

Systematic Review

Effects of Aquatic Exercise Training on Cardiovascular Functions and Cardiometabolic Risk Factors in Overweight and Obese Individuals: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

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Abstract

Excess adiposity increases cardiovascular and cardiometabolic risks, while aquatic exercise may reduce mechanical barriers to participation. This systematic review and meta-analysis examined aquatic exercise training in individuals with overweight or obesity. PubMed, Web of Science, and the Cochrane Library were searched through to June 2026. Eight randomized controlled trials involving 295 participants were included. Random-effects meta-analyses showed increased VO_2 max (MD 3.70 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, 95% CI 2.49–4.90; $p < 0.001$) and lower resting heart rate (MD -1.47 beats/min, 95% CI -2.73 to -0.21), systolic blood pressure (MD -4.50 mmHg, 95% CI -7.05 to -1.94), diastolic blood pressure (MD -2.17 mmHg, 95% CI -4.11 to -0.22), triglycerides (MD -15.75 mg/dL, 95% CI -23.12 to -8.39), and fasting glucose (MD -7.82 mg/dL, 95% CI -12.48 to -3.16). No significant pooled effects were observed for total cholesterol, HDL cholesterol, LDL cholesterol, BMI, or body fat percentage. Evidence certainty ranged from low to very low. Aquatic exercise may improve selected cardiovascular and metabolic outcomes, although small samples and heterogeneity limit confidence. Future research must focus on high-quality RCTs to further confirm these findings. PROSPERO: CRD420261340445.

Keywords: aquatic exercise; blood pressure; cardiorespiratory fitness; lipid profile; obesity



Academic Editor: Carmine Finelli

Received: 3 June 2026

Revised: 3 July 2026

Accepted: 5 July 2026

Published: 14 July 2026

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1. Introduction

Overweight and obesity represent a global epidemic and are key drivers that substantially contribute to the increasing burden of cardiovascular diseases (CVDs) [1]. According to the World Health Organization (WHO) 2025 report, the global prevalence of obesity has substantially increased since 1990, with approximately 2.5 billion individuals classified as overweight and over 890 million as obese. Obesity is a heterogeneous chronic disease state related to excess adiposity, abnormal adipose distribution, and/or adipose-tissue dysfunction rather than a uniform phenotype defined solely by body mass index (BMI) [2,3]. Excess visceral adiposity is strongly associated with impaired cardiovascular function, characterized by reduced cardiorespiratory fitness, elevated resting heart rate, inflammation,

beta-cell dysfunction, dyslipidemia, and insulin resistance [4]. These alterations increase the risk of cardiometabolic disorders, including coronary artery disease, hypertension, and type 2 diabetes, contributing to reduced functional capacity and increased healthcare burden [5].

Exercise plays a central role in improving one's body composition, lipid profile, glycemic control, muscle strength, and cardiorespiratory fitness in the overweight and obese population [6]. Both the American College of Sports Medicine (ACSM) and WHO recommend 60 min per day of moderate to vigorous-intensity physical activity per week, including three times per week for high-intensity training. Different exercise modalities influence cardiovascular health through distinct mechanisms; resistance training improves muscular health and arterial stiffness, and aerobic exercise enhances endothelial function and cardiac output, while combined training increases synergistic effects, collectively contributing to improved cardiovascular function [7]. Despite these beneficial effects of exercise for obesity and cardiovascular health, adherence to traditional land-based exercises like walking, jogging, and running remains challenging, particularly in the overweight and obese population. These activities impose a substantial load on the lower extremity joints, increasing the chances of musculoskeletal injuries [8]. This risk is significantly higher in individuals with excess body weight, where increased joint stress leads to pain and discomfort, ultimately reducing participation and leading to cessation of physical activity [9].

Aquatic exercise training is characterized by buoyancy, hydrostatic pressure, and drag forces, which distinguish its physiological demands from land-based exercise [10]. The unique characteristics of water, such as its non-weight-bearing nature, hydrostatic pressure, and thermal effects, relieve stress on joints, thus removing the mechanical load and pain during exercise, along with improving adherence compared with land-based exercise, make it more suitable for individuals with obesity [11]. Buoyancy reduces body-weight loading during movement, whereas drag increases with movement velocity and can be modified by the selected activity or equipment [12]. Water immersion also alters cardiovascular responses, including central blood-volume distribution, stroke volume, heart rate, and peripheral vascular resistance [13]. These characteristics raise the importance of examining cardiovascular and cardiometabolic effects of aquatic exercise in overweight and obese individuals. However, because water reduces gravitational loading, aquatic exercise may provide less bone-loading stimulus than land-based exercise, particularly when compared with weight-bearing training [14].

Moreover, individual studies have reported the beneficial effects of aquatic exercise training [15,16]. The overall evidence remains inconsistent, and a comprehensive synthesis of randomized controlled trials focusing on cardiometabolic outcomes in overweight and obese populations is lacking. Accordingly, clarifying the cardiovascular and cardiometabolic effects of aquatic exercise training may help clinicians and exercise physiologists prescribe an exercise option for individuals with overweight or obesity who experience pain-related difficulty with land-based activity. This systematic review and meta-analysis aimed to evaluate the effects of aquatic exercise on cardiovascular function and cardiometabolic risk factors in individuals with overweight and obesity, with particular consideration of its role as a rehabilitation-relevant intervention.

2. Materials and Methods

2.1. Registration and Study Design

This meta-analysis was registered with PROSPERO (CRD420261340445) and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-

Analyses (PRISMA) guidelines (Figure 1). In this systematic review and meta-analysis, only randomized controlled trials have been included.

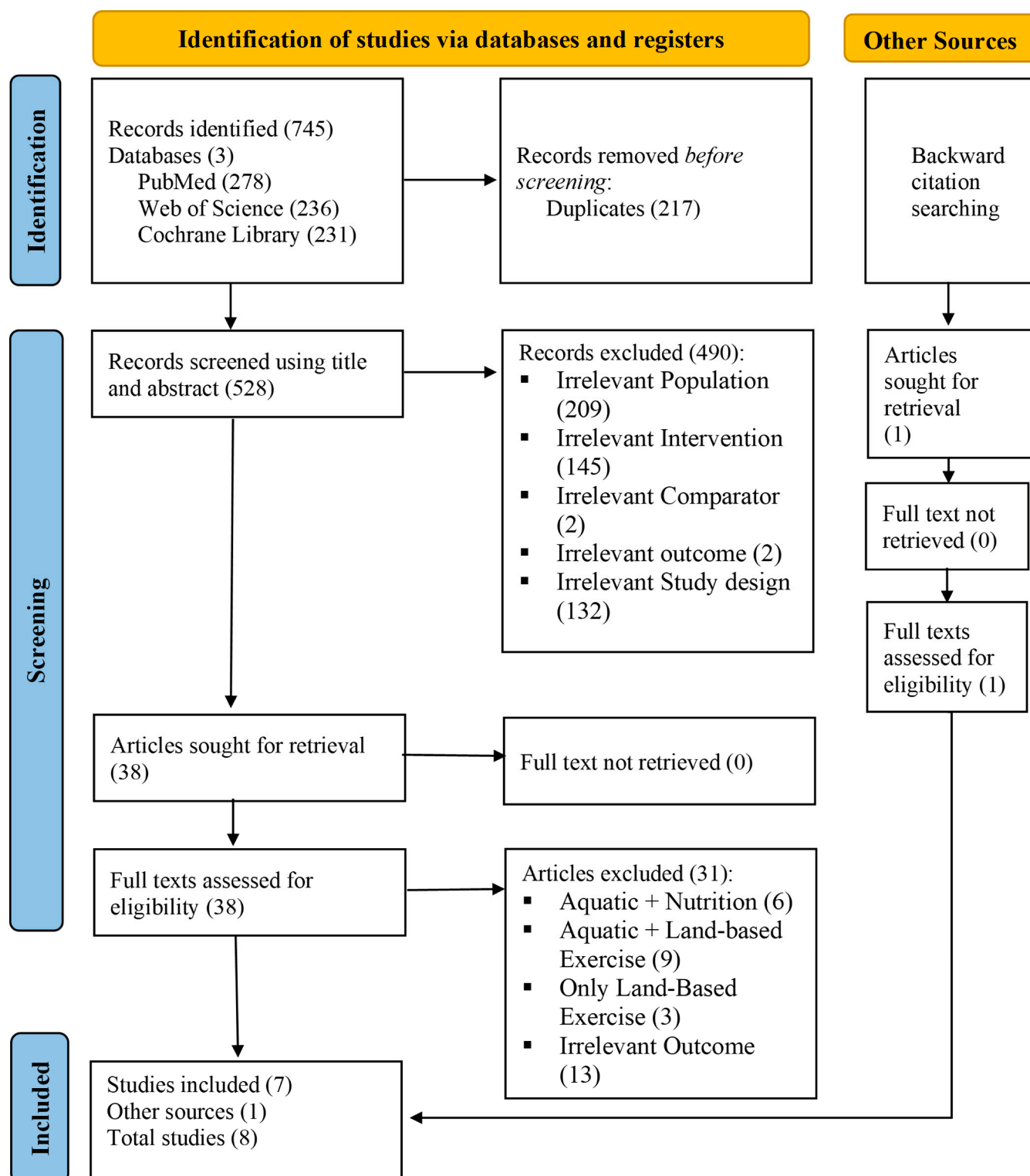


Figure 1. PRISMA flow diagram presenting the study selection methodology.

2.2. Inclusion and Exclusion Criteria

Studies were included based on the following PICOS criteria: population—individuals with overweight or obesity ($\text{BMI} \geq 25 \text{ kg/m}^2$); intervention—aquatic exercise interventions, including water aerobics, aquatic HIIT, water walking, and swimming-based training;

comparator—participants engaged exclusively in activities of daily living (ADLs) without structured exercise intervention; outcomes—cardiovascular and cardiometabolic outcomes, including VO₂ max, resting heart rate, blood pressure, lipid profile, BMI, and body fat. Study design: Randomized controlled trials. Although overweight and obesity are distinct BMI categories, both were eligible because each is associated with increased cardiovascular risk compared with a healthy weight; therefore, they were considered within the broader excess-adiposity population relevant to aquatic exercise interventions [17–19].

Studies were excluded if they did not involve aquatic exercise training as the primary intervention, did not involve overweight and obese individuals, lacked a comparator group, or were non-randomized controlled trials.

2.3. Information Sources and Search Strategy

Three databases were searched for relevant articles: the Cochrane Library, PubMed, and Web of Science up until June 2026. The search string used was (((“aquatic exercise” OR “water-based exercise” OR “aquatic therapy” OR hydrotherapy OR “water aerobics” OR swimming OR “water walking” OR “aquatic HIIT”)) AND ((obes* OR overweight OR “body mass index” OR BMI OR adiposity OR “body fat” OR “body composition”))) AND ((“cardiovascular function” OR “cardiorespiratory fitness” OR VO₂ max OR “oxygen uptake” OR “heart rate” OR “blood pressure” OR hypertension OR “lipid profile” OR “total cholesterol” OR “high-density lipoprotein” OR HDL OR “low-density lipoprotein” OR LDL OR triglycerid* OR TG)). The search library was maintained in EndNote version 21. Two reviewers independently screened titles/abstracts and full texts. Disagreements were resolved through discussion with a third reviewer. Data from eligible studies were entered into a standardized extraction worksheet, including participant characteristics, intervention and comparator details, outcome means and standard deviation, and the instruments or laboratory methods reported by each trial. No wearable-derived physical activity or sedentary-behavior data were synthesized as review outcomes. Where a study used a heart rate monitor for exercise prescription or measured cardiovascular outcomes with a device, the manufacturer/model and protocol details are reported exactly as available in Supplementary Table S1. The primary studies differed in the completeness of device validation reporting; unreported model or validation information is labelled “not reported” rather than inferred.

2.4. Outcome Measures

The primary outcomes were cardiovascular functions, including cardiorespiratory fitness (VO₂ max), heart rate (BPM), and hemodynamic variables such as systolic and diastolic blood pressure (SBP, DBP). The secondary outcomes were categorized as cardiometabolic risk factors, like lipid profiles including total cholesterol (TC), low-density lipoproteins (LDLs), high-density lipoproteins (HDLs), and triglycerides (TGs), along with anthropometric measures such as body mass index (BMI) and body fat (BF). Outcomes were reported in standardized units: VO₂ max in mL/kg/min, heart rate in bpm, blood pressure in mmHg, lipid profiles in mg/dL, BMI in kg/m², and BF in percentage (%).

2.5. Assessment of the Certainty of Evidence

The risk of bias (ROB) for the included studies was assessed using the revised Cochrane risk of bias tool (ROB-2), which evaluates studies across five major domains: (I) randomization process, (II) deviation from intended outcomes, (III) missing outcome data, (IV) measurement of the outcome, and (V) selection of the reported results. Each of the included studies was classified as either low risk, some concerns raised, or high risk based on the overall assessment across the five domains. The ROB-2 tool provided a structured and transparent evaluation of methodological quality, thereby strengthening the credibility and

reliability of our findings. Certainty of evidence was assessed using the GRADE framework (Grading of Recommendations, Assessment, Development and Evaluation) via the Cochrane GRADE-pro software version 5.1.0 [7]. This approach assesses outcomes based on five domains, which were risk of bias, inconsistency, indirectness, imprecision, and publication bias, and evidence was categorized as high, moderate, low, or very low. The evidence certainty was graded based on (I) risk of bias assessed through ROB-2, (II) statistical heterogeneity (I^2) for inconsistency, (III) PICO alignment for indirectness, (IV) sample size and CI for imprecision, and (V) funnel plot for publication bias. This structured approach ensures a reproducible and transparent grading of evidence, enhancing the quality of our systematic review and meta-analysis.

2.6. Statistical Analysis

Post-intervention means and standard deviation values were pooled using mean differences (MDs) with 95% confidence intervals (CIs), calculated as aquatic exercise minus control. Random-effects models were fitted using restricted maximum likelihood estimation. When restricted maximum likelihood estimation did not converge during leave-one-out analyses, the DerSimonian–Laird estimator was used. Statistical heterogeneity was assessed using Cochran’s Q , I^2 , and τ^2 . Leave-one-out sensitivity analyses were conducted by sequentially removing one study from each pooled outcome. No correction for multiple comparisons was applied because each cardiovascular and cardiometabolic outcome was analyzed separately and interpreted cautiously. All analyses were conducted in RStudio version 2025.09.1+401 using R and the metafor package. The raw datasheet is available in Supplementary File S1.

3. Results

3.1. Search Strategy

A total of 745 articles were identified from three databases: PubMed (278), Cochrane (231), and Web of Science (236). After removing (217) duplicates, (528) reports remained for screening. Following title and abstract screening, (490) records were removed for having an ineligible population (209), intervention (145), comparator (2), outcome (2), and study design (132). Subsequently, (38) records were assessed for eligibility, and 31 were excluded for non-relevant outcomes (13) or non-relevant intervention (18). An additional article was identified from the references of the already included articles, bringing the total to eight studies in the systematic review and meta-analysis, as shown in Figure 1.

3.2. Characteristics of Included Studies

The eight included randomized controlled trials enrolled 295 participants with overweight or obesity, comprising 160 participants allocated to aquatic exercise and 135 to control conditions. Sample sizes ranged from 8 to 29 participants per study arm. Participants included children, young adults, middle-aged adults, and older adults. All trials compared aquatic exercise with control groups maintaining activities of daily living. Training frequency ranged from two to five sessions per week, with sessions lasting 20–60 min and intervention durations ranging from 8 to 28 weeks. The included studies evaluated cardiovascular functions, including VO_2 max, resting heart rate, and blood pressure, together with cardiometabolic risk factors, including lipid measures, BMI, body fat percentage, and fasting glucose, as summarized in Table 1.

Table 1. Cardiovascular and cardiometabolic outcomes in individuals with overweight and obesity.

Authors Names	Participant Attributes	Study Design	Control	Dosage	Cardiorespiratory Fitness	Hemodynamics	Lipid Profile	Anthropometric Measures	Glycemic Measures
Cheikh et al. [16]	AE: n: 16 26 ± 4.1 y/o CG: n: 11 23.3 ± 1.4 y/o	RCT	ADLs	F: 3 s/wk T: 50 min D: 10 wk	RHR ↓	SBP ↔, DBP ↔	TC ↔, LDLs ↑, HDLs ↓, TGs ↔	BMI ↔, BF ↔	Fasting glucose ↓
Nosrani et al. [20]	AE: n: 19 71.2 ± 5.19 y/o CG: n: 13 73.4 ± 5.8 y/o	RCT	ADLs	F: 2 s/wk T: 20–30 min D: 28 wk		SBP ↔, DBP ↔	TC ↔, LDLs ↔, HDLs ↔, TGs ↓	BMI ↔, BF ↔	Fasting glucose ↓
Eichel et al. [21]	AE: n: 29 50.7 ± 11.4 y/o CG: n: 25 54.0 ± 14.9 y/o	RCT	ADLs	F: 2 s/wk T: 45 min D: 10 wk		SBP ↔, DBP ↔	TC ↔, LDLs ↔, HDLs ↔, TGs ↓	BMI ↔	
Yu et al. [22]	AE: n: 21 22 ± 2 y/o CG: n: 15 24.9 ± 7.1 y/o	RCT	ADLs	F: 3 s/wk T: 1 h D: 8 wk	VO ₂ max ↔, RHR ↔	SBP ↔, DBP ↔		BMI ↔, BF ↔	
Abadi et al. [23]	AE: n: 25: 22.6 ± 1.9 y/o CG: n: 25 21.1 ± 1.7 y/o	RCT	ADLs	F: 3 s/wk T: 1 h D: 12 wk	VO ₂ max ↑, RHR ↔			BMI ↓	
Kamalakkannan & Kumar. [24]	AE: n: 20 18–20 y/o CG: n: 20 18–20 y/o	RCT	ADLs	F: 5 s/week T: 1 h D: 12 wk	VO ₂ max ↑, RHR ↔	SBP ↓, DBP ↔	LDLs ↓, HDLs ↑, TGs ↓		
Lopes et al. [25]	AE: n: 22 12.05 ± 1.6 y/o CG: n = 18 12.4 ± 1.6 y/o	RCT	ADLs	F: 3 s/week T: 1 h D: 12 wk			TC ↔, LDLs ↔, HDLs ↑, TGs ↔	BMI ↓	Fasting glucose ↔

Table 1. Cont.

Authors Names	Participant Attributes	Study Design	Control	Dosage	Cardiorespiratory Fitness	Hemodynamics	Lipid Profile	Anthropometric Measures	Glycemic Measures
Soori et al. [26]	AE: n: 8 45–60 y/o CG: n: 8 45–60 y/o	RCT	ADLs	F: 3 s/wk T: 45 min D: 10 wk			TC ↔, HDLs ↔, LDLs ↔, TGs ↔	BMI ↔, BF ↔	

Table 1: Summarized effects of aquatic exercise on cardiovascular functions and cardiometabolic risk factors in overweight and obese individuals: aquatic exercise training group (AE), number of participants (n), control group (CG), years old (y/o), randomized controlled trial (RCT), activities of daily living (ADLs), frequency (F), time (T), duration (D), week (wk), increased compared with CG (↑), decreased compared with CG (↓), non-significant change compared with CG (↔), cardiorespiratory fitness (VO₂ max), resting heart rate (RHR), systolic blood pressure (SBP), diastolic blood pressure (DBP), total cholesterol (TC), low-density lipoproteins (LDLs), high-density lipoproteins (HDLs), triglycerides (TGs), body mass index (BMI), and body fat (BF).

Effects of Aquatic Exercise on Outcome Measures

Across three studies (126 participants), aquatic exercise significantly improved VO_2 max compared with control (MD 3.70 mL·kg⁻¹·min⁻¹, 95% CI 2.49 to 4.90; $p < 0.001$; $I^2 = 0\%$). This result remained statistically significant in all leave-one-out analyses. Resting heart rate was significantly lower across four studies (153 participants; MD -1.47 beats/min, 95% CI -2.73 to -0.21; $p = 0.022$; $I^2 = 0\%$); however, the pooled effect became non-significant after the removal of Cheikh et al. or Abadi et al. Systolic blood pressure was significantly reduced across five studies (189 participants; MD -4.50 mmHg, 95% CI -7.05 to -1.94; $p = 0.001$; $I^2 = 0\%$), although this effect became non-significant after exclusion of Kamalakkannan and Kumar. Diastolic blood pressure was also significantly lower (MD -2.17 mmHg, 95% CI -4.11 to -0.22; $p = 0.029$; $I^2 = 0\%$); this estimate became non-significant after the removal of Nosrani et al., Yu et al., or Kamalakkannan and Kumar.

For cardiometabolic outcomes, total cholesterol was not significantly different between groups across five studies (169 participants; MD -4.13 mg/dL, 95% CI -12.13 to 3.87; $p = 0.311$; $I^2 = 0\%$). HDL cholesterol was also not significantly changed across six studies (209 participants; MD 3.63 mg/dL, 95% CI -1.25 to 8.51; $p = 0.145$), with substantial heterogeneity ($I^2 = 65\%$). The HDL estimate became statistically significant only after the exclusion of Cheikh et al. LDL cholesterol showed no significant pooled difference across six studies (MD -3.13 mg/dL, 95% CI -13.94 to 7.67; $p = 0.570$), with substantial heterogeneity ($I^2 = 74\%$).

Aquatic exercise significantly reduced triglycerides across six studies (209 participants; MD -15.75 mg/dL, 95% CI -23.12 to -8.39; $p < 0.001$; $I^2 = 0\%$). The triglyceride effect remained significant in every leave-one-out analysis. BMI was not significantly reduced across six studies (215 participants; MD -0.88 kg/m², 95% CI -2.11 to 0.36; $p = 0.165$; $I^2 = 60\%$). However, BMI became significantly lower after the removal of Nosrani et al. or Eichel et al. Body fat percentage was not significantly different across four studies (111 participants; MD -0.19 percentage points, 95% CI -1.58 to 1.21; $p = 0.792$; $I^2 = 0\%$), and no leave-one-out analysis changed this conclusion. Fasting glucose was significantly lower across three studies (99 participants; MD -7.82 mg/dL, 95% CI -12.48 to -3.16; $p = 0.001$; $I^2 = 56\%$). This effect remained significant after the removal of Nosrani et al. or Lopes et al. but became non-significant after the removal of Cheikh et al. Baseline values were reviewed within each randomized comparison and were broadly comparable between aquatic-exercise and control groups; therefore, post-intervention mean differences were pooled (Figures 2 and 3).

3.3. Quality of Evidence

Risk of bias was assessed using the revised RoB-2 tool (Figure 4). Of the eight included studies, seven were judged to have some concerns, and one was judged to be at low risk of bias overall. Some concerns were most common in the randomization process and selective reporting domains. Concerns related to deviations from intended interventions and incomplete outcome data were also frequent. Most studies were judged at low risk of bias in outcome measurement because the included outcomes were assessed using objective physiological, laboratory, or anthropometric methods.

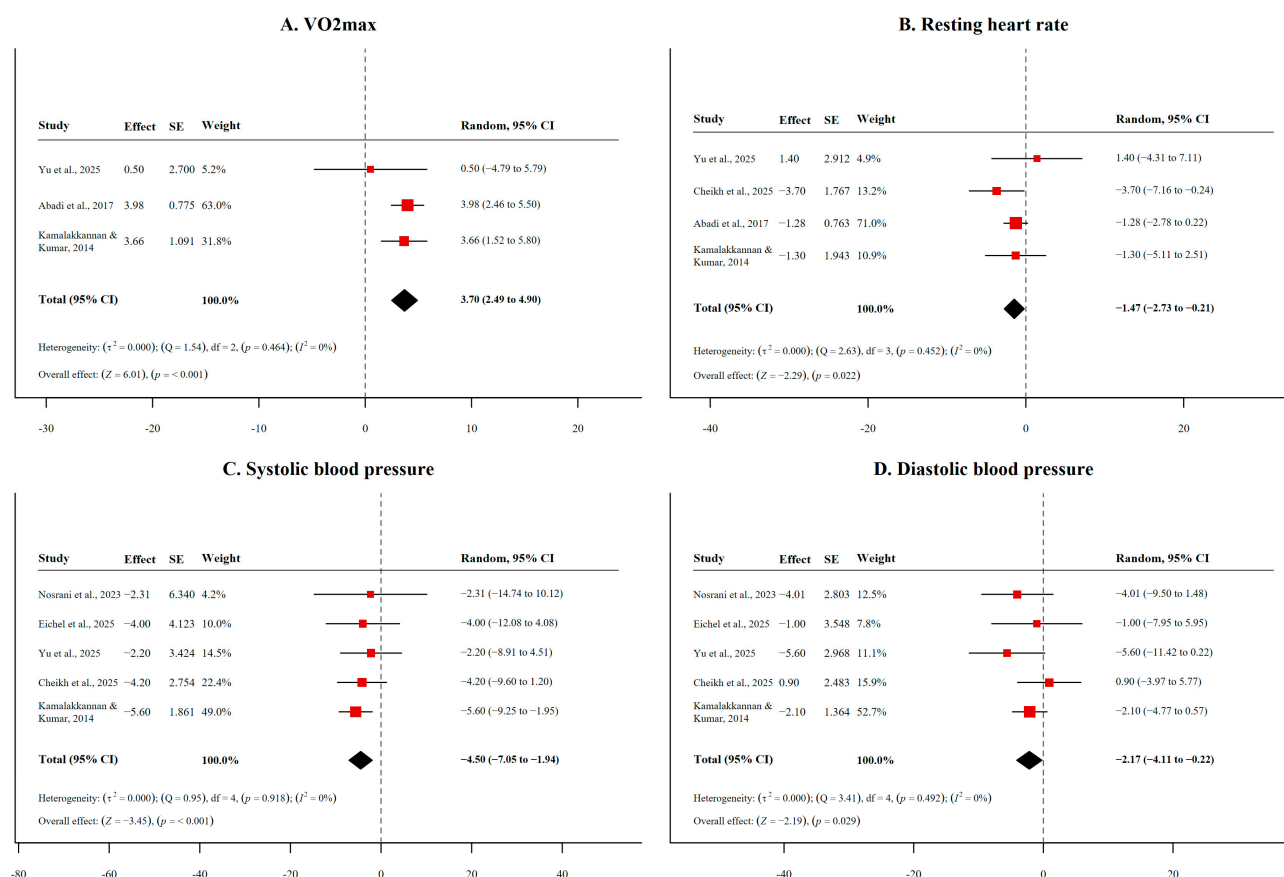


Figure 2. Random-effects meta-analyses of post-intervention mean differences between aquatic exercise and control groups for (A) VO₂ max, (B) resting heart rate, (C) systolic blood pressure, and (D) diastolic blood pressure. Squares represent individual-study mean differences, with square size proportional to study weight; horizontal lines indicate 95% confidence intervals. Diamonds represent pooled random-effects estimates. Positive values favor aquatic exercise for VO₂ max, whereas negative values favor aquatic exercise for resting heart rate and blood pressure outcomes. Red squares represent individual study effect estimates, horizontal lines represent 95% confidence intervals, and the black diamond represents the pooled random-effects estimate.

Certainty of evidence was assessed using the GRADE framework (Table 2). Evidence for VO₂ max, resting heart rate, systolic blood pressure, diastolic blood pressure, total cholesterol, triglycerides, and body fat percentage was rated as low, primarily because of serious risk of bias and imprecision. Evidence for HDL cholesterol, LDL cholesterol, BMI, and fasting glucose was rated as very low because of serious risk of bias, inconsistency, and imprecision. These findings indicate that aquatic exercise may improve selected cardiovascular and cardiometabolic outcomes; however, confidence in the estimated magnitude of effects differs across outcomes. Funnel plots and Egger's regression tests were not performed because fewer than 10 studies contributed to each meta-analysis.

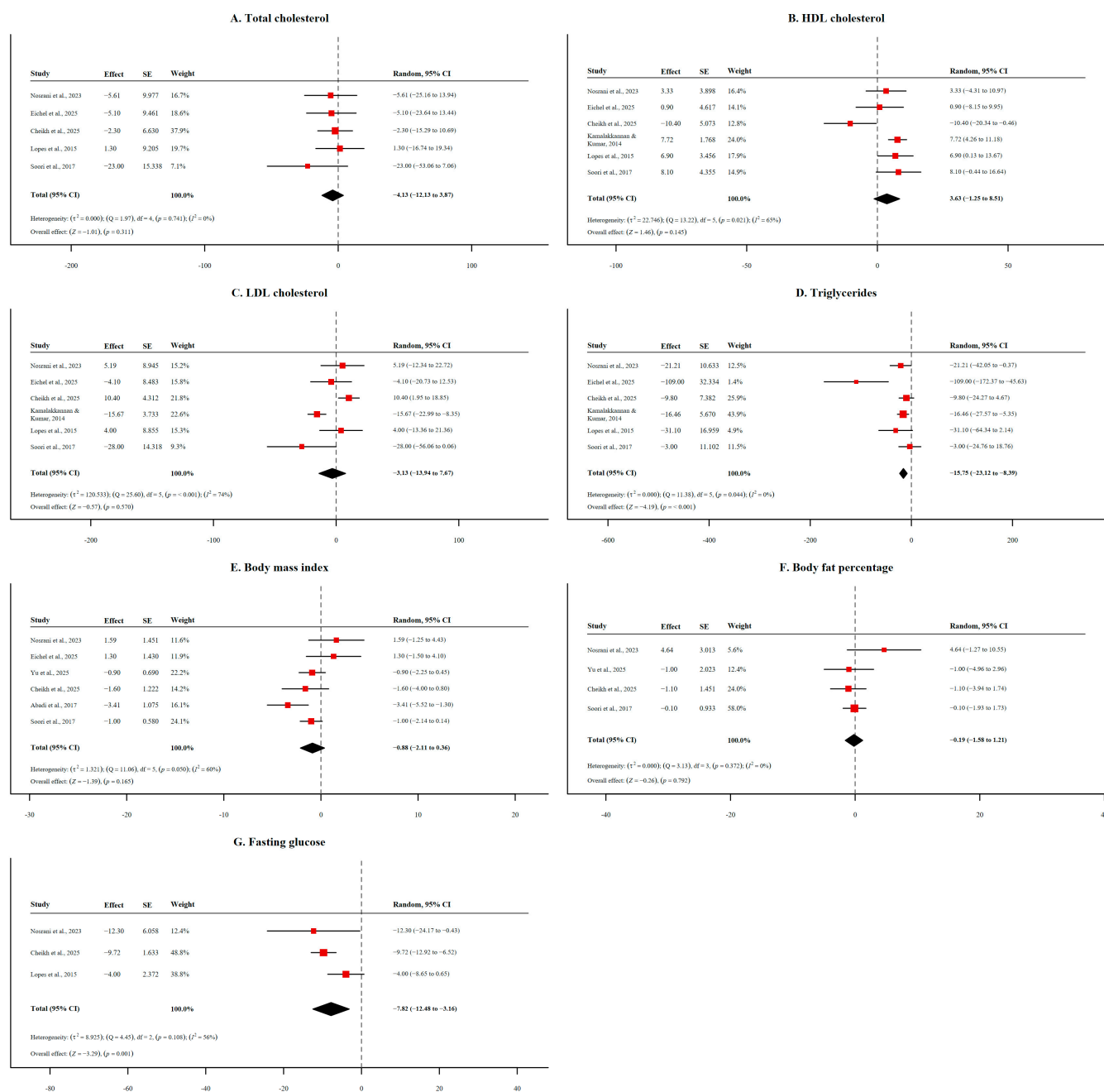


Figure 3. Random-effects meta-analyses of post-intervention mean differences between aquatic exercise and control groups for (A) total cholesterol, (B) HDL cholesterol, (C) LDL cholesterol, (D) triglycerides, (E) body mass index, (F) body fat percentage, and (G) fasting glucose. Squares represent individual-study mean differences, with square size proportional to study weight; horizontal lines indicate 95% confidence intervals. Diamonds represent pooled random-effects estimates. Negative values favor aquatic exercise for total cholesterol, LDL cholesterol, triglycerides, body mass index, body fat percentage, and fasting glucose; positive values favor aquatic exercise for HDL cholesterol. Red squares represent individual study effect estimates, horizontal lines represent 95% confidence intervals, and the black diamond represents the pooled random-effects estimate.

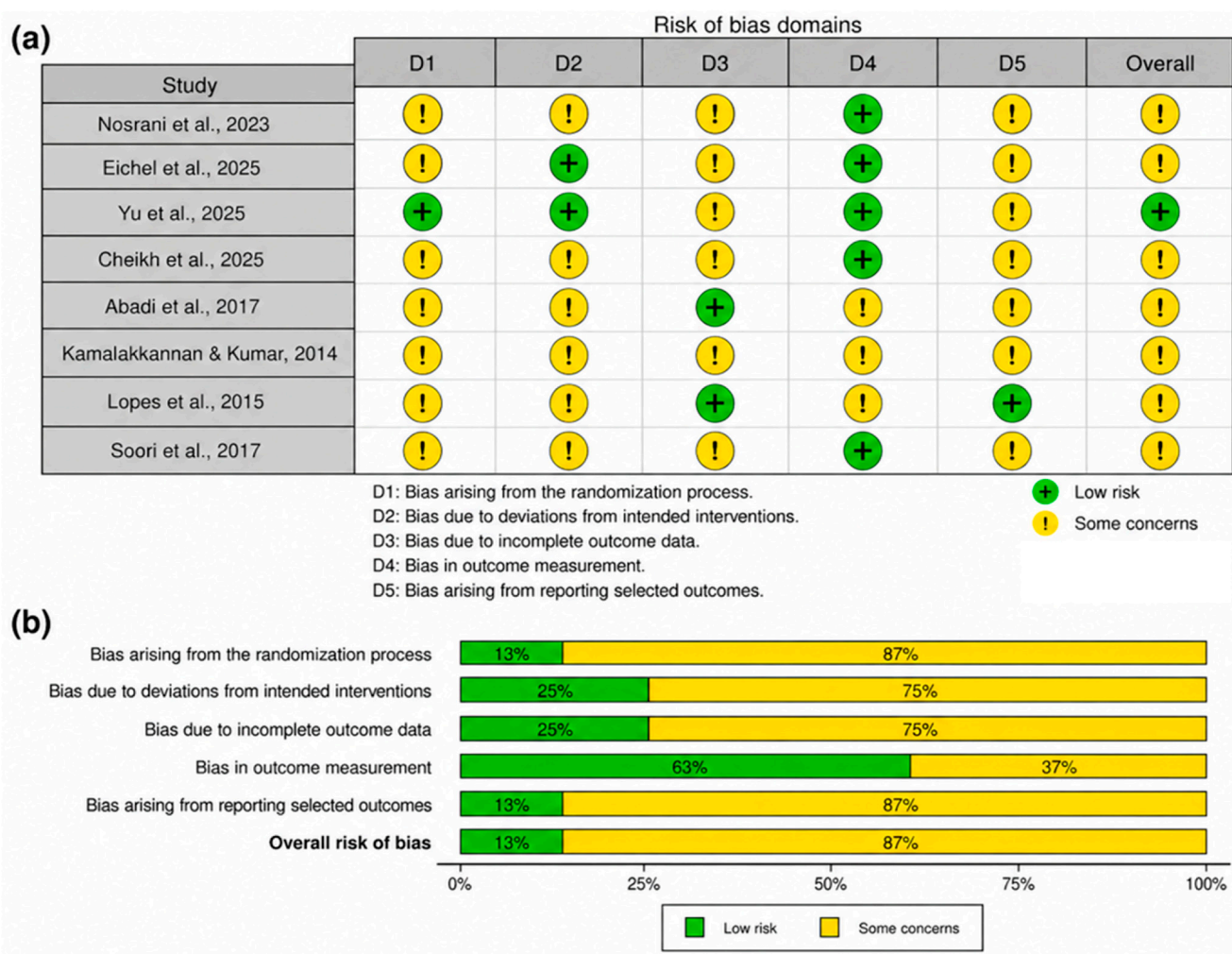


Figure 4. Risk-of-bias assessment of included studies using the revised Cochrane RoB 2 tool. **(a)** Risk-of-bias judgments for each included study across five domains and overall risk of bias. D1: bias arising from the randomization process; D2: bias due to deviations from intended interventions; D3: bias due to incomplete outcome data; D4: bias in outcome measurement; D5: bias arising from selection of the reported result. **(b)** Summary distribution of risk-of-bias judgments across included studies. Green circles/bars indicate low risk of bias, and yellow circles/bars indicate some concerns.

Table 2. GRADE assessment for quality of evidence.

Outcomes	Studies	Participants	Effect Estimates	Risk of Bias	Inconsistency	Indirectness	Imprecision	Certainty
VO ₂ max	3	126	MD 3.70 higher	Serious	Not serious	Not serious	Serious	Low
RHR	4	153	MD −1.47 lower	Serious	Not serious	Not serious	Serious	Low
SBP	5	189	MD −4.50 lower	Serious	Not serious	Not serious	Serious	Low
DBP	5	189	MD −2.17 lower	Serious	Not serious	Not serious	Serious	Low
TC	5	169	MD −4.13 lower, CI crosses null	Serious	Not serious	Not serious	Serious	Low
LDLs	6	209	MD −3.13 lower, CI crosses null	Serious	Serious	Not serious	Serious	Very Low
HDLs	6	209	MD 3.63 higher, CI crosses null	Serious	Serious	Not serious	Serious	Very Low
TGs	6	209	MD −15.75 lower	Serious	Not serious	Not serious	Serious	Low
BMI	6	215	MD −0.88 lower, CI crosses null	Serious	Serious	Not serious	Serious	Very Low
BF	4	111	MD −0.19 lower, CI crosses null	Serious	Not serious	Not serious	Serious	Low
Fasting glucose	3	99	MD −7.82 lower	Serious	Serious	Not serious	Serious	Very Low

4. Discussion

This systematic review and meta-analysis found that aquatic exercise improved cardiorespiratory fitness and selected hemodynamic outcomes in individuals with overweight or obesity. Aquatic exercise significantly increased VO_2 max and reduced resting heart rate, systolic blood pressure, and diastolic blood pressure. However, leave-one-out analyses indicated that the resting-heart-rate and blood-pressure estimates were sensitive to the removal of individual studies and should be interpreted cautiously. Among cardiometabolic outcomes, aquatic exercise significantly reduced triglycerides and fasting glucose, whereas no significant pooled effects were observed for total cholesterol, HDL cholesterol, LDL cholesterol, BMI, or body fat percentage. Overall, the findings suggest possible cardiovascular and selected metabolic benefits of aquatic exercise, although the small number of trials and variability in study populations and interventions limit certainty.

Aquatic exercise has demonstrated beneficial effects on cardiorespiratory functions, including VO_2 max and heart rate, in the normal and overweight population [27]. Aquatic exercise compared with land-based exercise enhanced maximal oxygen consumption (VO_2 max), an indicator of cardiorespiratory fitness, indicating higher energy expenditure, thereby improving cardio-respiratory capacity [28]. Similarly, these findings align with our study results, where aquatic training significantly increased VO_2 max. High-intensity aquatic exercise reduced resting heart rate, potentially by increasing central blood volume and venous return due to hydrostatic pressure, thereby enhancing stroke volume and promoting vagal-mediated bradycardia via increased parasympathetic activity, along with reduced sympathetic activity [29]. Consistently, these reports support our findings that aquatic exercise reduces resting heart rate. However, the resting heart rate estimate was sensitive to the removal of individual studies; therefore, this result should be interpreted cautiously.

Aquatic exercise has been shown to significantly improve systolic and diastolic blood pressures in hypertensive patients [30]. Aquatic exercise may cause benefits in patients with hypertension by suppressing sympathetic activity and reducing vascular resistance [31]. These reports are broadly consistent with the pooled estimates; however, the systolic- and diastolic-blood-pressure effects were sensitive to the removal of individual studies and should be interpreted cautiously.

Aquatic exercises have been shown to improve cardiometabolic risk factors, including lipid parameters (TC, LDLs, HDLs, and TGs), along with anthropometric measures, such as BMI and body fat percentage [32]. Notably, aquatic exercise has been associated with a significant reduction in TG and LDL levels in women with abdominal obesity, reflecting a meaningful improvement in lipid profile [33], consistent with our findings. Meanwhile water-based aerobic exercise has been reported to significantly reduce TC without a statistically significant increase in HDL levels in postmenopausal dyslipidemic women [34]. In this analysis, aquatic exercise significantly reduced triglycerides and fasting glucose, whereas total cholesterol, HDL cholesterol, and LDL cholesterol were not significantly changed. The non-significant HDL and LDL findings were accompanied by substantial heterogeneity, indicating inconsistency across studies. The triglyceride effect remained statistically significant in leave-one-out analyses, whereas the fasting-glucose estimate became non-significant after removal of Cheikh et al.; therefore, the fasting glucose finding should be interpreted cautiously. Although aquatic exercise may influence lipid metabolism and glycemic regulation, these mechanisms were not directly assessed in the included trials. Other evidence suggests that aquatic endurance exercise can improve TC, HDL, and TG levels, although the magnitude of changes depends on gender, type of exercise, and baseline lipid profile status [35]. These effects may be mediated by physiological mechanisms such as enhanced lipoprotein lipase activity, improved lipid metabolism, and increased

reverse cholesterol transport; however, these mechanisms were not directly assessed in the included studies [36].

Aquatic exercise has been shown to have no significant effects on metabolic profile indicators, including BMI and BF in overweight and obese individuals [37]. Another study reported that water-based aerobic exercises increased energy expenditure and improved metabolic profiles, such as BMI and BF, in the overweight and obese population [38]. No significant pooled differences were observed in BMI or body fat percentage. These findings suggest that changes in cardiorespiratory fitness and selected cardiometabolic markers may occur without statistically significant pooled changes in BMI or body fat percentage. However, heterogeneity for BMI was substantial, and differences in participant characteristics, intervention dose, and duration may have contributed to variation across the studies.

Aquatic exercise may be considered as one possible exercise modality for individuals with overweight or obesity, particularly when land-based activity is difficult because of joint discomfort, mobility limitations, or low exercise tolerance. The present findings suggest possible improvements in cardiorespiratory fitness and selected cardiovascular and metabolic outcomes; however, these estimates should be interpreted cautiously because the evidence was low to very low in certainty, and several findings were sensitive to individual studies. Aquatic exercise may therefore be used as an individualized, supportive component of broader lifestyle and clinical management, rather than as a stand-alone approach for cardiometabolic risk reduction. Further high-quality trials are needed before specific aquatic exercise prescriptions can be recommended.

5. Study Limitations

This study has several limitations. Aquatic interventions differed in their exercise mode, intensity, duration, and training volume, which may have contributed to clinical and statistical heterogeneity. Only English-language articles were included. The small number of included trials and limited sample sizes reduced the precision of several pooled estimates, particularly where confidence intervals were wide or crossed the null. The sensitivity of several pooled estimates to the removal of individual studies further limits confidence in the consistency of the observed effects. Because only aggregate post-intervention data were available, adjustment for individual-level factors such as age, baseline physical activity, and metabolic history was not possible. Although baseline values were broadly comparable within randomized comparisons, residual baseline differences may have influenced some pooled post-intervention estimates. The broad age range of participants, including pediatric and older-adult cohorts, may also have contributed to variation in cardiometabolic responses and may limit generalizability. Although I^2 was 0% for VO_2 max, resting heart rate, systolic blood pressure, diastolic blood pressure, total cholesterol, triglycerides, and body fat percentage, these estimates were based on only three to six studies and should not be interpreted as evidence of clinical homogeneity. Differences in participants, aquatic-exercise protocols, and outcome assessments may still have influenced the pooled results.

6. Conclusions and Recommendations

Aquatic exercise may improve VO_2 max and may be associated with lower resting heart rate, blood pressure, triglycerides, and fasting glucose in individuals with overweight or obesity. The resting-heart-rate, blood-pressure, and fasting-glucose estimates were sensitive to the removal of individual studies. However, effects on total cholesterol, HDL cholesterol, LDL cholesterol, BMI, and body fat percentage were not significant. Given the low to very low certainty of evidence, small sample sizes, and heterogeneity in inter-

ventions and populations, these findings should be regarded as suggestive rather than definitive. Larger, adequately powered randomized controlled trials with standardized aquatic-exercise training protocols are needed to further clarify long-term cardiovascular and cardiometabolic effects.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/obesities6040052/s1>, Table S1: Measurement instruments, protocol standardization, and reporting completeness in the included trials; File S1: Meta-analysis raw data file.

Author Contributions: I.A.S.: Conceptualization, data curation, formal analysis, investigation, methodology, and writing—original draft. F.Y.: Methodology, formal analysis, software, and writing—review and editing. S.I.: Formal analysis, validation, and writing—review and editing. S.-D.L.: Supervision, validation, and writing—review and editing. B.-T.W.: Supervision, project administration, writing—review, and supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors used artificial-intelligence-assisted tools, including ChatGPT version 5.5, for language editing and to support the visual development of Figure 4. However, Figures 2 and 3 were generated using RStudio version 2025.09.1+401 with R and the *metafor* package. All study selection, data extraction, statistical analyses, interpretation of findings, and final content verification were conducted by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the manuscript and its figures.

Conflicts of Interest: The authors declare no conflicts of interest.

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