Received: 16 June 2020 | Revised: 26 October 2020 | Accepted: 28 October 2020

DOI: 10.1111/ane.13371

REVIEW ARTICLE

WILEY

Aquatic therapy in stroke rehabilitation: systematic review and meta-analysis

Jitka Veldema | **Petra Jansen**

Faculty of Human Sciences, University of Regensburg, Regensburg, Germany

Correspondence
Jitka Veldema, University of Regensburg, Universitätsstraße 31, D-93053 Regensburg, Germany.
Email: jitka.veldema@ur.de

Funding information
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Abstract

The main object of this systematic review and meta-analysis is to collect the available evidence of aquatic therapy in stroke rehabilitation and to investigate the effect of this intervention in supporting stroke recovery. The PubMed, the Cochrane Central Register of Controlled Trials and the PEDro databases were searched from their inception through to 31/05/2020 on randomized controlled trials evaluating the effect of aquatic therapy on stroke recovery. Subjects´ characteristics, methodological aspects, intervention description, and outcomes were extracted. Effect sizes were calculated for each study and outcome. Overall, 28 appropriate studies (*N* = 961) have been identified. A comparison with no intervention indicates that aquatic therapy is effective in supporting walking, balance, emotional status and health-related quality of life, spasticity, and physiological indicators. In comparison with land-based interventions, aquatic therapy shows superior effectiveness on balance, walking, muscular strength, proprioception, health-related quality of life, physiological indicators, and cardiorespiratory fitness. Only on independence in activities of daily living the land- and water-based exercise induce similar effects. Established concepts of water-based therapy (such as the Halliwick, Ai Chi, Watsu, or Bad Ragaz Ring methods) are the most effective, aquatic treadmill walking is the least effective. The current evidence is insufficient to support this therapy form within evidence-based rehabilitation. However, the available data indicate that this therapy can significantly improve a wide range of stroke-induced disabilities. Future research should devote more attention to this highly potent intervention.

KEYWORDS
aquatic therapy, neurorehabilitation, stroke

1 | INTRODUCTION

Stroke is a devasting disease leading to a range of physical impairments and complications as well as psychosocial consequences and is considered to be the most common cause of complex disability.[1,2] Due to longer survival and reduced mortality after acute incidents, the number of people that suffer from stroke has almost doubled during the last three decades.[3] Thus, the problems related to this illness are of increasing socio-economic importance. One of the top research priorities relating to life after an acute cerebrovascular incident is to investigate the impact of fitness training and exercise on stroke recovery and on prevention of a subsequent stroke.[4]

Aquatic therapy is often applied in this cohort. The water environment is considered to have broad rehabilitative potential due to its essential physical properties.[5] Water density and specific gravity, hydrostatic pressure, buoyancy, viscosity, and thermodynamics have the potential to support the physiological effects of exercise.[5] Aquatic therapy can encompass an array of forms. Several standardized concepts of water-based therapy (such as the Halliwick, Ai Chi, Watsu, or Bad Ragaz Ring methods)[6] have already been established within rehabilitation. The Halliwick method was developed at the turn of the 1940s and 1950s by James McMillan to teach physically disabled children independence in water. This method is based on the application of a ten-point-program (mental adjustment, disengagement, transversal, sagittal, longitudinal and combined rotation control, mental inversion, balance in stillness, turbulent gliding, and simple progression and basic swimming movement) to develop balance control, swimming skills, and independence.6 Ai Chi, developed by Jun Konno in 1990s, is a kind of water-based exercise that bridges East and West philosophies. It combines Tai-Chi concepts with Shiatsu and Watsu techniques and is performed standing in shoulder-depth water using a combination of deep breathing and slow, broad movements of the arms, legs, and torso.6 The Bad Ragaz Ring methods, developed in the 1950s in the thermal waters of Bad Ragaz (Switzerland), bases on proprioceptive neuromuscular facilitation. Therapist-assisted strengthening and mobilization are applied to a patient that lies in the water (horizontal position is supported by rings or floats around the neck, arms, pelvis, and legs).6 Beside these established water-based concepts, traditional functional exercises (such as gait and balance exercises) can be performed in an aquatic environment. It is questionable though, whether the currently evidence is sufficient for application of this therapy form within the framework of evidence-based stroke rehabilitation.

Previous reviews and meta-analyses focused on the potential of aquatic therapy in supporting motor recovery after a stroke, and report between eight and 24 controlled trials on this topic.[7-10] Their results indicate that aquatic therapy is superior to land-based therapy on gait,[7,8,10] balance,[7-10] independence in activities of daily living,[7,10] mobility,[8,10] muscular strength,8 aerobic capacity8 and body structure and function.[10] No significant differences were found on quality of life.[8] Only one review and meta-analysis revealed the effectiveness of water-based therapy in comparison with no intervention up to now. A significant effect on gait and balance, but not on muscle strength, mobility, aerobic capacity, and quality of life was found.8 This partially contradicts previous evidence.[7-10] Despite the number of earlier systematic reviews and meta-analyses, there exist several gaps of the understanding of aquatic therapy effects in stroke recovery. Even though aquatic therapy approaches show great variety, previous analyses did not compare the effectiveness of different methods. Furthermore, no studies were included which directly compared different aquatic therapy methods. An important weakness of previous reviews and meta-analyses is the absence of information about the effectiveness of water-based exercise on “non-physical” deficits after stroke. The available data demonstrate that physical exercises may reduce the occurrence of depression symptoms,[11] and support the cognitive recovery after a stroke.[12] Furthermore, no review investigated aquatic therapy on stroke-related spasticity, even though evidence exists that the aquatic environment,[13] as well as the physical exercising[14,15] may significantly reduce this disability. We perform an up-to-date overview and meta-analysis to fill existing gaps.

Highlights

- Twenty-eight controlled studies (N = 961) investigated the effects of aquatic therapy on stroke rehabilitation
    a. Aquatic therapy is effective in supporting stroke recovery
    b. Aquatic therapy is superior to land-based therapies on balance, walking, muscular strength, proprioception, health-related quality of life, physiological indicators, and cardiorespiratory fitness
    - The type of aquatic therapy method impacts its effects

2 | METHODS

This systematic review and meta-analysis is performed in accordance with the PRISMA (Preferred Items for Reporting of Systematic reviews and Meta-Analyses) guidelines.[16] The protocol is not registered.

2.1 | Search strategy

Two independent reviewers searched electronic databases PubMed, PEDro, and Cochrane Central Register of Controlled Trials from inception to 31/05/2020 for controlled studies which tested the effectiveness of water-based therapy in supporting stroke recovery. Search terms “aquatic therapy” and “stroke,” “aquatic exercises” and “stroke,” “hydrotherapy” and “stroke,” “water-based therapy” and “stroke,” “water-based exercises,” and “stroke” were used. After the first screening of the titles and the abstracts for eligibility, the evaluation of the potentially eligible full-text publications was performed. Furthermore, previous relevant reviews and meta-analyses were searched for suitable studies. Disagreements were resolved by consensus. The detailed summary of the literature search is depicted in Figure 1.

2.2 | Selection criteria

Records matching the following criteria were included: (1) randomized controlled trials, (2) adult stroke subjects, (3) aquatic therapy as intervention, (4) pre- and post-interventional evaluation of

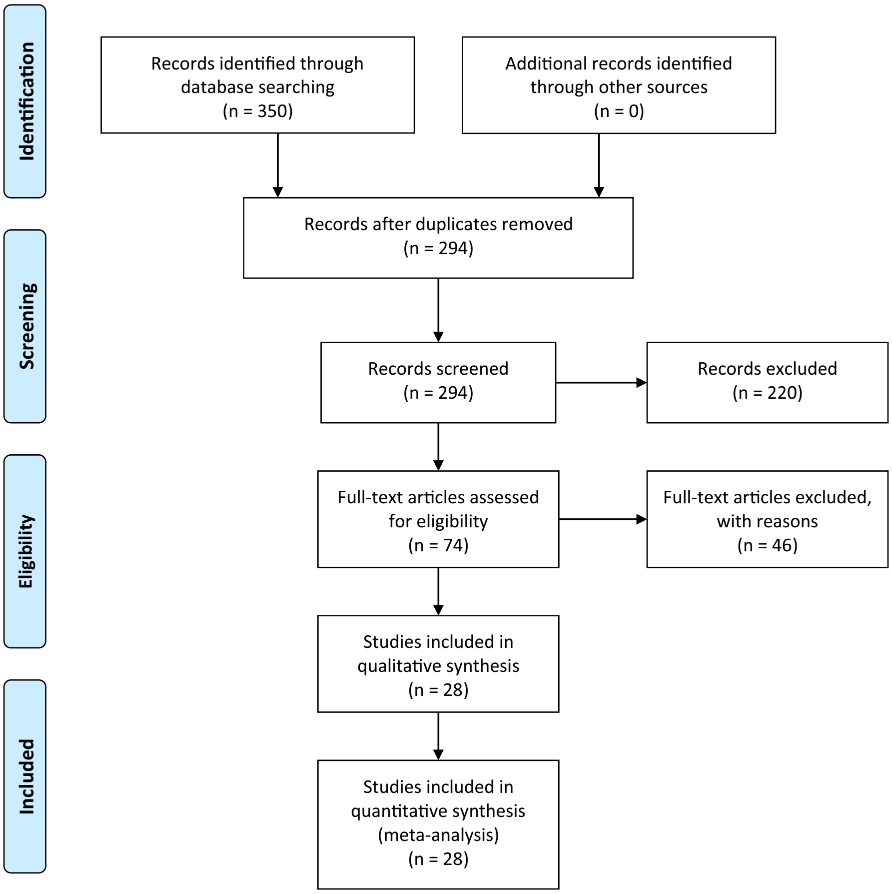


FIGURE 1 Summary of literature search results based on PRISMA guidelines

primary outcomes, (5) five individuals per intervention at least, (6) written in English or German.

2.3 | Quality assessment

The methodological quality and risk of bias of studies included were assessed using the PEDro scale.[17] This 11-items scale evaluates methodological aspects of clinical trials, such as random allocation, baseline comparability, evaluator, therapist, and patient blinding. The higher the total score, the higher the methodological quality of the study (10–9 excellent, 8–6 good, 5–4 fair, and <4 poor).

2.4 | Data extraction

The following information was extracted: (1) subjects´ characteristics (number, age, gender, time since stroke, stroke etiology, and stroke location), (2) methodological aspects (study design, methodological quality), (3) intervention description (number of intervention sessions, duration, type and intensity of intervention, aquatic environment characteristics) and (4) outcomes (assessments, between-group differences).

2.5 | Data synthesis

Based on the methodological approach, the included studies were divided into three categories: (i) trials comparing aquatic therapy with no intervention, (ii) trials comparing aquatic therapy with land-based interventions, and (iii) trials comparing different aquatic therapy methods. An additional subcategorization was performed within each category depending on aquatic therapy approach used: (i) trials applying standardized forms of aquatic therapy (Halliwick, Ai Chi, Watsu, and Bad Ragaz Ring methods), (ii) trials applying aquatic treadmill training, and (iii) trials applying remaining aquatic therapy approaches (water-based walking, balance training, strengthening, and stretching).

2.6 | Statistical analysis

Effect size and the 95% confidence intervals were calculated using effect size calculators.[18,19] The calculation bases either on means and standard deviations of repeated measures (pre, post), or on means and standard deviations of pre-post differences (in dependence on data available). The effect size and the 95% confidence intervals were calculated for each assessment. On their basis, overall outcomes (including whole outcomes) and pooled outcomes (e.g.

balance, gait, muscular strength, independence in activities of daily living) were calculated for each study and forest plots were constructed. For interpretation, the Cohen definition of effect size was used (d = 0.2 "small," d = 0.5 "medium," d = 0.8 "large").[20] The homogeneity of effects across studies was evaluated using the inconsistency test (I^2), where values above 50% were considered indicative of high heterogeneity.[21]

3 | RESULTS

Overall, 28 articles corresponded with our inclusion criteria and were selected for this systematic review and meta-analysis. A total of 961 stroke patients were enrolled. The trials show a large variability of methodological quality, study design, subjects, interventions, and outcomes. Adverse events were not described.

3.1 | Aquatic therapy versus no intervention

Six controlled trials[22-27] evaluated the potential of aquatic therapy in comparison with no intervention (Table 1, Figure 2).

3.1.1 | Participants and interventions

Overall 244 stroke patients were enrolled, between 24 weeks and >12 months after the acute incident. Between 20 and 30 sessions of aquatic therapy were implemented, with a duration between 30 and 60 minutes. One trial performed aquatic treadmill walking.[25] The remaining studies used diverse walking- and balance-based exercises in a pool. The water depth ranged between waist and breast level. The water temperature was between 27 and 34°C. Only two trials defined the exercise intensity using the Borg Scale[27] and percentage of gait speed.[25] The remaining studies provided no information on therapy intensity.

3.1.2 | Parameters assessed

The trials tested the effects of aquatic therapy on:

- gait[22-24,26] (Timed Up & Go, 7.62 Meter Walk Test, Ten Meter Walk Test, Functional Gait Assessment)
- balance[23-26] (getting up from sitting speed, Berg Balance Scale, Functional Reach Test, Five-Time Sit to Stand Test, static and dynamic balance)
- emotional status[26,27] (Beck Depression Inventory, State-Trait Anxiety Inventory)
- health-related quality of life[22] (short form 36 health survey)
- **spasticity**[22] (Modified Ashworth Scale)

All studies performed pre- and post-evaluation. No study implemented long-term follow-up.

3.1.3 | Effectiveness

The data show that aquatic therapy is an efficient tool for supporting walking, balance, emotional status, health-related quality of life, and spasticity after a stroke. The studies show an inhomogeneity of effect sizes. Water-based walking and balance exercises induced greater effects than aquatic treadmill walking on balance ability and overall score.

3.2 | Aquatic therapy versus land-based interventions

Twenty-one controlled studies[28-48] compared the benefits of aquatic therapy with land-based interventions (Table 2, Figure 3).

3.2.1 | Participants and interventions

Six hundred and ninety patients were included between 30 days and 3.6 years after stroke. The subjects received between six and 40 sessions either of water-based therapy or of land-based therapy, with a duration between 20 and 60 minutes. Diverse forms of water-based therapy were performed within the framework of the studies. Four trials applied aquatic treadmill walking.[28,29,38,41] Six trials performed established concepts of aquatic therapy, developed for rehabilitation purposes, such as Halliwick, Ai Chi, Watsu, or Bad Ragaz Ring methods.[30,32,33,42,45,47] The most of them combined these therapy forms with additional water-based gait or balance exercises.[30,32,33,42] All remaining trials applied mainly walking and/or balance-based exercises in a pool. The water depth ranged between 1.0 and 1.5 meters. The water temperature was between 26 and 38°C. Five trials did not define water depth[31,45,46] and/or water temperature.[30,41] The control intervention was applied in the form of land-based walking and balance exercises in the majority of studies. Two trials performed over-ground treadmill walking.[38,41] Two studies applied ergometer training.[28,29] Neuromuscular facilitation techniques were used in two trials.[36,42] One study performed functional motor training of the upper limb.[48] Only three studies specify the exercise intensity using a percentage of HR_{max},[29,48] Borg Scale,[37] and walking speed.[41]

3.2.2 | Parameters assessed

The trials examined:

- balance[28,30,31,33-40,42-44,46-48] (Berg Balance Scale, Functional Reach Test, Community Balance and Mobility Test, One Leg Stand Test, Short Physical Performance Battery, Performance

TABLE 1 Overview of studies investigating aquatic therapy in comparison with no intervention in supporting stroke recovery.

Reference	Subjects number/ gender /age (years)	Time since stroke	Stroke etiology/affected hemisphere	Study design/ sessions number/ PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results/Used assessments
Matsumoto et al., 2016	120/88 males, 32 females/63 ± 11 years	24 ± 14 weeks	80 ischemic, 40 hemorrhagic/68 right, 52 left	parallel groups (60 + 60)/24 sessions/5	A: 30 min aquatic therapy (walking-based exercises; intensity na; waist-deep water at 30–31°C) B: no therapy	aquatic therapy significantly better: Ten Meter Walk Test, Modified Ashworth Scale, short form 36 health survey
Kim et al., 2016	20/10 males, 10 females/69 ± 3 years	10.9 ± 1.1 months	na/na	parallel groups/ (20 + 20)/30 sessions/4	A: 30 min aquatic therapy (walking- and balance-based exercises; intensity na; 1.0 m deep water at 32–34°C) B: no therapy	aquatic therapy significantly better: Berg Balance Scale, Timed Up & Go, Functional Reach Test, Five-Time Sit to Stand Test, Ten Meter Walk Test, Functional Gait Assessment
Kim et al., 2015a	20/10 males, 10 females/65 ± 5 years	11.8 ± 1.2 months	na/na	parallel groups/ (10 + 10)/30 sessions/4	A: 30 min aquatic therapy (walking-based exercises; intensity na; 1.0 m deep water at 32–34°C) B: no therapy	aquatic therapy significantly better: Berg Balance Scale, Timed Up & Go, Functional Reach Test, Ten Meter Walk Test
Park et al., 2014	20/11 males, 9 females/61 ± 12 years	6–24 months	na/11 right, 9 left	parallel groups (10–10)/20 sessions/5	A: 30 min aquatic treadmill walking (36% of ground gait speed; waist-deep water at 34°C) B: no therapy	no significant differences: static balance (anterioposterior, mediolateral, total), dynamic balance (total)
Aidar et al., 2018	36/19 males, 17 females/52 ± 8 years	>12 months	36 ischemic/na	parallel groups (19 + 17)/24 sessions/5	A: 45–60 min aquatic therapy (walking-based exercises, upper and lower limbs strengthening exercises, swimming; intensity na; breast-deep water at 27°C) B: no therapy	aquatic therapy significantly better: Timed Up & Go, 7.62 Meter Walk Test, getting up from sitting (30 s), Beck Depression Inventory, State-Trait Anxiety Inventory
Aidar et al., 2013	28/19 males, 9 females/51 ± 8 years	>12 months	28 ischemic/na	parallel groups (15 + 13)/na/5	A: 45–60 min aquatic therapy (walking-based exercises, upper and lower limbs strengthening exercises, swimming; Borg Scale 12–17; breast-deep water at 27°C) B: no therapy	aquatic therapy significantly better: Beck Depression Inventory, State-Trait Anxiety Inventory

Abbreviations: °C, grad Celsius; m, meter; min, minute; na, not available, not applicable; PEDro, physiotherapy evidence database; s, second.

	Aquatic therapy	Effect size	Lower limit	Upper limit	Relative weight
Overall (n = 251)					
Aidar et al., 2013	walking	0,33	−0,42	1,08	11,48
Park et al., 2014	treadmill	0,46	−0,48	1,40	8,20
Aidar et al., 2018	walking	0,60	−0,07	1,27	14,75
Matsumoto et al., 2016	walking	0,69	0,33	1,06	49,18
Kim et al., 2015a	walking	1,30	0,33	2,27	8,20
Kim et al., 2016	walking	1,77	0,74	2,81	8,20
Subtotal	**treadmill**	**0,46**	**−0,48**	**1,40**	**8,20**
Subtotal	**walking**	**0,78**	**0,21**	**1,36**	**91,80**
Total		**0,76**	**0,15**	**1,37**	**100,00**
Subgroup heterogeneity: I^2 = 64.9%					
Gait (n = 196)					
Matsumoto et al., 2016	walking	0,54	0,17	0,90	61,22
Aidar et al., 2018	walking	0,70	0,02	1,37	18,37
Kim et al., 2015a	walking	1,38	0,41	2,36	10,20
Kim et al., 2016	walking	1,98	0,91	3,06	10,20
Total		**0,80**	**0,25**	**1,36**	**100,00**
Subgroup heterogeneity: I^2= 86,5%					
Balance (n = 96)					
Park et al., 2014	treadmill	0,46	−0,48	1,40	20,83
Aidar et al., 2018	walking	0,60	−0,07	1,27	37,50
Kim et al., 2015a	walking	1,21	0,26	2,17	20,83
Kim et al., 2016	walking	1,56	0,56	2,56	20,83
Subtotal	**treadmill**	**0,46**	**−0,48**	**1,40**	**20,83**
Subtotal	**walking**	**1,02**	**0,18**	**1,85**	**79,17**
Total		**0,90**	**0,04**	**1,76**	**100,00**
Subgroup heterogeneity: I^2 = 81,9%					
Health related quality of life, emotional status (n = 184)					
Aidar et al., 2013	walking	0,33	−0,42	1,08	15,22
Aidar et al., 2018	walking	0,66	−0,08	1,41	19,57
Matsumoto et al., 2016	walking	0,71	0,34	1,08	65,22
Total		**0,64**	**0,14**	**1,14**	**100,00**
Subgroup heterogeneity: I^2 = 87.5%					
Spasticity (n = 120)					
Matsumoto et al., 2016	walking	0,91	0,54	1,29	100,00

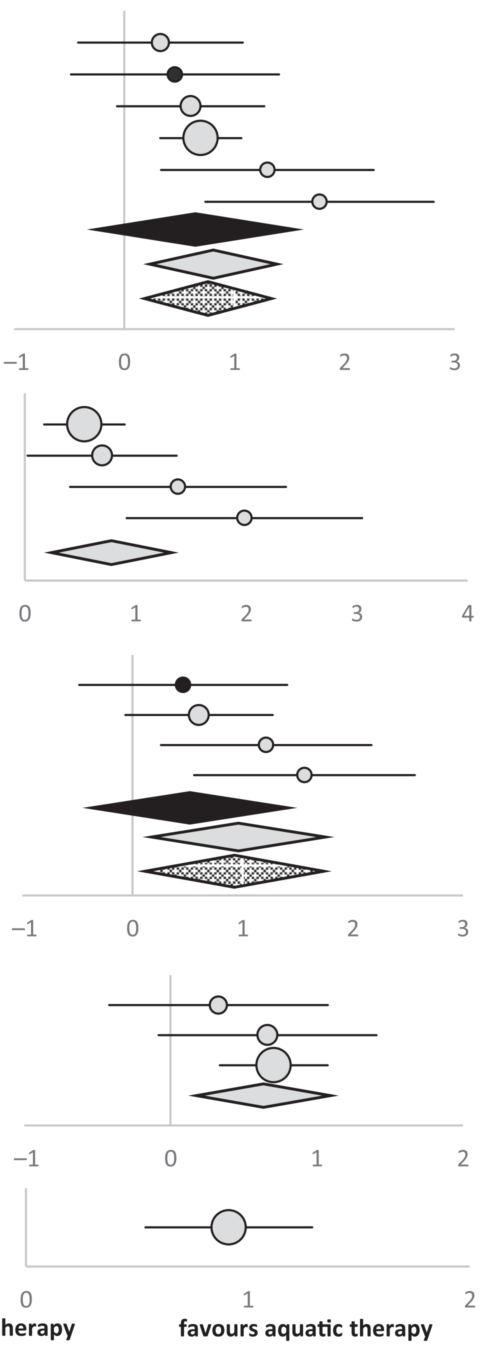


FIGURE 2 Overview of effect sizes, 95% confidence intervals and homogeneity for studies comparing aquatic therapy with no intervention in supporting stroke recovery. Notes: black =aquatic treadmill walking; gray =water-based walking and balance exercises; patterned =water-based therapies overall; I^2 = inconsistency test

Oriented Mobility Assessment, stand with open and closed eyes, balance index, anterior-posterior and medial-lateral sway velocity, sway area, static and dynamic balance, static postural stability, weight-shift)

- gait[29-31,33-36,38,41,42,45-48] (Six Minute Walk Test, Two Minute Walk Test, Eight Meter Walk Test, Functional Ambulation Categories, Timed Up & Go, Figure of Eight Walk Test, Functional Gait Assessment, Modified Motor Assessment Scale, walking speed, walking pattern, step length, stride length, cadence, stance, swing and double support phase duration, gait symmetry)
- muscular function/strength of the lower limbs[28,32,41,46-48] (knee flexion and extension, hip flexion and extension, dorsiflexion, plantarflexion, Fugl-Meyer-Assessment)
- independency in activities of daily living[28-30,36,46] (ADL independency, Korean-Modified Barthel Index, Rivermead Mobility Index, Functional Independence Measure)

TABLE 2 Overview of studies investigating aquatic therapy in comparison with land-based interventions in supporting stroke recovery.

Reference	Subjects number / gender /age (years)	Time since stroke	Stroke etiology / affected hemisphere	Study design / sessions number / PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results / Used assessments
Lee et al. (2018)	37 / 19 males, 18 females / 61 ± 13 years	30 ± 21 days	20 ischemic, 17 hemorrhagic / 19 right, 18 left	Parallel groups (19 + 18) / 20 sessions / 7	A: 30 min aquatic treadmill walking (gradually increased walking speed; water at 30–33°C with changing depth)	aquatic treadmill significantly better: muscular strength (knee extension - affected, non-affected leg, knee flexion - affected leg); graded test on treadmill (VO_{2max}), EQ-5D index
					B: 30 min ergometer training (upper- and lower-extremities; gradually increased effort)	no significant differences: muscular strength (knee flexion - non-affected leg); graded test on treadmill (HR_{rest}, BP_{rest}, HR_{max}, BP_{max}, rate pressure product, respiratory exchange ratio), arterial stiffness, Fugl-Meyer Assessment, Berg Balance Scale, Korean-Modified Barthel Index
Han et al. (2018)	20 / 12 males, 8 females / 61 ± 13 years	36 ± 23 days	14 ischemic, 6 hemorrhagic / 12 right, 8 left	parallel groups (10 + 10) / 30 sessions / 5	A: 30 min aquatic treadmill walking (50–85% of HR_{max}, waist-deep water at 30–33°C)	aquatic treadmill significantly better: Six Minute Walk Test, graded test on treadmill (oxygen $uptake_{max}$, HR_{max}, rate pressure $product_{max}$, percentage of age-predicted heart $rate_{max}$, duration)
					B: 30 min ergometer training (upper- and lower-extremities, 50–85% of HR_{max})	no significant differences: Korean-Modified Barthel Index, graded test on treadmill (heart $rate_{rest}$)
Tripp et al. (2014)	30 / 19 males, 11 females / 65 ± 15 years	45 ± 32 days	27 ischemic, 3 hemorrhagic / 20 right, 10 left	parallel groups (14 + 16) / 6 sessions / 6	A: 45 min aquatic therapy (Halliwick method, walking based exercises; intensity na; water depth changing, temperature na)	aquatic therapy significantly better: Functional Ambulation Categories
					B: 45 min land-based therapy (mobility, treadmill walking; intensity na)	no significant differences: Rivermead Mobility Index, Berg Balance Scale, Functional Reach Test
Chan et al. (2017)	25 / 13 males, 12 females / 65 ± 11 years	96 ± 30 days	25 ischemic / 10 right, 15 left	parallel groups (13 + 12) / 12 sessions / 6	A: 30 min aquatic therapy (balance, stretching, strengthening, endurance; intensity na; water at 34.5°C, depth na)	no significant differences: Berg Balance Scale, Community Balance and Mobility Test, Timed Up & Go, Two Minute Walk Test
					B: 30 min land-based therapy (transfer, balance, stretching, strengthening, endurance, gait and stairs; intensity na)	

(Continues)

TABLE 2 (Continued)

Reference	Subjects number / gender /age (years)	Time since stroke	Stroke etiology / affected hemisphere	Study design / sessions number / PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results / Used assessments
Zhang et al. (2016)	36 / 17 males, 19 females / 56 ± 8 years	4.3 ± 0.9 months	25 ischemic, 11 hemorrhagic / 21 right, 15 left	parallel groups / (18 + 18) / 40 sessions / 6	A: 40 min aquatic therapy (Halliwick method, standing, balance, treadmill walking; intensity na; waist-deep water at 37–38°C) B: 40 min land-based therapy (mobility, balance, strengthening; intensity na)	aquatic therapy significantly better: Barthel Index, Functional Ambulation Category, muscular strength (knee extension - torque, contraction ratios, plantarflexion - torque) no significant differences: Modified Ashworth Scale, muscular strength (knee flexion - torque, contraction ratios, dorsiflexion - torque, contraction ratios, plantarflexion - contraction ratios)
Furnari et al. (2014)	40 / 20 males, 20 females / 70 ± 6 years	6.4 ± 1.5 months	na / na	parallel groups / (20 + 20) / 24 sessions / 5	A: 60 min aquatic therapy (walking, balance, Halliwick method, Ai Chi method, strengthening; intensity na; 1.15 m deep water at 33–34°C) B: 60 min physical therapy (stretching, strengthening, balance, walking based exercises; intensity na)	aquatic therapy significantly better: stand with open and closed eyes (length of the ball), gait (speed, cadence, stance phase, swing phase, double support phase) no significant differences: static postural stability (plantar surface, plantar load), gait (step length)
Zhu et al. (2016)	28 / 22 males, 6 females / 57 ± 8 years	8.4 ± 1.9 months	21 ischemic, 7 hemorrhagic / 19 right, 8 left	parallel groups / (14 + 14) / 20 sessions / 6	A: 45 min aquatic therapy (stretching, strengthening, balance and coordination, aquatic treadmill; intensity na; 1.4 m deep water at 34–36°C) B: 45 min land-based therapy (stretching, strengthening, trunk mobility, treadmill; intensity na)	aquatic therapy significantly better: Functional Reach Test, Two Minute Walk Test no significant differences: Berg Balance Scale, Timed Up & Go Test
Saleh et al. (2019)	50 / 24 males, 26 females / 50 ± 2 years	9 ± 2 months	28 ischemic, 22 hemorrhagic / 25 right, 25 left	parallel groups (25 + 25) / 18 sessions / 5	A: 45 min aquatic therapy (walking-based exercises, balance; intensity na; 1.3 m deep water at 30°C) B: 45 min land-based therapy (walking-based exercises, balance; intensity na)	aquatic therapy significantly better: balance index, walking speed, step length (affected and non-affected limbs), support time (affected limb)

(Continues)

TABLE 2 (Continued)

Reference	Subjects number / gender /age (years)	Time since stroke	Stroke etiology / affected hemisphere	Study design / sessions number / PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results / Used assessments
Kim et al. (2015b)	20 / 10 males, 10 females / 69 ± 3 years	10 ± 1 months	na / na	parallel groups / (20 + 20) / 30 sessions / 4	A: 30 min aquatic proprioceptive neuromuscular facilitation (lower extremity patterns; intensity na; 1.1 m deep water at 31–33°C) B: 30 min land-based proprioceptive neuromuscular facilitation (lower extremity patterns; intensity na)	aquatic therapy significantly better: Berg Balance Scale, Timed Up & Go, Functional Reach Test, One Leg Stand Test, Functional Independence Measure
Lee et al. (2010)	34 / 16 males, 18 females / 62 ± 11 years	13 ± 3 months	19 ischemic, 15 hemorrhagic / 11 right, 23 left	parallel groups / (17 + 17) / 36 sessions / 7	A: 50 min aquatic therapy (walking-based exercises, balance; Borg Scale 11–13; 1.25–1.5 m deep water at 33–34°C) B: 50 min land-based therapy (walking-based exercises, balance; Borg Scale 11–13)	aquatic therapy significantly better: anterioposterior sway velocity (closed eyes), dynamic balance (time, distance) no significant differences: anterioposterior and mediolateral sway velocity (open eyes), mediolateral sway velocity (closed eyes)
Park et al. (2012)	20 / 9 males, 11 females / 55 ± 11 years	13 ± 8 months	12 ischemic, 8 hemorrhagic / 8 right, 12 left	parallel groups / (10 + 10) / 24 sessions / 5	A: 30 min aquatic treadmill walking (intensity na; waist-deep water at 28–30°C) B: 30 min over ground treadmill walking (intensity na)	underwater treadmill walking significantly better: walking pattern - affected side (weight-bearing ability - entire foot, hindfoot, heel contact - knee joint, toe-off - hip and knee joint) no significant differences: walking pattern - affected side (weight-bearing ability - forefoot, heel contact - hip and ankle joint, toe-off - ankle joint), Short Physical Performance Battery
Jung et al. (2014)	30 / 16 males, 14 females / 56 ± 4 years	14 ± 3 months	10 ischemic, 20 hemorrhagic / 12 right, 18 left	parallel groups / (15 + 15) / 36 sessions / 5	A: 40 min aquatic therapy (walking-based exercises, stretching; intensity na; 1.1 m deep water at 33–35°C) B: 40 min land-based therapy (walking-based exercises, stretching; intensity na)	aquatic therapy significantly better: mediolateral sway velocity, anteroposterior sway velocity, sway area

(Continues)

TABLE 2 (Continued)

Reference	Subjects number / gender /age (years)	Time since stroke	Stroke etiology / affected hemisphere	Study design / sessions number / PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results / Used assessments
Han et al. (2013)	62 / 28 males, 33 females / 56 ± 9 years	16 ± 5 months	na / 33 right, 29 left	parallel groups (31 + 31) / 18 sessions / 4	A: 40 min aquatic therapy (balance; intensity na; 1.3 m deep water at 33–37°C) B: 40 min land-based therapy (balance; intensity na)	aquatic therapy significantly better: Berg Balance Scale, sway area (open and closed eyes), joint position sense
Kum et al. (2017)	28 / 15 males, 13 females / 54 ± 11 years	17 ± 5 months	16 ischemic, 12 hemorrhagic / na	parallel groups (13 + 15) / 12 sessions / 5	A: 20 min aquatic treadmill walking (gradually increased speed of > 1.0 m/s; waist-deep water, temperature na) B: 20 min over ground treadmill walking (gradually increased speed of > 1.0 m/s)	aquatic therapy significantly better: joint position sense (knee flexion, hip flexion and extension) no significant differences: muscular strength (knee flexion and extension, hip flexion and extension), joint position sense (knee extension), Figure of Eight Walk Test, Functional Gait Assessment
Cha et al. (2017)	22 / 13 males, 9 females / 64 ± 12 years	18 ± 5 months	16 ischemic, 6 hemorrhagic / na	parallel groups (11 + 11) / 18 sessions / 7	A: 30 min aquatic therapy (Bar Ragaz Ring method; intensity na; 1.3 m deep water at 33–37°C) B: 30 min conventional rehabilitation (facilitation technique; intensity na)	aquatic therapy significantly better: balance index, EMG (tibialis anterior, gastrocnemius) no significant differences: Timed Up&Go
Park et al. (2011a)	44 / 27 males, 17 females / 54 ± 8 years	> 6 months	16 ischemic, 28 hemorrhagic / 22 right, 22 left	parallel groups (22 + 22) / 36 sessions / 3	A: 30 min aquatic therapy (walking-based exercises, balance; intensity na; 1.3 m deep water at 33–35°C) B: 30 min land-based therapy (balance, trunk stability strengthening; intensity na)	water-based therapy significantly better: joint position sense, Performance Oriented Mobility Assessment
Park et al. (2011b)	46 / 25 males, 21 females / 56 ± 6 years	> 6 months	18 ischemic, 28 hemorrhagic / 25 right, 21 left	parallel groups (23 + 23) / 36 sessions / 4	A: 35 min aquatic therapy (walking-based exercises, balance, stretching; intensity na; 1.3 m deep water at 33–35°C) B: 35 min land-based exercises (balance, walking, mobility; intensity na)	aquatic exercises significantly better: stand with eyes open (mediolateral and anterioposterior sway velocity, velocity moment) no significant differences: stand with eyes closed (mediolateral and anterioposterior sway velocity, velocity moment)

(Continues)

TABLE 2 (Continued)

Reference	Subjects number / gender /age (years)	Time since stroke	Stroke etiology / affected hemisphere	Study design / sessions number / PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results / Used assessments
Park et al. (2016)	28 / 20 males, 8 females / 46 ± 4 years	21 ± 3 months	19 ischemic, 9 hemorrhagic / 11 right, 17 left	parallel groups (13 + 15) / 12 sessions / 4	A: 30 min aquatic therapy (Halliwick method, Watsu method, trunk exercises; intensity na; water at 30°C, depth na)	no significant differences: walking speed, step length, stance phase and stride length of affected limb, symmetry index of stance phase and stride length
					B: 30 min land-based therapy (trunk exercises; intensity na)	
Eyvaz et al. (2018)	60 / 31 males, 29 females / 58 ± 6 years	24 ± 15 months	50 ischemic, 10 hemorrhagic / 28 right, 32 left	parallel groups (30 + 30) / 18 sessions / 5	A: 60 min aquatic therapy (strengthening, balance, coordination; intensity na; water at 33°C, depth na)	land-based therapy significantly better: Berg Balance Scale
					B: 60 min land-based therapy (stretching, strengthening, trunk mobility, balance, walking; intensity na)	no significant differences: Functional Independence Measure, Timed Up&Go, static and dynamic balance, muscular strength (affected and non-affected lower limbs), Brunnstrom Recovery Stages, short form 36 health survey
Noh et al. (2008)	25 / 11 males, 14 females / 64 ± 11 years	2.2 ± 2.8 years	13 ischemic, 12 hemorrhagic / 12 right, 13 left	parallel groups (13 + 12) / 24 sessions / 6	A: 60 min aquatic therapy (walking, Halliwick method, Ai Chi method; intensity na; 1.15 m deep water at 34°C)	aquatic therapy significantly better: Berg Balance Scale, weight-shift forward and backward (affected limb), muscular strength (knee flexion - affected limb)
					B: 60 min land-based therapy (stretching, strengthening, walking; intensity na)	no significant differences: rising from a chair, weight-shift laterally (both limbs), weight-shift forwards and backwards (non-affected limb), Modified Motor Assessment Scale, muscular strength (knee extension - both limbs, knee flexion - non-affected limb, back flexion and extension)
Chu et al. (2004)	12 / 11 males, 1 female / 63 ± 9 years	3.6 ± 2.0 years	8 ischemic, 4 hemorrhagic / 5 right, 7 left	parallel groups (7 + 5) / 24 sessions / 6	A: 60 min aquatic therapy (walking-based exercises, stretching; 50–80% of HR_{max}; chest-deep water at 26–28°C)	aquatic therapy significantly better: maximal ergometer test (VO_{2max}, $workload_{max}$), Eight Meter Walk Test, muscular strength (affected lower limb), short form 36 health survey
					B: 60 min functional motor training of the affected upper limb (intensity na)	no significant differences: Berg Balance Scale, muscular strength (non-affected lower limb)

Abbreviations: °C, grad Celsius; BP, blood pressure; EMG, electromyography; HR, heart rate; HR_{max}, maximum heart rate; m, meter; min, minute; na, not available, not applicable; PEDro, physiotherapy evidence database; s, second; VO_2, oxygen consumption rate.

(A)	Aquatic therapy	Effect size	Lower limit	Upper limit	Relative weight
Overall (n = 691)					
Eyvaz et al., 2018	walking	0,09	–0,42	0,60	8,77
Lee et al., 2018	treadmill	0,18	–0,53	0,88	4,68
Park et al., 2012	treadmill	0,23	–0,65	1,11	2,92
Lee et al., 2010	walking	0,29	–0,39	0,97	4,97
Zhang et al., 2016	concept	0,32	–0,35	0,98	5,26
Tripp et al., 2014	concept	0,32	–0,44	1,09	3,95
Chan et al.,2017	walking	0,38	–0,42	1,17	3,65
Chu et al., 2004	walking	0,39	–0,78	1,57	1,75
Han et al., 2018	treadmill	0,43	–0,45	1,32	2,92
Noh et al., 2008	concept	0,51	–0,39	1,40	2,92
Park et al., 2011b	walking	0,64	0,04	1,23	6,73
Kum et al., 2017	treadmill	0,66	–0,11	1,42	4,09
Park et al., 2011a	walking	0,69	0,07	1,30	6,43
Saleh et al., 2019	walking	0,81	0,23	1,39	7,31
Zhu et al., 2016	walking	0,85	0,07	1,64	4,09
Cha et al., 2017	concept	0,92	0,04	1,81	3,22
Kim et al., 2015b	walking	0,99	0,06	1,92	2,92
Han et al., 2013	walking	1,05	0,52	1,59	9,06
Park et al., 2016	concept	1,12	0,28	1,90	4,09
Jung et al., 2014	walking	1,13	0,36	1,91	4,39
Funari et al., 2014	concept	2,09	1,17	3,02	5,85
Subtotal	**treadmill**	**0,37**	**–0,42**	**1,17**	**14,62**
Subtotal	**walking**	**0,66**	**0,01**	**1,31**	**60,09**
Subtotal	**concepts**	**0,96**	**0,13**	**1,77**	**25,29**
Total		**0,70**	**–0,02**	**1,41**	**100,00**
Subgroup heterogeneity: I^2 = 11.4%					
Balance (n = 572)					
Chu et al., 2004	walking	–0,41	–1,57	0,75	2,10
Park et al., 2012	treadmill	0,00	–0,88	0,88	3,50
Eyvaz et al., 2018	walking	0,04	–0,30	0,37	10,49
Lee et al., 2018	treadmill	0,23	–0,48	0,93	5,59
Tripp et al., 2014	concept	0,23	–0,53	0,99	4,72
Lee et al., 2010	walking	0,29	–0,39	0,97	5,94
Park et al., 2011a	walking	0,32	–0,27	0,92	7,69
Noh et al., 2008	concept	0,50	–0,39	1,40	3,50
Saleh et al., 2019	walking	0,57	0,00	1,13	8,74
Park et al., 2011b	walking	0,64	0,04	1,23	8,04
Chan et al., 2017	walking	0,75	–0,06	1,56	4,37
Kim et al., 2015b	walking	0,99	0,06	1,92	3,50
Zhu et al., 2016	walking	1,00	0,21	1,79	4,90
Jung et al., 2014	walking	1,13	0,36	1,91	5,24
Han et al., 2013	walking	1,20	0,65	1,75	10,84
Cha et al., 2017	concept	1,42	0,48	2,35	3,85
Funari et al., 2014	concept	3,27	2,08	4,46	6,99
Subtotal	**treadmill**	**0,14**	**–0,63**	**0,91**	**9,09**
Subtotal	**walking**	**0,62**	**–0,01**	**1,24**	**71,85**
Subtotal	**concepts**	**1,64**	**0,66**	**2,62**	**19,06**
Total		**0,77**	**0,06**	**1,47**	**100,00**
Subgroup heterogeneity: I^2 = 75.2%					

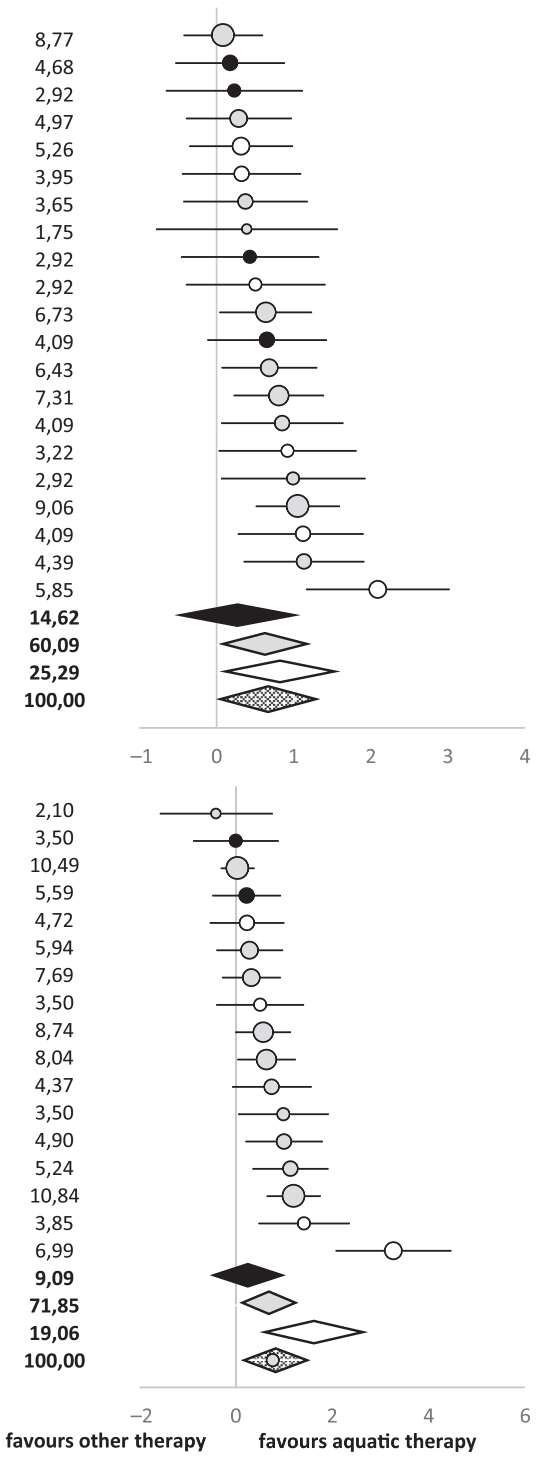


FIGURE 3 Overview of effect sizes, 95% confidence intervals and homogeneity for studies comparing aquatic therapy with land-based interventions in supporting stroke recovery. Notes: white =established concepts of aquatic therapy (such as the Halliwick, Ai Chi, Watsu, or Bad Ragaz Ring methods); black =aquatic treadmill walking; gray =water-based walking and balance exercises; patterned =water-based therapies overall; I^2 = inconsistency test.

- proprioception[40,41,43] (joint position sense)
- health-related quality of life[28,46] (short form 36 health survey, EQ-5D index)
- physiological indicators[28* MERGEFORMAT42] (arterial stiffness, blood pressure, EMG)
- cardiorespiratory fitness[28,29,48] (graded test on treadmill, maximal ergometer test).

All trials applied pre- and post-interventional assessments. No study evaluated the preservation of the effects by long-term follow-up.

(B)

	Aquatic therapy	Effect size	Lower limit	Upper limit	Relative weight
Gait (n = 400)					
Eyvaz et al., 2018	walking	−0,24	−0,74	0,27	15,00
Chan et al.,2017	walking	0,00	−0,78	0,79	6,25
Park et al., 2012	treadmill	0,26	−0,63	1,14	5,00
Cha et al., 2017	concept	0,34	−0,50	1,18	5,50
Kum et al., 2017	treadmill	0,45	−0,31	1,20	7,00
Chu et al., 2004	walking	0,45	−0,71	1,62	3,00
Han et al., 2018	treadmill	0,47	−0,42	1,36	5,00
Noh et al., 2008	concept	0,62	−0,27	1,52	5,00
Tripp et al., 2014	concept	0,65	−0,13	1,43	6,75
Zhu et al., 2016	walking	0,70	−0,08	1,48	7,00
Funari et al., 2014	concept	0,91	0,25	1,57	10,00
Saleh et al., 2019	walking	0,99	0,40	1,58	12,50
Kim et al., 2015b	walking	1,04	0,11	1,97	5,00
Park et al., 2016	concept	1,09	0,28	1,90	7,00
Subtotal	**treadmill**	**0,40**	**−0,43**	**1,23**	**17,00**
Subtotal	**walking**	**0,42**	**−0,27**	**1,10**	**48,75**
Subtotal	**concepts**	**0,76**	**−0,01**	**1,54**	**34,25**
Total		**0,53**	**−0,21**	**1,27**	**100,00**
Subgroup heterogeneity: I^2 = 32.1%					
Muscular function/strength of lower limbs (n = 188)					
Eyvaz et al., 2018	walking	−0,04	−0,55	0,46	31,91
Chu et al., 2004	walking	0,29	−0,86	1,45	6,38
Zhang et al., 2016	concept	0,32	−0,35	0,98	19,15
Lee et al., 2018	treadmill	0,32	−0,38	1,03	17,02
Kum et al., 2017	treadmill	0,48	−0,27	1,24	14,89
Noh et al., 2008	concept	0,49	−0,40	1,39	10,64
Subtotal	**walking**	**0,01**	**−0,60**	**0,63**	**38,30**
Subtotal	**concepts**	**0,38**	**−0,37**	**1,13**	**29,79**
Subtotal	**treadmill**	**0,40**	**−0,33**	**1,13**	**31,91**
Total		**0,25**	**−0,45**	**0,94**	**100,00**
Subgroup heterogeneity: I^2 = 0.0%					
ADL independence (n = 159)					
Eyvaz et al., 2018	walking	−0,10	−0,61	0,40	37,74
Lee et al., 2018	treadmill	−0,02	−0,72	0,68	20,13
Tripp et al., 2014	concept	0,18	−0,58	0,94	16,98
Han et al., 2018	treadmill	0,26	−0,62	1,14	12,58
Kim et al., 2015b	walking	0,97	0,04	1,89	12,58
Subtotal	**treadmill**	**0,09**	**−0,68**	**0,85**	**32,70**
Subtotal	**walking**	**0,17**	**−0,45**	**0,78**	**50,31**
Subtotal	**concepts**	**0,18**	**−0,58**	**0,94**	**16,98**
Total		**0,14**	**−0,55**	**0,83**	**100,00**
Subgroup heterogeneity: I^2 = 65.4%					
Proprioception (n = 124)					
Kum et al., 2017	treadmill	0,62	0,11	1,13	74,19
Park et al., 2011a	walking	0,93	0,15	1,72	16,13
Han et al., 2013	walking	1,05	0,42	1,68	9,68
Subtotal	**treadmill**	**0,62**	**0,11**	**1,13**	**74,19**
Subtotal	**walking**	**0,98**	**0,25**	**1,70**	**25,81**
Total		**0,71**	**0,14**	**1,28**	**100,00**
Subgroup heterogeneity: I^2 = 44.0%					
Health related quality of life (n = 92)					
Lee et al., 2018	treadmill	0,19	−0,51	0,89	65,22
Eyvaz et al., 2018	walking	0,30	−0,21	0,81	34,78
Total		**0,23**	**−0,41**	**0,86**	**100,00**
Subgroup heterogeneity: I^2 = 0.0%					

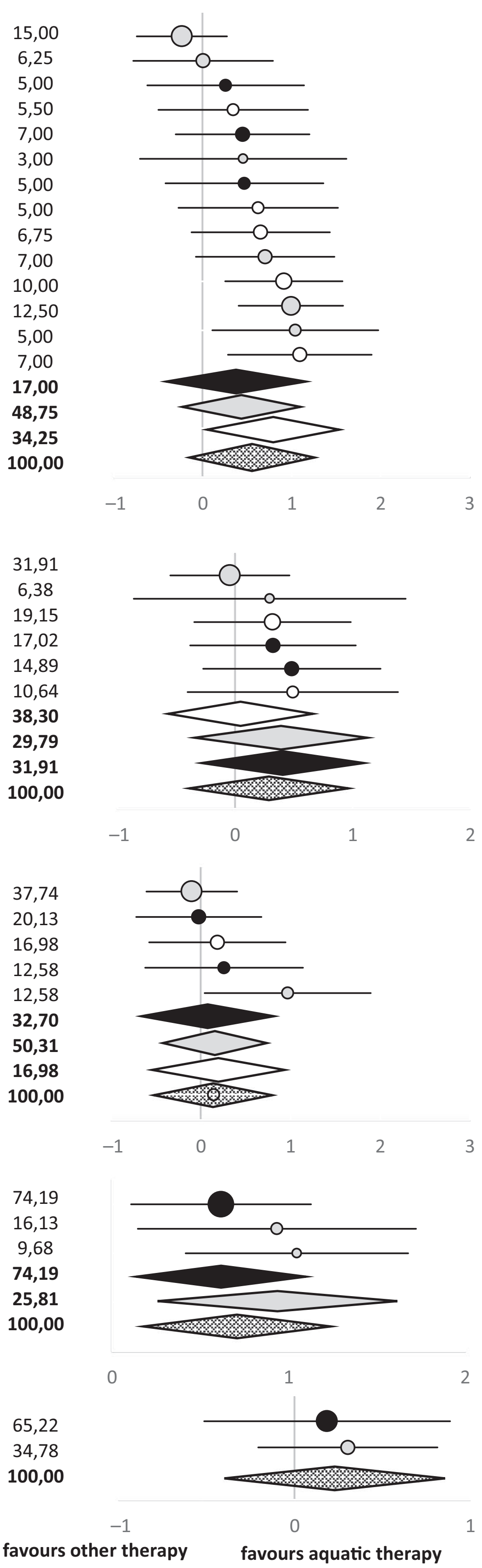


FIGURE 3 (Continued)

3.2.3 | Effectiveness

The data indicate that aquatic therapy is superior to most of other interventions in supporting balance, walking, muscular strength, cardiorespiratory fitness, health-relevant physiological indicators, health-related quality of life, and proprioception. Only on ADL independence, water- and land-based therapies induced similar effects. The studies show homogeneity of effect sizes on overall score, walking, muscular strength, proprioception, and health-related quality of life, but not on balance, ADL independence, health-relevant physiological indicators, and cardiorespiratory fitness. Established concepts of water-based therapy show the highest effects compared with land-based interventions. Aquatic treadmill walking demonstrates the lowest effects.

3.3 | Comparison of aquatic techniques

There exists currently only one study[49] which compared the effects of different aquatic therapy methods (Table 3, Figure 4).

3.3.1 | Participants and interventions

Twenty stroke patients were enrolled 16 months after an acute incident. Eighteen sessions either of strength and stretching based aquatic therapy or of Ai Chi method based aquatic therapy, with a duration of 60 minutes, were applied. The water at 35° was 1.2 meters deep. The exercise intensity was not specified.

Parameters assessed: The study evaluated:

- gait (gait speed, gait cadence, stride length, stride time, stride length variability, stride time variability, spatial asymmetry ratio, and temporal asymmetry ratio)
- balance (Berg Balance Scale, Limits of Stability Test)
- muscular function/strength of lower limbs (Fugl-Meyer-Assessment)

Pre- and post-evaluation but not follow-up examination was performed in this study.

3.3.2 | Effectiveness

The data indicate that Ai Chi method based aquatic therapy is superior to strength and stretching-based aquatic therapy in supporting balance and muscular function/strength of lower limbs after a stroke. No intervention-induced differences were detected on gait.

4 | DISCUSSION

This systematic review and meta-analysis aims to evaluate the effectiveness of water-based therapy in supporting the recovery after a stroke. The available data indicate that: (1) water-based therapy considerably reduces stroke-induced disabilities compared to no interventions; (2) water-based therapy supports the recovery after a stroke significantly better than land-based therapy; (3) established concepts of water-based therapy (such as the Halliwick, Ai Chi, Watsu, or Bad Ragaz Ring methods) are the most effective, aquatic treadmill walking is the least effective in supporting stroke recovery, when compared to other water-based methods. Adverse intervention-induced events were not described. However, the current data are too limited for evidence-based rehabilitation and future research should devote more attention to this important topic. We will discuss the curative potential of aquatic therapy in common stroke-induced disabilities.

4.1 | Balance

We found overall 22 trials (*N* = 688), that test the potential of aquatic therapy on reduction of balance disability after stroke.[23-26,28,30,31,33-40,42-44,46-49] Thus, we included more studies than previous reviews and meta-analyses,[7,8,10] which identified between four and eleven appropriate trials. Our data indicate that aquatic therapy significantly improves the balance ability in comparison with no intervention. Furthermore, its effectiveness is significantly superior to essentially all forms of land-based therapy. These findings confirm results of previous studies.[7,8,10] Our data give a hint that different water-based therapy methods may induce significantly different balance recovery in this cohort. Water-based gait and balance exercises are more effective than treadmill walking in comparison with no intervention. Established concepts of water-based therapy induced the greatest, aquatic treadmill training the smallest improvement of balance ability in comparison with land-based interventions. The established Ai Chi concept induced significantly greater effect than water-based stretching and strengthening in a direct comparison of both water-based therapy methods. These findings have not been detected in previous analysis.[7,8,10] Balance and coordination deficits are one of the most frequent stroke-induced disabilities,[50] and are associated with increased fall risk,[51] as well as with difficulties during activities of daily living and during reintegration into the community.[50]

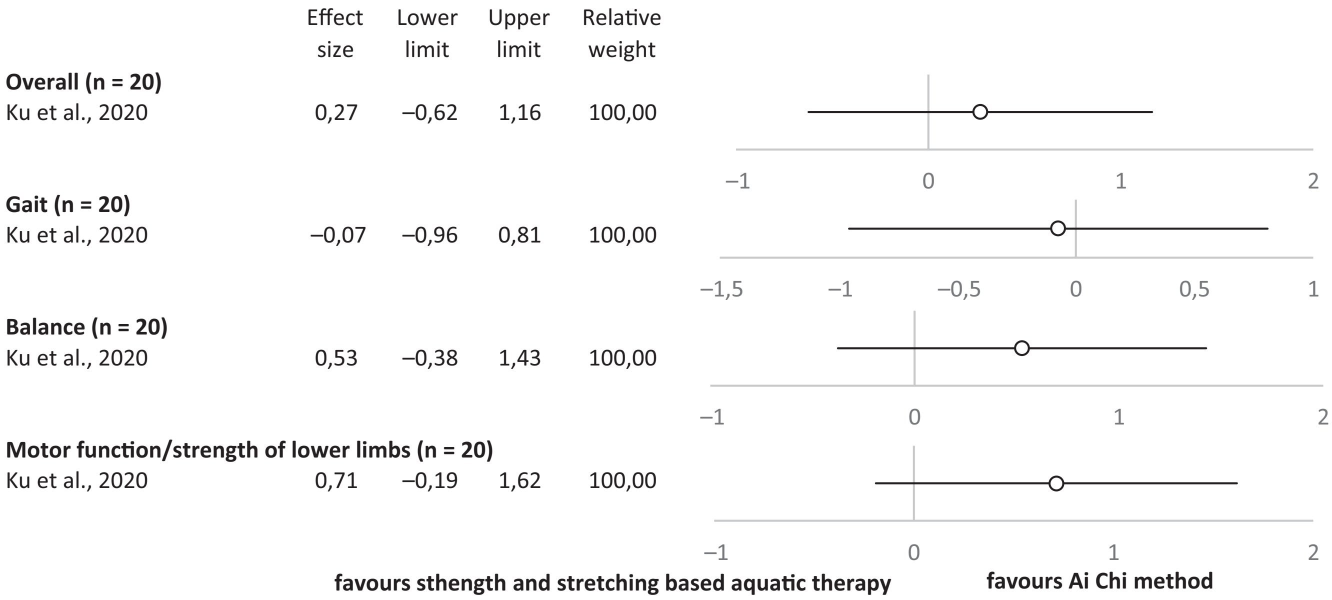
4.2 | Walking ability

Overall 19 controlled trials (*N* = 616) investigated the effectiveness of water-based therapy on walking ability in stroke patients.[22-24,26,29-31,33-36,38,41,42,45-49] Previous reviews and meta-analyses found between 10 and 12 controlled studies about this topic.[7,8] Our data clearly show that aquatic therapy is highly efficient in supporting walking ability in comparison with no intervention. Furthermore, aquatic therapy shows to be more effective than almost all land-based interventions. Similar data were detected in previous studies.[7,8] Our data are inconsistent regarding the different effectiveness of different water-based therapy methods. On

TABLE 3 Overview of studies comparing different aquatic therapy methods in supporting stroke recovery.

Reference	Subjects number / gender /age (years)	Time since stroke	Stroke etiology / affected hemisphere	Study design / sessions number / PEDro scale (score)	Intervention (duration, exercise types, exercise intensity, water environment characteristics)	Results / Used assessments
Ku et al. (2020)	20 / 14 males, 6 females / 55 ± 7 years	16 ± 15 months	13 ischemic, 4 hemorrhagic, 3 mixed / 13 right, 7 left	parallel groups (10 + 10) / 18 sessions / 8	60 min aquatic therapy (Ai Chi method; intensity na; 1.2 m deep water at 35°C)	AiChi method significantly better: Berg balance Scale, Fugl-Meyer-Assessment, Limits of Stability Test (endpoint excursion, maximal excursion, directional control, movement velocity), gait speed
					60 min aquatic therapy (stretching, strengthening; intensity na; 1.2 m deep water at 35°C)	no significant differences: gait cadence, stride length, stride time, stride length variability, stride time variability, spatial asymmetry ratio, temporal asymmetry ratio

Abbreviations: °C, grad Celsius; m, meter; min, minute; na, not available, not applicable.



	Effect size	Lower limit	Upper limit	Relative weight
Overall (n = 20)				
Ku et al., 2020	0,27	–0,62	1,16	100,00
Gait (n = 20)				
Ku et al., 2020	–0,07	–0,96	0,81	100,00
Balance (n = 20)				
Ku et al., 2020	0,53	–0,38	1,43	100,00
Motor function/strength of lower limbs (n = 20)				
Ku et al., 2020	0,71	–0,19	1,62	100,00

FIGURE 4 Overview of effect sizes, 95% confidence intervals and homogeneity for studies comparing different aquatic therapy methods in supporting stroke recovery.

TABLE 4 Methodological quality of the included studies - assessed with the 10-item Physiotherapy Evidence Database (PEDro) scale

PEDro scale items	Matsumo et al., 2016	Kim et al., 2016	Kim et al., 2015a	Park et al., 2014	Aidar et al., 2018	Aidar et al., 2013	Lai et al., 2005	Lee et al., 2018	Han et al., 2018	Tripp et al., 2014	Chan et al., 2017	Zhang et al., 2016	Funari et al., 2014
Eligibility criteria specified	+	+	+	+	+	+	+	+	+	+	+	+	+
Random allocation	0	1	1	1	1	1	0	1	1	1	1	1	1
Concealed allocation	0	0	0	0	1	0	0	1	1	1	1	1	0
Comparable baseline	1	1	1	1	1	1	1	1	1	1	1	1	1
Subject blinding	0	0	0	0	0	0	0	0	0	0	0	0	0
Therapist blinding	0	0	0	0	0	0	0	0	0	0	0	0	0
Assessor blinding	1	0	0	0	0	1	0	0	0	1	1	1	1
Less than 15% dropouts	1	0	0	1	0	0	0	1	0	0	0	0	0
Intention-to-treat analysis	0	0	0	0	0	0	0	1	0	0	0	0	0
Between-group comparison	1	1	1	1	1	1	1	1	1	1	1	1	1
Point estimates and variability	1	1	1	1	1	1	1	1	1	1	1	1	1
PEDro score total (0–10)	5	4	4	5	5	5	3	7	5	6	6	6	5

the one hand, established concepts of water-based therapy have greater effects than aquatic treadmill training and water-based walking compared with land-based interventions. On the other hand, the established Ai Chi concept induced a similar effect as water-based strengthening and stretching in a direct comparison of both water-based methods. A direct comparison of diverse water-based therapy strategies should be investigated more fully in future studies. Walking independently is the most common rehabilitation goal after stroke.[52] Despite this, 50% of stroke patients suffer from gait disability a half year after an acute incident.[53] For these reasons, the development of powerful therapy strategies for supporting gait recovery after stroke is one of the top research priorities in neurorehabilitation.[4]

4.3 | Muscular strength

Overall seven controlled trials (N = 208) investigated the effects of water-based intervention on the muscular strength of lower limbs.[28,32,41,46-49] The available data indicate that water-based exercises are superior to land-based exercises in supporting this ability. The same results were found in a previous meta-analysis, which detected four appropriate studies to this topic.8 Our data indicate that only aquatic treadmill walking and established concepts of water-based therapies induce additional effects on muscular strength in comparison with land-based interventions. Water-based walking and balance exercises do not differ from land-based interventions in supporting muscular strength. A direct comparison of water-based interventions shows similar results: the established Ai Chi concept induces greater effects than water-based stretching and strengthening. Future research could compare water-based therapy with force-oriented therapy strategies (such as resistance training) on improving muscular force in this cohort. The potential of therapies to support muscular force in the affected and the non-affected hemi body has a great clinical importance. Muscular force insufficiency and muscular imbalances within the affected upper limb are considered as key causes of hemiparetic gait abnormalities,[54] and of reduced fitness level.[55] Furthermore, reduced muscular mass and muscular strength (stroke-related sarcopenia) are observed in both the affected as well as non-affected hemi body six months after an acute incident.[56]

Zhu et al., 2016	Saleh et al., 2019	Kim et al., 2015b	Lee et al., 2010	Park et al., 2012	Jung et al., 2014	Han et al., 2013	Kum et al., 2017	Cha et al., 2017	Park et al., 2011a	Park et al., 2011b	Park et al., 2016	Eyvaz et al., 2018	Noh et al., 2008	Chu et al., 2004	Lai et al., 2005	Ku et al., 2020
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1
1	1	0	1	1	0	0	0	1	0	0	0	0	1	1	0	1
1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	1
0	0	0	1	0	1	1	1	0	0	0	0	1	0	0	0	1
0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	5	4	7	5	5	4	5	7	3	4	4	5	6	6	3	7

4.4 | ADL independence

Five studies (*N* = 159) were identified that compare aquatic training and land-based training on supporting ADL independence.[28-30,36,46] Our analysis indicates no significantly different effectiveness of either therapy strategy. A previous meta-analysis shows the same result.7 Another meta-analysis, which revealed the effect of water-based exercises in diverse neurological diseases, found no superior effect of aquatic therapy neither in stroke nor in Parkinson´s disease.[10] However, the current data are insufficient for a definitive statement about the effectiveness of aquatic exercises on ADL independence. Future research should devote more attention to this important topic. 40% of people with stroke suffer from ADL disability three months after the acute incident.[57] In 20% of patients, ADL disability is present five years after the stroke.[58]

4.5 | Proprioception

Three trials (*N* = 124) have explored the effectiveness of aquatic training on proprioception in stroke patients up to now.[40,41,43] Their results demonstrate homogenously that aquatic therapy is more efficient than land-based interventions. Furthermore, water-based walking and balance exercises are more effective than aquatic treadmill walking in supporting this capability. Proprioception deficits are common post-stroke and may lead to impaired standing balance and restricted mobility.[59] Thus, proprioceptive screening is recommended for clinical practice and future research.[59]

4.6 | Health-related quality of life, emotional status

Five trials (*N* = 276) evaluated the impact of aquatic therapy on emotional status or health-related quality of life after stroke up to now.[22,26-28,46] Their results indicate (1) beneficial effects of water-based therapy on these outcomes, as well as (2) superior effects in comparison with land-based interventions. Unfortunately, the current evidence is insufficient for evidence-based rehabilitation. Future research should focus on this relevant topic. About 25% of patients reported a decrease of health-related quality of life in the first three months after stroke.[60] Furthermore, a significant number of stroke patients suffer from post-stroke depression, which leads to a greater disability as well as increased mortality.[61]

4.7 | Physiological indicators

Only two studies (*N* = 68) tested the impact of aquatic training of diverse physiological indicators.[28,31] The meta-analysis shows that aquatic training is beneficial in this area and its effect is superior in comparison with land-based training. Future research should try to explain the neurological background of diverse therapy strategies in this cohort. Animal studies demonstrate that early initiated moderate forced exercises reduce lesion volume and protect perilesional tissue against oxidative damage and inflammation, at least for the short term.[62] No data exist about the reparative effects of physical exercising in human stroke up to now.[63]

4.8 | Cardiorespiratory fitness

Three trials (*N* = 64) evaluated aquatic therapy on supporting cardiorespiratory fitness after stroke.[28,29,48] Their results indicate better effectiveness in comparison with land-based intervention. Water-based walking and balance exercises evoke greater improvement than aquatic treadmill walking, in comparison with land-based interventions. Future research could compare water-based exercises with endurance-oriented intervention (such as ergometer training) on this ability. The potential of therapies to support cardiovascular capacity is highly relevant for rehabilitation of stroke subjects. The available data demonstrate an extreme reduction of cardiorespiratory fitness (by 30–70%) in these patients.[64] This is coupled with enhanced energetic requirements during activities of daily living, because of motor deficit.[65] These limitations lead to an inability to carry out the activities of daily living in a large part of patients.[65] Furthermore, reduced cardiorespiratory capacity is associated with secondary stroke risks.[63]

4.9 | Spasticity

Only one trial (*N* = 120) tested the potential of aquatic therapy on spasticity after stroke.[22] Its results indicate high effectiveness of this therapy form in comparison with no intervention. The lack of data in this area is striking considering the fact that about 30% of stroke victims suffer from this disease.[66] This condition can induce pain, ankylosis, tendon retraction, or muscle weakness.[66] All this can limit ADL independency, quality of life as well as rehabilitation progress.[67]

5 | STRENGTH AND LIMITATIONS

There are obvious strength and limitations of this manuscript. An important aspect is that this manuscript included and analyzed substantially more studies than previous reviews and meta-analyses. Moreover, this is the first meta-analysis that investigates the potential of water-based therapy on reducing cognitive and emotional decline as well as spasticity after a stroke. This is also the first meta-analysis that compares the effectiveness of different water-based therapy methods. A weakness of our meta-analysis is the inconsistency of studies regarding their methodological design (parallel, crossover), interventions (different aquatic therapy methods, different control interventions, and different intervention durations), and outcomes (more than fifty outcomes were pooled in eight areas). This all may be the reasons for the high inconsistency of effect sizes detected. Another limitation of our manuscript is the high inconsistency of the methodological quality of the studies analyzed. The most frequent methodological deficiencies are (1) absence of subjects, therapist and/or assessor blinding, (2) absence of statement about the number of subjects from whom key outcomes were obtained, and (3) absence of intention to treat analysis (Table 4). This all may hamper the interpretation of the data. Furthermore, no data exist about the long-term effects of water-based therapy in this cohort. Thus, we cannot make any explicit statements on the persistence of the positive effects of this therapy form.

6 | CONCLUSIONS

The meta-analysis presented here shows that water-based therapy is highly effective in supporting gait, balance, spasticity, and physiological indicators and moderately effective in supporting emotional status and health-related quality of life in stroke patients. Furthermore, aquatic therapy is superior to land-based interventions on balance, gait, muscular strength, proprioception, health-related quality of life, physiological indicators, and cardiorespiratory fitness. Only on independence in activities of daily living does the land- and water-based exercises induce similar effects. The current evidence on balance and walking ability is good. In contrast, the evidence on emotional status and spasticity is very limited. No evidence exists on cognitive abilities. Future studies should fill this gap. The data suggest that the effectiveness of aquatic therapy depends on technique used. Standardized concepts are more effective than both aquatic treadmill walking, as well as water-based walking, balance training, strengthening, and stretching. Future research should more extensively investigate these technique-induced differences.

ACKNOWLEDGEMENT

Open access funding enabled and organized by ProjektDEAL.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

ORCID

Jitka Veldema https://orcid.org/0000-0002-9184-9776

REFERENCES

1. Adamson J, Beswick A, Ebrahim S. Is stroke the most common cause of disability? *J Stroke Cerebrovasc Dis*. 2004;*13*:171-177.
2. Maaijwee NA, Rutten-Jacobs LC, Schaapsmeerders P, van Dijk EJ, de Leeuw FE. Ischaemic stroke in young adults: risk factors and long-term consequences. *Nat Rev Neurol*. 2014;*10*:315-325.
3. Avan A, Digaleh H, Di Napoli M, et al. Socioeconomic status and stroke incidence, prevalence, mortality, and worldwide burden: an ecological analysis from the Global Burden of Disease Study 2017. *BMC Med*. 2019;*17*:191.
4. Pollock A, St George B, Fenton M, Firkins L. Top ten research priorities relating to life after stroke. *Lancet Neurol*. 2012;*11*:209.
5. Becker BE. Aquatic therapy: scientific foundations and clinical rehabilitation applications. *PM R*. 2009;1:859-872.
6. Brody LT, Geigle PR. *Aquatic exercise for rehabilitation and training*. Champaign: Human Kinetics; 2009.
7. Iliescu AM, McIntyre A, Wiener J, et al. Evaluating the effectiveness of aquatic therapy on mobility, balance, and level of functional independence in stroke rehabilitation: a systematic review and meta-analysis. *Clin Rehabil*. 2020;*34*:56-68.
8. Saquetto MB, da Silva CM, Martinez BP, et al. Water-Based Exercise on Functioning and Quality of Life in Poststroke Persons: A Systematic Review and Meta-Analysis. *J Stroke Cerebrovasc Dis*. 2019;*28*:104341.
9. Iatridou G, Pelidou HS, Varvarousis D, et al. The effectiveness of hydrokinesiotherapy on postural balance of hemiplegic patients after stroke: a systematic review and meta-analysis. *Clin Rehabil*. 2018;*32*:583-593.
10. Moritz TA, Snowdon DA, Peiris CL. Combining aquatic physiotherapy with usual care physiotherapy for people with neurological conditions: A systematic review. *Physiother Res Int*. 2020;*25*:e1813.
11. Stanton R, Reaburn P. Exercise and the treatment of depression: a review of the exercise program variables. *J Sci Med Sport*. 2014;*17*:177-182.
12. Lloyd M, Skelton DA, Mead GE, Williams B, van Wijck F. Physical fitness interventions for nonambulatory stroke survivors: A mixed-methods systematic review and meta-analysis. *Brain Behav*. 2018;8:e01000.
13. Matsumoto S, Shimodozono M, Etoh S, et al. Anti-spastic effects of footbaths in post-stroke patients: a proof-of-principle study. *Complement Ther Med*. 2014;*22*:1001-1009.
14. Veldema J, Jansen P. Ergometer Training in Stroke Rehabilitation: Systematic Review and Meta-analysis. *Arch Phys Med Rehabil*. 2020;*101*:674-689.
15. Veldema J, Jansen P. Resistance training in stroke rehabilitation: systematic review and meta-analysis. *Clin Rehabil*. 2020;*34*:1173-1197.
16. Moher D, Shamseer L, Clarke M, et al. Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 statement. *Syst Rev*. 2015;*4*:1.
17. Macedo LG, Elkins MR, Maher CG, Moseley AM, Herbert RD, Sherrington C. There was evidence of convergent and construct validity of Physiotherapy Evidence Database quality scale for physiotherapy trials. *J Clin Epidemiol*. 2010;*63*:920-925.
18. Lenhard W, Lenhard A. Calculation of Effect Sizes; 2016. Retrieved from: 11 https://www.psychometrica.de/effect_size.html. Accessed October 2020.
19. Centre for Evaluation & Monitoring. Effect size calculator; 2000. 13 https://www.cem.org/effect-size-calculator. Accessed October 2020.
20. Campbell MJ, Machin D, Walters SJ. *Medical Statistics: A Textbook for the Health Sciences*, 4th edn. 2007.
21. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;*327*:557-560.
22. Matsumoto S, Uema T, Ikeda K, et al. Effect of underwater exercise on lower-extremity function and quality of life in post-stroke patients: a pilot controlled clinical trial. *J Altern Complement Med*. 2016;*22*:635-641.
23. Kim K, Lee DK, Kim EK. Effect of aquatic dual-task training on balance and gait in stroke patients. *J Phys Ther Sci*. 2016;*28*:2044-2047.

24. Kim K, Lee DK, Jung SI. Effect of coordination movement using the PNF pattern underwater on the balance and gait of stroke patients. *J Phys Ther Sci*. 2015a;*27*:3699-3701.
25. Park SW, Lee KJ, Shin DC, Shin SH, Lee MM, Song CH. The effect of underwater gait training on balance ability of stroke patients. *J Phys Ther Sci*. 2014;*26*:899-903.
26. Aidar FJ, Jacó de Oliveira R, Gama de Matos D, et al. A randomized trial of the effects of an aquatic exercise program on depression, anxiety levels, and functional capacity of people who suffered an ischemic stroke. *J Sports Med Phys Fitness*. 2018;*58*:1171-1177.
27. Aidar FJ, Garrido ND, Silva AJ, Reis VM, Marinho DA, de Oliviera RJ. Effects of aquatic exercise on depression and anxiety in ischemic stroke subjects. *Health*. 2013;*5*:222-228.
28. Lee SY, Im SH, Kim BR, Han EY. The effects of a motorized aquatic treadmill exercise program on muscle strength, cardiorespiratory fitness, and clinical function in subacute stroke patients: a randomized controlled pilot trial. *Am J Phys Med Rehabil*. 2018;*97*:533-540.
29. Han EY, Im SH. Effects of a 6-week aquatic treadmill exercise program on cardiorespiratory fitness and walking endurance in subacute stroke patients: a pilot trial. *J Cardiopulm Rehabil Prev*. 2018;*38*:314-319.
30. Tripp F, Krakow K. Effects of an aquatic therapy approach (Halliwick-Therapy) on functional mobility in subacute stroke patients: a randomized controlled trial. *Clin Rehabil*. 2014;*28*:432-439.
31. Chan K, Phadke CP, Stremler D, et al. The effect of water-based exercises on balance in persons post-stroke: a randomized controlled trial. *Top Stroke Rehabil*. 2017;*24*:228-235.
32. Zhang Y, Wang YZ, Huang LP, et al. Aquatic therapy improves outcomes for subacute stroke patients by enhancing muscular strength of paretic lower limbs without increasing spasticity: a randomized controlled trial. *Am J Phys Med Rehabil*. 2016;*95*:840-849.
33. Furnari A, Calabrò RS, Gervasi G, et al. Is hydrokinesitherapy effective on gait and balance in patients with stroke? A clinical and baropodometric investigation. *Brain Inj*. 2014;*28*:1109-1114.
34. Zhu Z, Cui L, Yin M, et al. Hydrotherapy vs. conventional land-based exercise for improving walking and balance after stroke: a randomized controlled trial. *Clin Rehabil*. 2016;*30*:587-593.
35. Saleh MSM, Rehab NI, Aly SMA. Effect of aquatic versus land motor dual task training on balance and gait of patients with chronic stroke: A randomized controlled trial. *NeuroRehabilitation*. 2019;*44*:485-492.
36. Kim EK, Lee DK, Kim YM. Effects of aquatic PNF lower extremity patterns on balance and ADL of stroke patients. *J Phys Ther Sci*. 2015b;*27*:213-215.
37. Lee D, Ko T, Cho Y. Effects on static and dynamic balance of task-oriented training for patients in water or on land. *J Phys Ther Sci*. 2010;*22*:331-336.
38. Park SE, Kim SH, Lee SB, et al. Comparison of underwater and overground treadmill walking to improve gait pattern and muscle strength after stroke. *J Phys Ther Sci*. 2012;*24*:1087-1090.
39. Jung J, Lee J, Chung E, Kim K. The effect of obstacle training in water on static balance of chronic stroke patients. *J Phys Ther Sci*. 2014;*26*:437-440.
40. Han SK, Kim MC, An CS. Comparison of effects of a proprioceptive exercise program in water and on land the balance of chronic stroke patients. *J Phys Ther Sci*. 2013;*25*:1219-1222.
41. Kum D-M, Shin W-S. Effect of backward walking training using an underwater treadmill on muscle strength, proprioception and gait ability in persons with stroke. *Phy Ther Rehabil Sci*. 2017;*6*:120-126.
42. Cha HG, Shin YJ, Kim MK. Effects of the Bad Ragaz Ring Method on muscle activation of the lower limbs and balance ability in chronic stroke: A randomised controlled trial. *Hong Kong Physiother J*. 2017;*37*:39-45.
43. Park J, Lee D, Lee S, et al. Comparison of the effects of exercise by chronic stroke patients in aquatic and land environments. *J Phys Ther Sci*. 2011a;*23*:821-824.
44. Park J, Roh H. Postural balance of stroke survivors in aquatic and land environments. *J Phys Ther Sci*. 2011;*23*:905-908.
45. Park BS, Noh JW, Kim MY, et al. A comparative study of the effects of trunk exercise program in aquatic and land-based therapy on gait in hemiplegic stroke patients. *J Phys Ther Sci*. 2016;*28*:1904-1908.
46. Eyvaz N, Dundar U, Yesil H. Effects of water-based and land-based exercises on walking and balance functions of patients with hemiplegia. *NeuroRehabilitation*. 2018;*43*:237-246.
47. Noh DK, Lim JY, Shin HI, Paik NJ. The effect of aquatic therapy on postural balance and muscle strength in stroke survivors–a randomized controlled pilot trial. *Clin Rehabil*. 2008;*22*:966-976.
48. Chu KS, Eng JJ, Dawson AS, Harris JE, Ozkaplan A, Gylfadóttir S. Water-based exercise for cardiovascular fitness in people with chronic stroke: a randomized controlled trial. *Arch Phys Med Rehabil*. 2004;*85*:870-874.
49. Ku PH, Chen SF, Yang YR, Lai TC, Wang RY. The effects of Ai Chi for balance in individuals with chronic stroke: a randomized controlled trial. *Sci Rep*. 2020;*10*:1201.
50. Iruthayarajah J, McIntyre A, Cotoi A, Macaluso S, Teasell R. The use of virtual reality for balance among individuals with chronic stroke: a systematic review and meta-analysis. *Top Stroke Rehabil*. 2017;*24*:68-79.
51. Minet LR, Peterson E, von Koch L, Ytterberg C. Occurrence and Predictors of Falls in People With Stroke: Six-Year Prospective Study. *Stroke*. 2015;*46*:2688-2690.
52. Bohannon RW, Andrews AW, Smith MB. Rehabilitation goals of patients with hemiplegia. *Int J Rehabil Res*. 1988;*11*:181-183.
53. Jørgensen HS, Nakayama H, Raaschou HO, Olsen TS. Recovery of walking function in stroke patients: the Copenhagen Stroke Study. *Arch Phys Med Rehabil*. 1995;*76*:27-32.
54. Souissi H, Zory R, Boudarham J, Pradon D, Roche N, Gerus P. Muscle force strategies for poststroke hemiparetic patients during gait. *Top Stroke Rehabil*. 2019;*26*:58-65.
55. Ryan AS, Dobrovolny CL, Smith GV, Silver KH, Macko RF. Hemiparetic muscle atrophy and increased intramuscular fat in stroke patients. *Arch Phys Med Rehabil*. 2002;*83*:1703-1707.
56. Scherbakov N, von Haehling S, Anker SD, Dirnagl U, Doehner W. Stroke induced Sarcopenia: muscle wasting and disability after stroke. *Int J Cardiol*. 2013;*170*:89-94.
57. Gargano JW, Reeves MJ. Paul Coverdell National Acute Stroke Registry Michigan Prototype Investigators. Sex differences in stroke recovery and stroke-specific quality of life: results from a statewide stroke registry. *Stroke*. 2007;*38*:2541-2548.
58. Rejnö Å, Nasic S, Bjälkefur K, Bertholds E, Jood K. Changes in functional outcome over five years after stroke. *Brain Behav*. 2019;*9*(6):e01300.
59. Rand D. Mobility, balance and balance confidence - correlations with daily living of individuals with and without mild proprioception deficits post-stroke. *NeuroRehabilitation*. 2018;*43*:219-226.
60. Lo Buono V, Corallo F, Bramanti P, Marino S. Coping strategies and health-related quality of life after stroke. *J Health Psychol*. 2017;*22*:16-28.
61. Robinson RG, Jorge RE. Post-stroke depression: a review. *Am J Psychiatry*. 2016;*173*:221-231.
62. Austin MW, Ploughman M, Glynn L, Corbett D. Aerobic exercise effects on neuroprotection and brain repair following stroke: a systematic review and perspective. *Neurosci Res*. 2014;*87*:8-15.
63. Ploughman M, Kelly LP. Four birds with one stone? Reparative, neuroplastic, cardiorespiratory, and metabolic benefits of aerobic exercise poststroke. *Curr Opin Neurol*. 2016;*29*:684-692.
64. Smith AC, Saunders DH, Mead G. Cardiorespiratory fitness after stroke: a systematic review. *Int J Stroke*. 2012;*7*:499-510.

65. Kramer S, Johnson L, Bernhardt J, Cumming T. Energy expenditure and cost during walking after stroke: a systematic review. *Arch Phys Med Rehabil*. 2016;*97*:619-632.
66. Thibaut A, Chatelle C, Ziegler E, Bruno MA, Laureys S, Gosseries O. Spasticity after stroke: physiology, assessment and treatment. *Brain Inj*. 2013;*27*:1093-1105.
67. Doan QV, Brashear A, Gillard PJ, et al. Relationship between disability and health-related quality of life and caregiver burden in patients with upper limb poststroke spasticity. *PM R*. 2012;*4*:4-10.

How to cite this article: Veldema J, Jansen P. Aquatic therapy in stroke rehabilitation: systematic review and meta-analysis. *Acta Neurol Scand*. 2020;00:1–21. https://doi.org/10.1111/ane.13371