Thomaz et al., 2005) showed no statistically significant difference between the aquatic and control groups ($Z = 0.760$, $p = 0.447$, $I^2 = 0\%$). Overall, these findings indicate that aquatic therapy has a significant positive effect on key parameters of respiratory function (FVC, VC and ERV), while the effects on inspiratory capacity remain insufficiently confirmed. The low value of heterogeneity in most analyzes testifies to the consistency of findings among studies and confirms the potential of aquatic therapy as an effective rehabilitation intervention in the population of persons with spinal cord injury.

The methodological quality of the included randomized and controlled trials (RCTs and CCTs) was assessed using the SIGN checklist (Table 3). All studies clearly stated their research objectives and included groups that were comparable in baseline characteristics. Standardized and reliable methods were employed to measure outcomes. Only one study implemented randomization, and procedures for allocation concealment and investigator blinding were often not reported, which could increase the risk of bias. The dropout rate was low (0%), and where feasible, analyses were conducted on an intention-to-treat basis. Based on the SIGN criteria, all studies were considered to have a minimal risk of bias (+) (Kesiktas et al., 2004; Jung et al., 2014; DaSilva et al., 2009).

Table 3. Risk of assessment in individual studies: SIGN scoring system (RCTs and CCTs).

Risk	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2.1
Studies	**clear focused question**	**randomization**	**concealment**	**treatment blinding**	**Baseline groups similarity**	**Groups only differ in treatment under investigation**	**Standard and reliable outcome measures**	**Drop out (%)**	**Intention to treat analysis**	**Results comparable for all sites**	**Quality assessment based on bias minimality**
Kesiktas et al. 2004	yes	no	no	no	yes	yes	yes	0%	yes	N/A	+
Jung et al. 2014	yes	yes	can't say	can't say	yes	yes	yes	0%	yes	N/A	+
DaSilva et al. 2009	yes	no	no	no	yes	yes	yes	0%	yes	N/A	+

Risk of bias in individual studies was assessed using the SIGN system for RCTs and CCTs (Table 4). All studies had a clearly focused research question and comparable populations, with mostly consistent exclusion criteria. Participation rates ranged from 32% to 52%, and participants were generally compared with non-participants to reduce bias. Case-control differentiation was clear, and controls were confirmed as non-cases in most studies. Exposure measurement was generally valid and reliable. All studies were rated as having minimal risk of bias (+).

Table 4. Risk of assessment in individual studies: SIGN scoring system (RCTs and CCTs).

Risk	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	2.1
Studies	**Clear focused question**	**Comparable populations**	**Same exclusion criteria**	**Percentage participation (case and control respectively)**	**Participants and non-participants compared**	**Clearly defined differentiation of cases from controls**	**Controls are non-cases established**	**Case ascertainment bias prevented**	**Standard, valid, reliable measurement of**	**Potential confounders addressed**	**Set confidence intervals**	**Quality assessment based on bias minimality**
Bosch et al. 1991	yes	Yes	yes	50% 50%	yes	yes	yes	can't say	yes	yes	no	+
Thomaz et al. 2005	yes	No	yes	68% 32%	yes	yes	yes	no	yes	yes	yes	+
Leal et at. 2009	yes	Yes	yes	48% 52%	yes	Yes	yes	can't say	yes	yes	no	+
Tamburella et al. 2013	yes	Yes	yes	50% 50%	yes	yes	yes	Yes	yes	yes	no	**+**

Figure 2. presents the results of a meta-analysis showing standardized mean differences in lung function measures (FVC, VC, ERV, IC) across multiple studies, including confidence intervals and the weight of each study. It visually assesses whether the effects favor the control or aquatic intervention groups, along with the statistical significance and heterogeneity of the data.

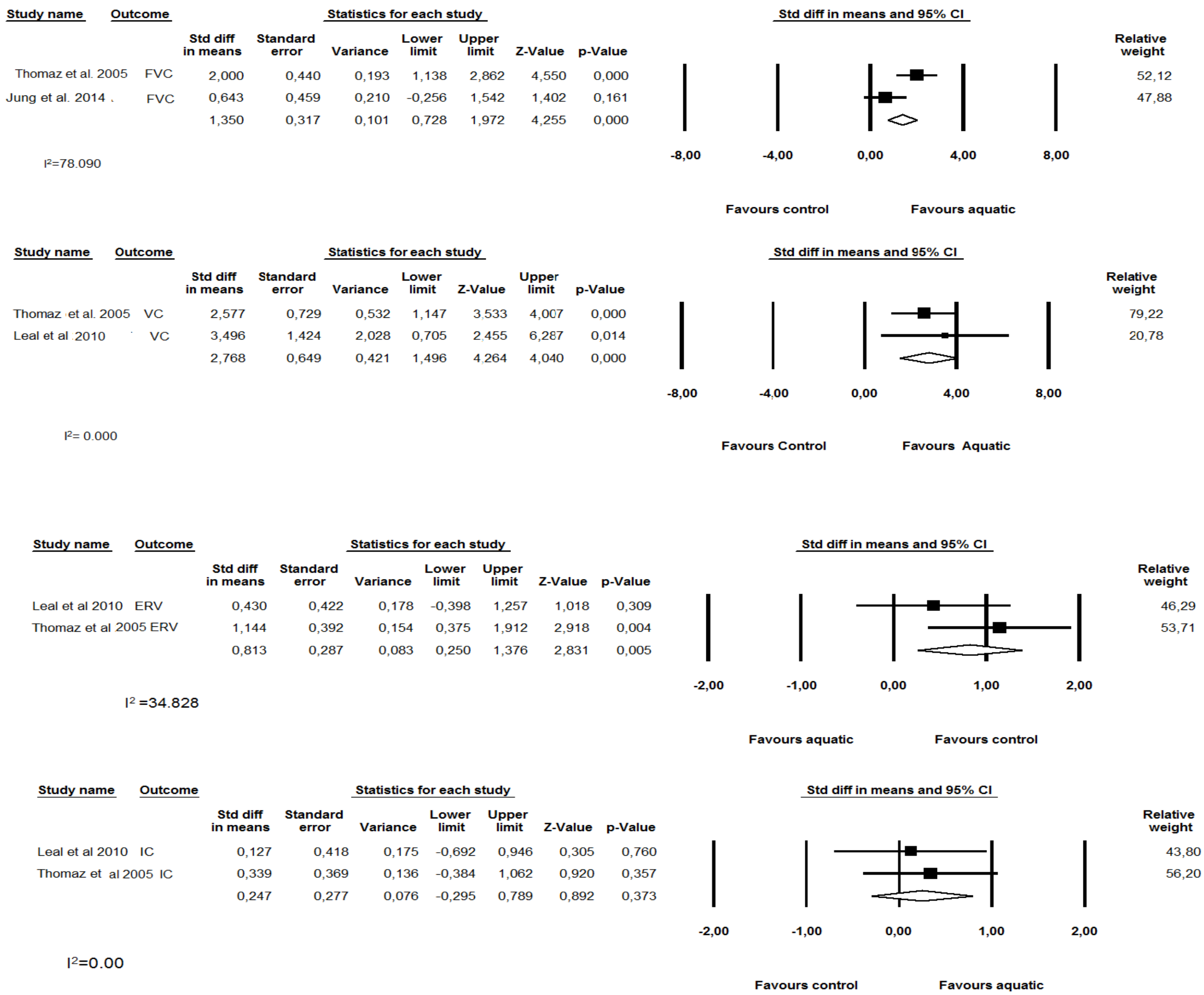


Figure 2. Meta-analysis showing summary of effect of aquatic therapy on respiratory functions in forest plot. **Note:** Standardized difference in means plot for effect, diamond =overall effect size of studies combined, squares = study effect size, size of box represents weight of study, horizontal lines represent CI=confidence Interval. Heterogenty= I^2

Figure 3 shows the overall effect of hydrotherapy on functional mobility, where squares represent individual studies, diamonds the combined effect of all studies. $Y^2 = 0$ and p = 1.000 indicate that there is no heterogeneity among studies, i.e. the results are consistent.

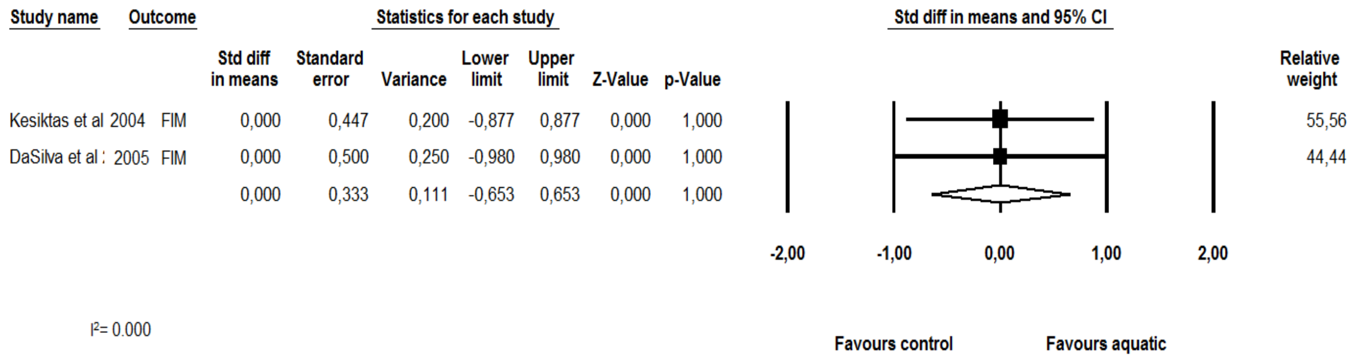


Figure 3. Meta-analysis showing summary of overall result for the effect of aquatic therapy on functional mobility in forest plot. **Note:** Standardized difference in means plot for effect, diamond =overall effect size of studies combined, squares = study effect size, size of box represents weight of study, horizontal lines represent Confidence interval = CI. Heterogenty I^2= 0 , p= 1.000.

Table 5 summarizes the effects of various interventions across several studies. Bosch et al. (1990) reported reductions in body density measures (RVW, QUAD) in the experimental group (*P<0.001*). Kesiktas et al. (2004) observed significant decreases in spasm severity and improvements in FIM scores with oral baclofen treatment (*p<0.05–0.0001*). Thomaz et al. (2005) found notable improvements in pulmonary function (FVC, FEV1, %FVC, %VC, %IC, %ERV) in the experimental group. DaSilva et al. (2009) reported significant enhancements in FIM sub-scores, including self-care, transference, communication, and social integration (*p<0.05*). Leal et al. (2010) demonstrated improvements in lung volumes, inspiratory and expiratory capacities, and hematocrit levels (p<0.008–0.017). Tamburella et al. (2013) observed significant gains in gait parameters (speed, stride length, stance phase, gait cycle time) (*p<0.05–0.005*). Jung et al. (2014) reported significant improvements in FVC, FER, FEV1, and FEV1/FVC ratios (**p<0.001–0.01*). Overall, the table highlights that the experimental interventions led to statistically significant improvements in functional, motor, and respiratory outcomes compared to control groups.

Table 5. Summary measures of individual studies.

Study	Primary outcome measure(s)	EG intervention values (SD)		CG intervention values (SD)		p
		Pre	Post	pre	Post	
Bosch et al. 1990	RVW (L)	PARA 1.50(0.42)	1.24(0.19)	1.44(0.46)	1.40(0.41)	*P<0.001
		QUAD 2.43(0.34)	1.44(0.19)			
	Body density	PARA 1.049	1.043			
		QUAD 1.050	1.033	1.062	1.062	
Kesiktas et al. 2004	Ashworth	4.1	1.7	3.9	2.1	
	spasm severity	2.4	0.7**	2.3	1.4*	*p<0.05
	FIM score	52	94**	54.7	69.1*	**p<0.0001
	oral baclofen (mg)	100	45	96	96	

Thomaz et al. 2005	FVC (L)	2.9(14.6)	3.3(0.7)**	5.2(0.7)	4.7(0.7)**	
	FEV1(L)	2.6(0.7)	2.9(-0.6)*	4.5(0.7)	4.0(0.7)**	**p<0.001
	△ %FVC		18.8(18.4)**		-8.8(4.4)	*p<0.05
	△%VC		24.7(28.1)		-3.9(5.6)**	
	△ %IC		40.7(48.6) **		26.7(15.7)**	
	△% ERV		-6.4(58.4)		-62.7(15.9)**	
DaSilva et al. 2009	FIM total score	102.0	109.7*	100.4	103.1*	*p<0.05
	BODY CARE	34.7	38.0*	34.6	36.1*	
	to eat	6.7	6.7	6.6	6.4	
	to get ready	6.2	6.6	6.4	6.4	
	to shower	5.7	6.5*	5.1	5.7	
	to dress upper body	6.2	6.4*	6.4	6.4	
	to dress lower body	5.0	6.2*	5.1	5.5	
	to use bathroom	4.7	5.5	5.0	5.5*	
	TRANSFERENCE	14.9	19.2*	14.0	15.6*	
	bed, chair, wheelchair	5.1	6.4*	4.7	5.4	
	bathroom	4.9	6.5*	4.7	5.4	
	bathtub, shower	4.9	6.4*	4.5	4.9	
	Motor score: Subtotal	67.0	74.7*	65.2	68.4*	
	COMMUNICATION	14.0	14.0	14.0	14.0	
	comprehension	7.0	7.0	7.0	7.0	
	expression	7.0	7.0	7.0	7.0	
	SOCIAL INTEGRATION	21.0	21.0	20.9	21.0	
	Social interaction	7.0	7.0	6.9	7.0	
	resolution of problems	7.0	7.0	7.0	7.0	
	memory	7.0	7.0	7.0	7.0	
	Cognitive Score subtotal	35.0	35.0	34.9	35.0	
Leal et al. 2010	VC land (L)	2.80(0.94)		5.20(0.74)		***p<0.008
	pelvis		-6.8 (-12.5)		-1.9(5.7)	**p<0.017
	xiphoid		8.6(26.2)		-4.3(5.5)	
	neck		27.2(25.8)***		-6.3(5.0)***	
	IC (L)	2.32(0.06)		3.74(0.80)		
	IC neck	0.61(0.31)	36.1(23.14)**	1.46(0.55)	15.7(15.6)**	
	ERV (L)	NR		NR		
	ERV xiphoid		40.3(51.5)**		-27.6(21.9)**	
	ERV neck				56.4(16.3)**	
	Hematocrit level (%)		4		4	
Tamburella et al. 2013	Speed (m/s)	0.27(0.22)	0.17(0.09) *	0.95(0.21)	0.33(0.05)***	*p<0.05
	Stride length(cm)	0.67(0.21)	0.69(0.20)	1.25(0.24)	1.02(0.15)***	**p<0.005
	Stance phase (%)	71.49(7.52	60.60(15.48)*	65.13(2.71)	63.98(3.25)	
	Gait cycle time (s)	2.75(3.78)	3.78(1.11)**	1.34(0.2)	3.15(0.73)***	
Jung et al. 2014	FVC (L)	2.5(0.7)	4.3 (1.4)**	3.0(0.9)	3.4 (1.4)	***p<0.001
	FER (L)	80.5(15.5)	90.5(17.0)*	85.2(18.0)	90.6(18.0)*	**p<0.01
	FEV1(L)	2.1(0.9)	3.2(1.2)*	2.7(1.0)	2.9 (1.0)	*p<0.05
	FEV1/FVC	89.3(3.8)	93.0 (3.6)**	88.3 (4.6)	90.4 (3.2	

Note: EG – Experimental Group (intervention group) CG – Control Group RVW – Residual Volume in Water (L) FVC – Forced Vital Capacity (L) FEV1 – Forced Expiratory Volume in 1 second (L) VC – Vital Capacity (L) IC –

Inspiratory Capacity (L) ERV – Expiratory Reserve Volume (L) FIM – Functional Independence Measure (total score and subscales) PARA – Paraplegic TETRA – Tetraplegic p – p-value (statistical significance).

Discussion

Results show that aquatic therapy improves respiratory function in people with SCI, especially forced vital capacity (FVC) and vital capacity (VC). Immersion up to neck level is beneficial due to hydrostatic pressure and strengthening of respiratory muscles (Thomaz et al., 2005; Jung et al., 2014). Respiratory parameters were assessed mainly by spirometry, including FVC, VC, inspiratory capacity (IC) and expiratory reserve volume (ERV), while mobility was assessed by Walking Index for Spinal Cord Injury II (WISCI-II) and Functional Independence Measure (FIM). While respiratory parameters improved, functional independence showed no significant improvement.

The body of evidence included in the meta-analysis is limited, therefore results are interpreted with great caution. Findings related to body structure and functioning suggest that aquatic therapy significantly improves respiratory functions in SCI individuals, especially when immersed to the neck (Thomaz et al., 2005; Jung et al., 2014). Forced Vital Capacity (FVC) and Vital Capacity (VC), major determinants of inspiratory strength (McKinley et al., 2002), show improvement during immersion and aquatic exercise. In the meta-analysis of studies investigating FVC (Figure 2a), results indicate that overall, aquatic therapy is highly effective in improving FVC during immersion to the neck as well as during aquatic exercise compared to land. However, the high effect size is accompanied by similarly high heterogeneity, and one study shows effectiveness but with no significance, suggesting a disparity between both studies. The effect of aquatic therapy on increasing VC (Thomaz et al., 2005; Leal et al., 2010) was even much higher than that of FVC, with a wide confidence interval and high homogeneity. Analysis on Inspiratory Capacity (IC) (Thomaz et al., 2005; Leal et al., 2010) showed immersion had a small effect in increasing IC that was not statistically significant, as well as a wide confidence interval demonstrating variability in the true effect. A decrease in Expiratory Reserve Volume (ERV) (Thomaz et al., 2005; Leal et al., 2010) during immersion was also highly effective with similarly wide confidence intervals as seen in IC increase and with high heterogeneity.

A significant level of morbidity and mortality is associated with respiratory dysfunction in persons with chronic SCI (Brown et al., 2006; Zimmer et al., 2007), which impacts respiratory efficiency and quality of life, especially in high lesion levels. Restriction of pulmonary volumes and respiratory capacity, including FVC, VC, and IC in SCI, has been reported in other studies (Schilero et al., 2009; Linn et al., 2000; Stepp et al., 2008) as consequences of respiratory dysfunction resulting from the injury. The resulting restriction of respiratory efficiency has been linked to respiratory muscle paralysis (Zimmer et al., 2007), hence the need for effective management to reduce impairment and fatality. Respiratory training, based on two systematic reviews of RCTs (Van Houtte et al., 2006; Sheel et al., 2008), has not demonstrated superior effectiveness on land. Whereas, findings in this review indicate that the use of aquatic therapy—either one-time immersion or exercise—is highly effective in the management of respiratory complications by improving lung volumes such as FVC, VC, and IC. This benefit may stem from respiratory muscle strengthening and hydrostatic pressure, similar to abdominal binding on land that has been demonstrated to improve lung volumes in persons with SCI (Langbein et al., 2001). One of the studies presented hematocrit level changes during immersion in both tetraplegic and able-bodied persons as a means to determine the underlying mechanism behind the increase in VC in its complementary study (Leal et al., 2010). It concluded that despite blood volume changes, hydrostatic pressure was responsible for the observed increase in VC in tetraplegics. This was supported by the finding that when pressure cuffs fitted around the leg at the groin were used to evoke a shift in blood volume on land, VC remained unchanged, in contrast to during immersion where inflation or deflation of cuffs increased VC in the tetraplegic group, but its extent did not differ based on inflation or deflation of the cuffs in water, thereby suggesting hydrostatic pressure as the true cause. Regardless of the mechanism involved (hydrostatic pressure or respiratory muscle strengthening), SCI patients with respiratory restrictions can certainly benefit from aquatic exercise or immersion to the neck level in a pool temperature between 33-34.5°C to enhance short-term respiratory functions. Short-term is specified because only one of the studies in our meta-analysis used a long-term intervention as opposed to immersion in improving lung volumes.

Similarly, immersion to the neck is specified, as it remains the common depth where significant improvement in lung volumes were recorded for all SCI individuals. Further research on the long-term benefits of immersion on respiratory restrictions in SCI will be of great value. In this interest, considerations for the assessment of respiratory function in SCI should also be of concern; it was observed during this review that spirometry testing equation of percentage predicted values were only modified to the SCI group in one study (Leal et al., 2010), similarly familiarization sessions were only conducted in two studies (Jung et al., 2014; Bosch & Wells, 1991). While we consider that this may not have influenced the results as gains were clearly recorded, it follows that specific volumes reported of the predicted range may not be accurate due to the flawed equation. In support of this, a cross-sectional study with 278 participants recommended the modification of spirometry testing standards to include excessive back-extrapolated volume to reduce the potential for bias during testing (Kelley et al., 2003). Also observed were the reported outcome measures. Studies that investigated respiratory responses or changes inconsistently reported VC, FVC, IC, ERV, RV, FEV1, FEV1/FEV. Studies tended to report only 3 out of all volumes even when the study aim referred to respiratory or pulmonary functions as a whole and not specific outcomes such as VC or FVC changes. This may be attributed to selective reporting across all studies, perhaps because outcomes were not in the interest of the author(s). Especially when armed with the knowledge that measurement of FVC, a measure of total lung capacity, is clinically accompanied by the measurement of RV (Langbein et al., 2001). Only one study reported change in RV during immersion (Bosch & Wells, 1991); it focused on changes in RV and its impact as a determinant of body density and body weight. It concluded that using RV as a derivative, body weight and body density differed if RV was measured on land or in water. The study concluded that body weight and density for tetraplegics should be derived from RV in water when it is reduced, but not for paraplegics or healthy population, as water or land measurements had no impact on their hydrostatic weight. These considerations should be taken into account for future studies.

Changes in mobility function differed in the results of this review. The inability or difficulty to walk is one of the most visible disabilities in SCI individuals (Dobkin et al., 2006), depending on lesion type. Muscle paralysis and spasticity are often the most common contributing factors (McKinley et al., 2002). Consequently, reducing spasticity and optimizing mobility independence and ambulation are crucial. A decrease in spasticity severity as well as oral baclofen intake was reported by one of the studies included in this review (Kesiktas et al., 2004). While a finite conclusion of spasticity reduction in SCI resulting from the use of hydrotherapy cannot be based on one study, as at the time of this review, it remained the only existing evidence to this effect. Nonetheless, similar findings of spasticity reduction in neurological diseases as a result of aquatic therapy have been reported (Becker, 1997; Beresneva et al., 2009; Geytenbeek, 2008), credited to the temperature of the water and the ease of conducting passive stretching in this environment. Future research in this area will provide much-needed concrete evidence, as land management of spasticity remains insufficient, with only pharmacological agents and transcutaneous electrical nerve stimulation (TENS) cited as possible management techniques (Hsieh et al., 2007). Functional independence on the other hand appeared to show no significant improvement based on our meta-analysis (Figure 2b). Both the aquatic intervention and conventional intervention did not effectively improve FIM scores, neither was more superior to the other as a 0 effect was attained. Yet, the two studies in the review reported a significant increase in overall FIM scores, although all increases were limited to transference and shower alone. It is plausible the flaw in both studies included in the meta-analysis evaluated improvement in independence with an inappropriate tool (FIM), as studies have shown the Spinal Cord Independence Measure (SCIMIII), which has demonstrated extensive validity and reliability, to be a more acceptable tool for measurement of independence in SCI individuals (Itzkovich et al., 2007). Previously, Oakley et al. (2013) in a single case study reported a 10% increase in SCIMIII scores of an SCI individual following aquatic activity-based restoration therapy. This study was not included in this review because it is a case study that combined both aquatic and land treatment without a control. Regardless, the strides made through the intervention may be of clinical consideration.

Changes in gait pattern during walking in water were explored in one of the studies included in this review (Tamburella et al., 2013). The study compared walking on land to walking in water. A decrease in gait speed and stance phase yielded values similar to those of healthy individuals. Similarly, hyper-flexion of the knee and hip were also reported in water. Ideally, clinical considerations for gait rehabilitation in SCI include reduction in speed, stance phase duration, and increased hip and knee flexion in order to allow transition to a more physiologic gait (Nudo, 2003), supporting the outcome of this study. Considering that gait rehabilitation of SCI on land is guided by the principles of task-acquisition, retention, and transfer principles of motor learning, i.e., functional repetition of a movement task to strengthen neural connectivity (Nudo, 2003; Marsh et al., 2011), gait training in water in a simple walkway as in the study of Tamburella et al. (2013) may be the key to providing the environment where optimal physiologic walking can be practiced through aquatic therapy. However, further research is needed to solidify these findings. Similarly, a case study (Rotondo et al., 2013) identified during our search, but not included in this review due to the study design, assessed gait-related functions in an individual with SCI following an aquatic therapy program including underwater treadmill adjunct to over-ground training. The results of the study revealed no change in SCIM III, however, the individual's walking index for spinal cord injury increased from 0-8, demonstrating an improvement in gait function similar to our reports above. As is evident in our search, underwater treadmill training in general was not included in this review as it is considered a body weight supported treadmill training technique (BWSTT), which is beyond the scope of this review and the approach hinges on its own specific principles similar to BWSTT on land.

The two additional unpublished studies obtained from conference abstracts identified during our search but not included in this review, as the authors did not permit publication of their results, investigated the effect of aquatic therapy on abdominal adiposity and insulin resistance in two people with chronic motor incomplete spinal cord injury with positive results (Geigle et al., 2015), while the other investigated cardiovascular and functional effects with results in favor of aquatic therapy (Geigle et al., 2015).

Conclusion

The evidence reviewed in this study indicates that aquatic therapy holds considerable promise for improving functional, motor, and respiratory outcomes in individuals with spinal cord injury (SCI). Across the included studies, participants undergoing aquatic interventions consistently demonstrated improvements in mobility, pulmonary function, muscle strength, body composition, and performance in activities of daily living, as reflected in measures such as FIM scores, FVC, FEV1, gait parameters, and body density. These findings underscore the unique advantages of aquatic therapy, which leverages buoyancy, resistance, and hydrostatic pressure to facilitate movement, reduce spasticity, and promote cardiovascular and muscular conditioning.

However, the overall methodological quality of the existing literature is moderate, with only two controlled trials (one RCT and one CCT) and the remaining studies being case-control in design. Limitations such as small sample sizes, unequal group distributions, heterogeneous intervention protocols, and diverse outcome measures restrict the generalizability of findings and complicate meta-analytic synthesis. To address these gaps, future research should implement standardized reporting practices, including detailed participant characteristics, SCI-adapted spirometry, validated mobility assessments, and objective measures such as the Walking Index for Spinal Cord Injury (WISCI).

Moreover, long-term outcomes, including quality of life, social participation, psychological well-being, and functional independence, remain largely unexplored and should be a focus of upcoming studies. High-quality, adequately powered randomized controlled trials are essential to confirm the efficacy of aquatic therapy, identify optimal intervention parameters, and inform evidence-based clinical guidelines. Overall, while current evidence is limited, aquatic therapy appears to be a safe, effective, and versatile intervention with the potential to significantly enhance rehabilitation outcomes and overall quality of life for individuals with SCI.

Acknowledgements: The authors acknowledge no conflicts of interest.

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