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Effect of aquatic exercise on cardiovascular fitness in people with type 2 diabetes mellitus: a systematic review and meta-analysis

Aims To systematically review and meta-analyze the impact of aquatic exercise (AE) on cardiovascular health in patients with type 2 diabetes mellitus (T2DM).

Material and methods Relevant literature about AE in patients with T2DM up to May 25, 2021, were collected from the PubMed, the Cochrane, EMBASE, Web of Science, and Ovid databases. The main outcomes were 6-min walking distance (6MWD) and maximal oxygen uptake (VO_{2max}). Secondary outcomes were resting heart rate (RHR) and resting systolic (RSBP) and diastolic blood pressures (RDBP).

Results 12 articles including 320 participants were identified. Among them, three trials compared AE to land-based exercise (LE), six compared AE to non-intervention control (Ctrl), and three were pre-/post-AE design without a control group. Meta-analysis showed that compared with baseline, VO_{2max} increased (WMD=0.71, 95%CI 0.47 to 0.94), while RHR, RSBP and RDBP declined (WMD=–5.88, 95%CI –6.88 to –4.88; WMD=–5.76, 95%CI –7.75 to –3.78; WMD=–2.48, 95%CI –3.83 to –1.13, respectively) post-AE. 6WMD and VO_{2max} increased (WMD=127.00, 95%CI 49.26 to 204.74; WMD=2.02, 95%CI 1.66 to 2.38, respectively) and RHR declined (WMD=–4.20, 95%CI –6.36 to –2.03, AE vs Ctrl) when AE was compared to Ctrl. There were no significant differences in the above indicators between AE and LE.

Conclusions AE, like LE, increases VO_{2max}, and reduces RHR, RSBP, and RDBP. These responses may improve cardiovascular health in patients with T2DM. However, more data are needed to confirm the effect of AE on 6MWD in T2DM patients.

Keywords Aquatic exercise; type 2 diabetes mellitus; cardiovascular health

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Introduction

In recent years, the prevalence of type 2 diabetes mellitus (T2DM) has increased rapidly. Cardiovascular complications are among the main causes of death in the T2DM population [1]. It is accepted that exercise exerts a protective effect on the cardiovascular system by changing the internal structure of myocardium, by adjusting cytokine mediated metabolism, and by having an anti-inflammatory effect [2]. Compared to land-based exercise (LE), aquatic exercise (AE) displays special advantages, including its effects in cardiovascular system. Firstly, due to the existence of hydrostatic pressure, the blood flow to the lower limbs decreases. This leads to redistribution of blood and increases cardiac preload, so stroke volume increases. In addition, myocardial force and vascular elasticity are improved under these conditions of repeatedly overcoming the additional water pressure to necessary to transport blood to the whole body [3]. Secondly, the oxygen needed for long-term continuous exercise mainly comes from breathing and this oxygen is transported to various organs of the body through the circulation. When the body enters the water, pressure on the circulation increases, which would further affect respiratory effort. These changes are beneficial by increasing the elasticity and strength of the respiratory muscles and by improving the body's ability to uptake oxygen [4]. Thirdly, the buoyancy of water counteracts gravity and facilitates full extension of the limbs.

The resistance and heat dissipation effects of water are conducive to energy expenditure and improve the effects of exercise [5]. Finally, the buoyancy of water can reduce the burden on and damage to joints [6, 7]. Therefore, AE could be regarded as a favorable alternative choice to LE.

A previous review showed that AE could improve cardiovascular health in non-diabetic people [8]. However, there seems to be no meta-analysis about the effect of AE on cardiovascular function in the T2DM population.

Material and methods

Search strategy

Literature up to May 25, 2021, were searched from PubMed, EMBASE, Web of Science, the Cochrane, and

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Ovid databases. Reference lists of qualified trials were also searched for additional eligible articles. The databases were examined using the following combination of items:

"All fields" =

1) ["aquatic aerobics" or "aquatic exercise*" or "aquatic sport*" or "aquatic rehabilitation" or "aquatic activity" or "aquatic physical therapy" or "water-based exercise*" or "water aerobics" or "water exercise*" or "water sport*" or "water rehabilitation" or "water activity" or "water therapy" or "swimming"] and
2) (["diabetes" or "T2DM" or "NIDDM"] and
3) ["cardiovascular" or "6-min walking" or "6-min walking" or "6-min walking" or "maximal oxygen" or "VO_{2max}" or "blood pressure" or "heart rate"]. No language and time restrictions were set during the search.

Inclusion and exclusion criteria

Inclusion criteria: Studies involving the effect of AE on cardiovascular function in patients with T2DM. Any form of research was allowed, such as randomized controlled trial, single group cohort study, etc. Exclusion criteria: those without T2DM; subjects under 18 yrs; patients diagnosed with heart disease; severe liver, and kidney insufficiency; trials about acute effects of exercise. Moreover, studies that did not include exercise but only soaking in water were excluded.

Main outcomes: 6-min walking distance (6MWD) and maximal oxygen uptake (VO_{2max}). Secondary outcomes: resting heart rate (RHR), systolic (RSBP), and diastolic blood pressure (RDBP).

Data extraction

Basic characteristics of the participants, such as age and duration of diabetes, were extracted from each eligible study. Characteristics of each intervention, such as frequency, intensity and time of exercise, were also collected. Two reviewers extracted data from the various databases independently. Any disagreements were resolved by the second reviewer. A detailed flow chart of the study selection is shown in Figure 1.

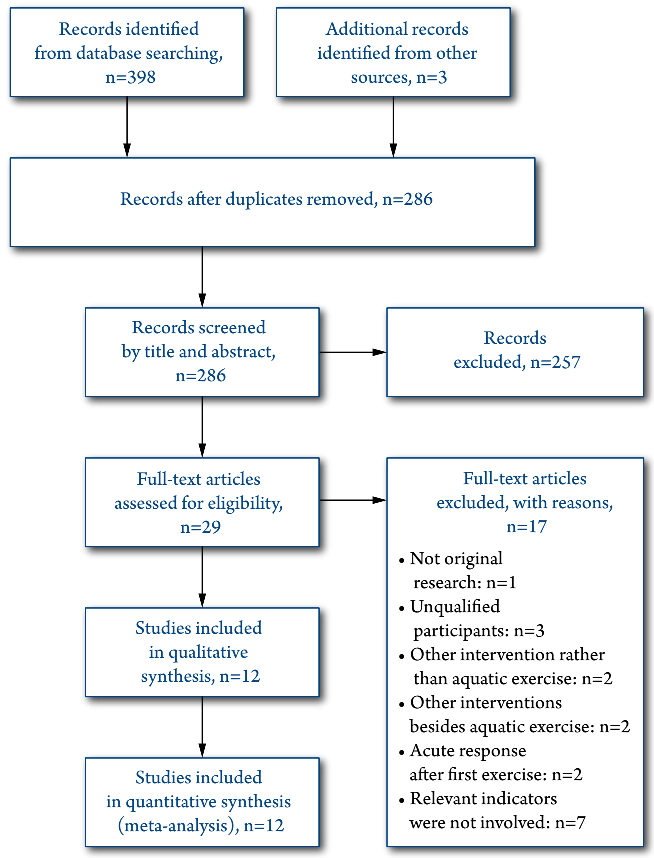
Quality appraisal

The quality of the literature was evaluated by using "The Quality Assessment Tool for Quantitative Studies" (https://merst.ca/ephpp/). According to the guidelines, articles with an overall score of strong or moderate were considered eligible. As a result, the 12 selected articles were judged qualified.

Data analysis

The data was analyzed using RevMan5.4. Heterogeneity was estimated by a chi square test. I2 was expressed as the

Figure 1. Study selection flow diagram



percentage of total variability due to heterogeneity, and I2 higher than 50% was considered to be high heterogeneity. If heterogeneity was present, Galbraith diagram and sensitivity analysis were used to analyze the source of heterogeneity. And the results would be explained by subgroup analysis or analyzed by using random models.

Results

12 studies [9–20] involving 320 participants were included in the final analysis. The basic characteristics of each study were shown in Table 1. 6MWD was mentioned in two studies, among which, one was designed as AE vs non-intervention control (Ctrl) [11], and another was pre-/post-AE design [15]. 6MWD increased in AE group when compared to Ctrl (WMD=127.00, 95%CI 49.26 to 204.74). To our surprise, the increase of 6MWD did not reach statistical difference post-AE when compared to the pre-AE (WMD=55.23, 95%CI –22.55 to 133.02) (Figure 2).

A total of 9 articles [10, 12–14, 16–20] described the changes of "VO_{2max}". In these articles, one [13] was excluded because its record of oxygen uptake was taken during the process of an intervention trial The remaining eight articles were analyzed, of which VO_{2max} was measured by using a cycle ergometer or a treadmill. Among the eight studies, two [17, 20] compared AE to LE, four [14, 16, 18, 19]

Table 1. Characteristics of included trials

Study	Sample size (M/F)	Age, Duration (year)	Study design	Water depth, temp	Sessions (weeks* n / week)	Length / session (min)	Exercise intensity
Cha# 2020	25 (0/25)	66.17±8.34; 10.31±7.35	RCT (muscle stretching vs Ctrl)	1.3 m, 28°C	12*2	50	60–75% HRR
Con# 2020	7 (2/5)	55.3±7.7; 5.7±3.1	Cohort (underwater treadmill)	below xiphoid, 29–30°C	8*3	30–60	40–70% HRR
Con# 2020	26 (10/16)	58.0±5.0; ≥2	RCT (underwater treadmill vs Ctrl)	below xiphoid, 29–31°C	12*3	30–60	40–70% HRR
Cug# 2014	18 (18/0)	52.2± 9.3; ≤10	Cohort (swimming and muscle stretching)	NR, 31–32°C	12*3	50	50–75% VO_{2max}
Del# 2016	35 (15/20)	56.7±7.9; 6.53±2.38	RCT (walking/running in water vs on athletic track)	deep water, NR	12*3	45	85–100% HRAT
Del# 2016	38 (19/19)	58.05±8.59; 6.18±2.85	RCT (running, joint flexion/extension exercise vs Ctrl)	shallow pool, NR	15*3	56	85–100% HRAT
Joh# 2018	30; (15/15)	67.7±7.0; NR	Cohort (underwater walking)	chest deep; 32–34°C	12*2	45–50	40–65%HRR
Nut# 2012	40 (?)	≥60; NR	RCT (continuous aerobics vs Ctrl)	NR, 34–36°C	12*3	50	70% HRR
Nut# 2014	19 (0/19)	60–70; NR	RCT (continuous aerobics in water vs on land)	NR; 34–36°C	12*3	50	70% HRR
Rez# 2019	20 (20/0)	42.90±4.78; ≥1	RCT (fast walking vs Ctrl)	NR, NR	8*3	30–60	55–70% HRR
Sch# 2019	35 (?)	62.46±9.52; NR	RCT (running, joint flexion/extension vs Ctrl)	NR; 30°C	8*3	50	60–80% HRR
Sun# 2017	36 (?)	60–75; NR	RCT (cycling in water vs on cycle ergometer)	hip level; 36°C	12*3	35–50	50–70% HRR

Date are values, percentages or Mean±SD. Temp, temperature; RCT, randomized controlled trial; HRR, heart rate reserve; HRAT, anaerobic threshold heart rate; VO_{2max}, maximal oxygen uptake; NR, not reported.

compared AE to Ctrl, and two [10, 12] had a pre-/post-AE design. Analysis showed that two studies [16, 17] carried out by Nuttamonwarakul had strong heterogeneity with the other six articles [10, 12, 14, 18–20].

Conclusions were drawn from subgroup analysis that VO_{2max} was increased in post-AE as compared to pre-AE (WMD=0.71, 95%CI 0.47 to 0.94) and Ctrl (WMD=2.02, 95%CI 1.66 to 2.38). No difference of VO_{2max} was found in AE vs LE (WMD=0.8, 95%CI –0.18 to 1.78) (Figure 3).

There were ten studies [9–17, 20] about the effect of AE on RHR. Three [13, 17, 20] were designed as AE vs LE, four [9, 11, 14, 16] designed as AE vs Ctrl, and three [10, 12, 15] were pre-/post-AE design. RHR was declined in post-AE when compared to pre-AE (WMD= – 5.88, 95%CI –6.88 to

Figure 2. Effect of AE on 6MWD

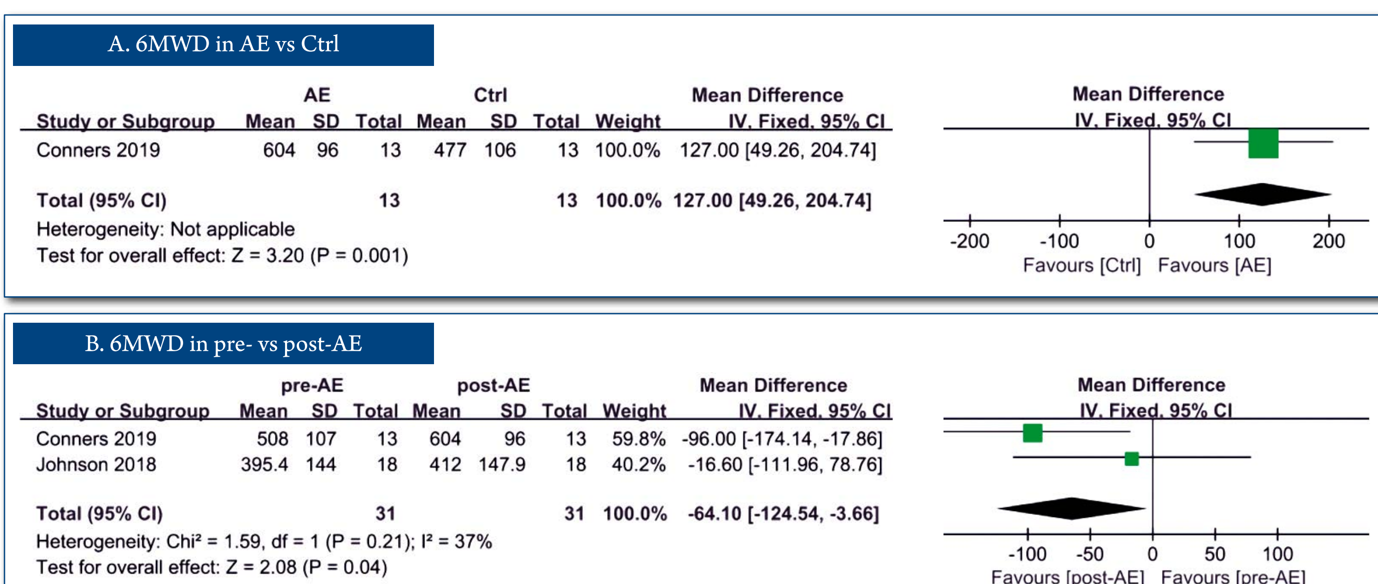


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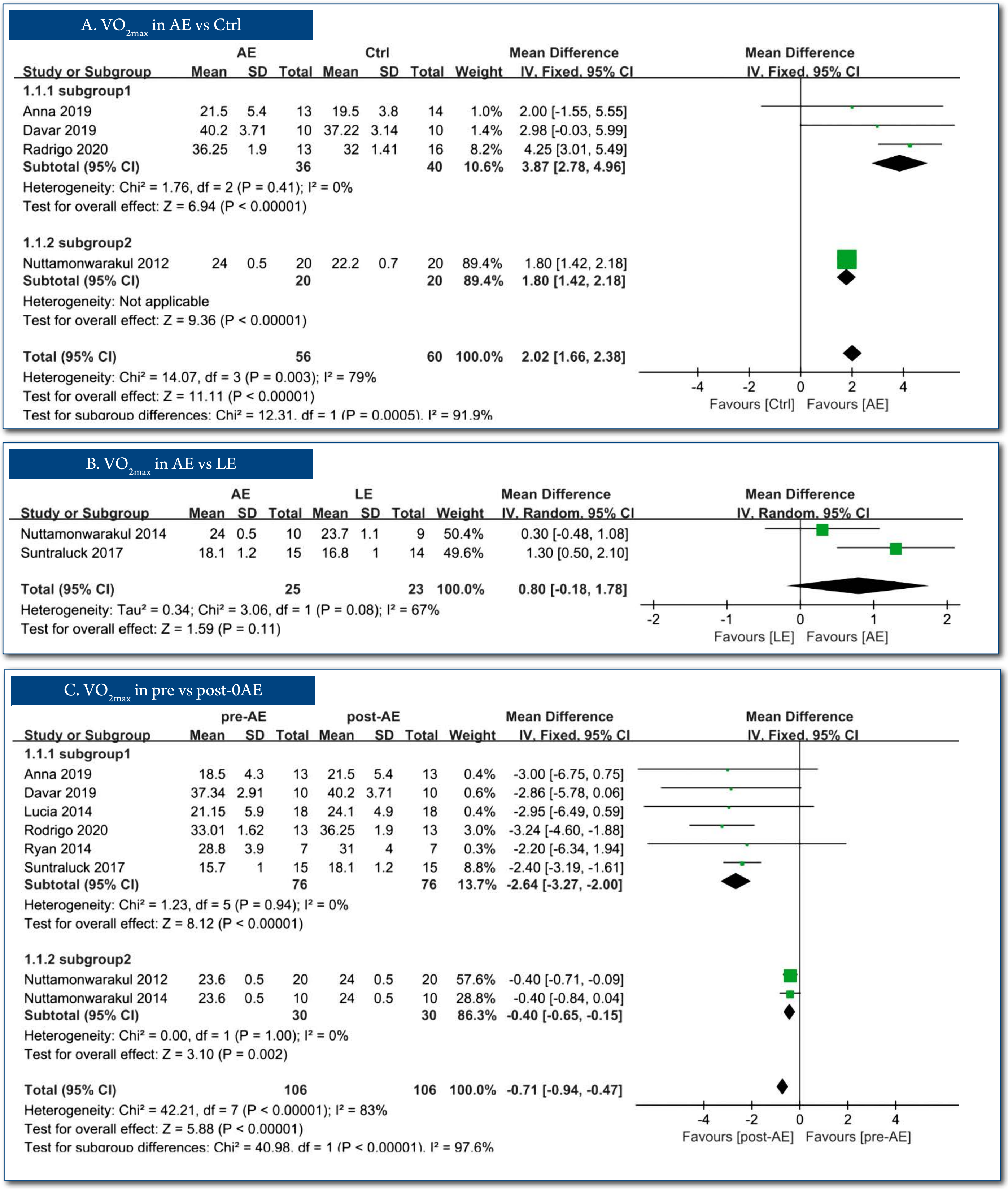
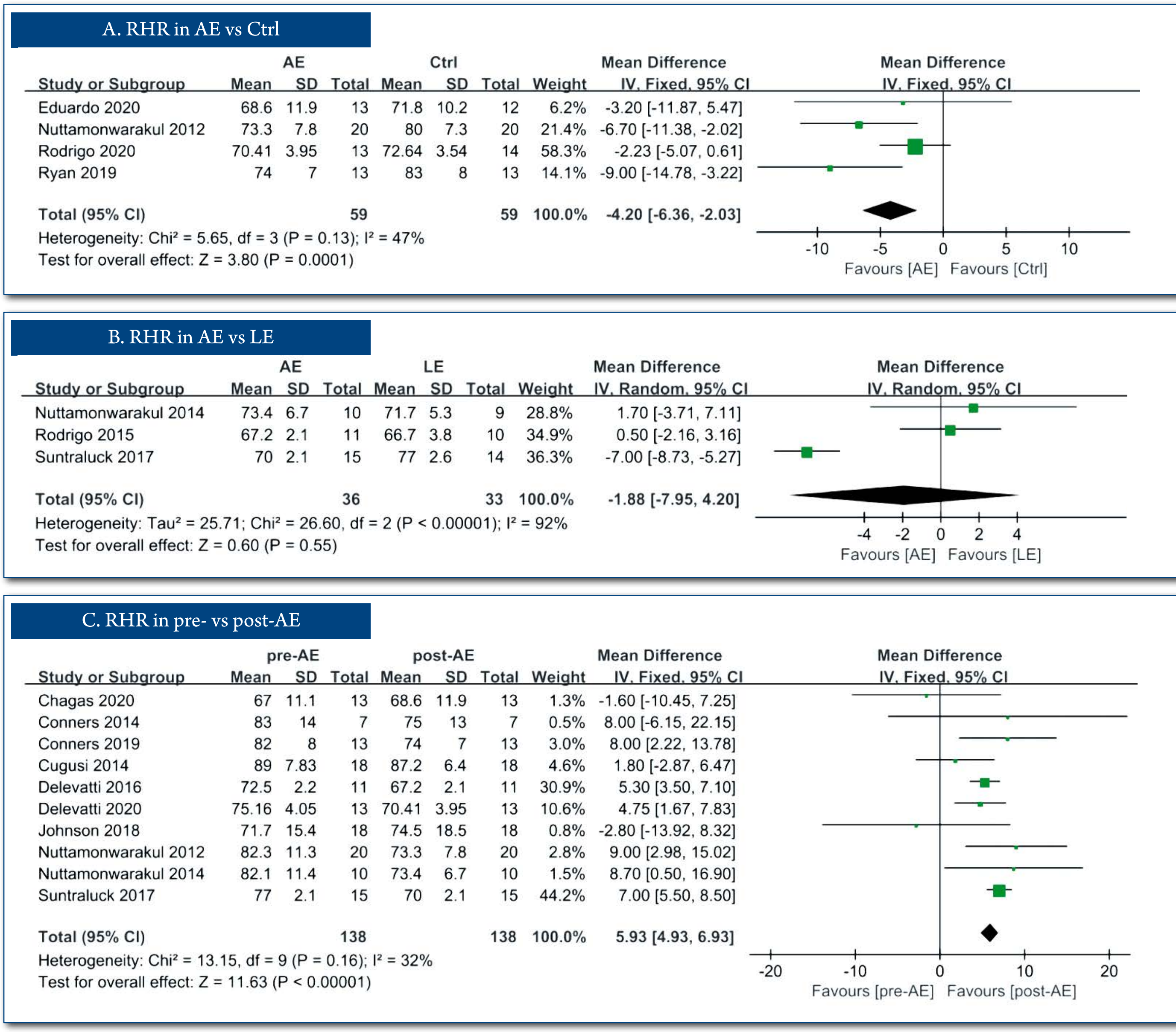
Figure 3. Effect of AE on 6MWD



–4.88) and Ctrl (WMD= –4.20, 95%CI –6.36 to –2.03). No differences of RHR were found in AE vs LE (WMD= – 1.88, 95%CI –7.95 to 4.20) (Figure 4).

Eight articles [9, 11–13, 15–17, 20] involved the effect of AE on blood pressure. Three [13, 17, 20] were AE vs LE, three [9, 11, 16] were AE vs Ctrl, and two [12, 15] were pre-AE vs post-AE without a comparison. Analysis showed that RSBP and RDBP declined after AE when compared to baseline (WMD= – 5.76, 95%CI –7.75 to –3.78, and WMD= – 2.48, 95%CI –3.83 to –1.13, respectively). No difference of RSBP

Figure 4. Effect of AE on RSBP



A. RHR in AE vs Ctrl

Study or Subgroup	AE Mean	AE SD	AE Total	Ctrl Mean	Ctrl SD	Ctrl Total	Weight	Mean Difference IV, Fixed, 95% CI
Eduardo 2020	68.6	11.9	13	71.8	10.2	12	6.2%	-3.20 [-11.87, 5.47]
Nuttamonwarakul 2012	73.3	7.8	20	80	7.3	20	21.4%	-6.70 [-11.38, -2.02]
Rodrigo 2020	70.41	3.95	13	72.64	3.54	14	58.3%	-2.23 [-5.07, 0.61]
Ryan 2019	74	7	13	83	8	13	14.1%	-9.00 [-14.78, -3.22]
Total (95% CI)			**59**			**59**	**100.0%**	**-4.20 [-6.36, -2.03]**

Heterogeneity: Chi² = 5.65, df = 3 (P = 0.13); I² = 47%
Test for overall effect: Z = 3.80 (P = 0.0001)

B. RHR in AE vs LE

Study or Subgroup	AE Mean	AE SD	AE Total	LE Mean	LE SD	LE Total	Weight	Mean Difference IV, Random, 95% CI
Nuttamonwarakul 2014	73.4	6.7	10	71.7	5.3	9	28.8%	1.70 [-3.71, 7.11]
Rodrigo 2015	67.2	2.1	11	66.7	3.8	10	34.9%	0.50 [-2.16, 3.16]
Suntraluck 2017	70	2.1	15	77	2.6	14	36.3%	-7.00 [-8.73, -5.27]
Total (95% CI)			**36**			**33**	**100.0%**	**-1.88 [-7.95, 4.20]**

Heterogeneity: Tau² = 25.71; Chi² = 26.60, df = 2 (P < 0.00001); I² = 92%
Test for overall effect: Z = 0.60 (P = 0.55)

C. RHR in pre- vs post-AE

Study or Subgroup	pre-AE Mean	pre-AE SD	pre-AE Total	post-AE Mean	post-AE SD	post-AE Total	Weight	Mean Difference IV, Fixed, 95% CI
Chagas 2020	67	11.1	13	68.6	11.9	13	1.3%	-1.60 [-10.45, 7.25]
Conners 2014	83	14	7	75	13	7	0.5%	8.00 [-6.15, 22.15]
Conners 2019	82	8	13	74	7	13	3.0%	8.00 [2.22, 13.78]
Cugusi 2014	89	7.83	18	87.2	6.4	18	4.6%	1.80 [-2.87, 6.47]
Delevatti 2016	72.5	2.2	11	67.2	2.1	11	30.9%	5.30 [3.50, 7.10]
Delevatti 2020	75.16	4.05	13	70.41	3.95	13	10.6%	4.75 [1.67, 7.83]
Johnson 2018	71.7	15.4	18	74.5	18.5	18	0.8%	-2.80 [-13.92, 8.32]
Nuttamonwarakul 2012	82.3	11.3	20	73.3	7.8	20	2.8%	9.00 [2.98, 15.02]
Nuttamonwarakul 2014	82.1	11.4	10	73.4	6.7	10	1.5%	8.70 [0.50, 16.90]
Suntraluck 2017	77	2.1	15	70	2.1	15	44.2%	7.00 [5.50, 8.50]
Total (95% CI)			**138**			**138**	**100.0%**	**5.93 [4.93, 6.93]**

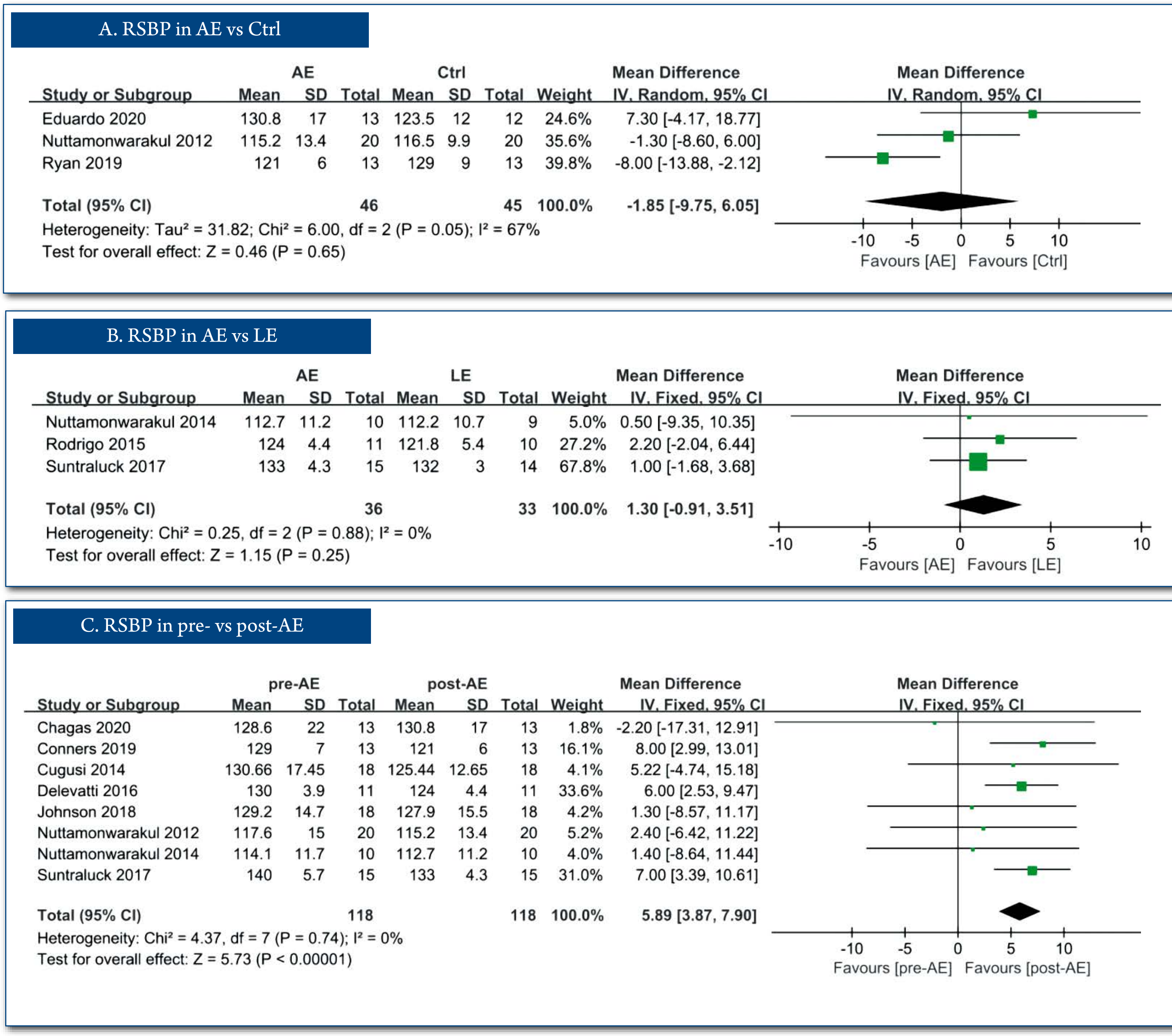
Heterogeneity: Chi² = 13.15, df = 9 (P = 0.16); I² = 32%
Test for overall effect: Z = 11.63 (P < 0.00001)

or RDBP changing was found in both AE vs Ctrl (WMD=–1.85, 95%CI –9.75 to 6.05, WMD= – 4.07, 95%CI –9.36 to 1.21, respectively) and AE vs LE (WMD=1.30, 95%CI –0.91 to 3.51, WMD=0.51, 95%CI –0.84 to 1.87, respectively) (Figures 5 and 6).

Discussion

The 6MWD is widely used to evaluate cardiac function. It is generally believed that the longer the walking distance, the better is the cardiac function [21]. Regular exercise, both in water and on land, can improve 6MWD by increasing cardiac reserve and lower limb strength [22]. AE might have special effects on cardiovascular system as mentioned above. Nevertheless, it was not been confirmed which exercise was more beneficial to improve 6MWD when AE was compared to LE in a previous meta-analysis [23]. Some studies tended to favor LE [24], while others thought that AE was better [25, 26]. In our review, two studies [11, 15] about the effect of AE on 6MWD in people with T2DM were analyzed. Results showed that 6MWD was increased in post-AE when compared to Ctrl. However, the change of 6MWD post-AE proved not to be statistically different when compared with pre-AE. It's worth mentioning that, in Johnson's study [15], only 18 people completed all the exercises, while information was obtained from all 30 participants. This might have diminished the actual effect of AE. In addition, another study [27] was not included in this review because the participants also had heart failure. In that trial, the 6MWD of the patients with T2DM tended to increase by performing AE. We hypothesized that 6MWD in T2DM patients could be improved after AE. Moreover, we have not found any trial that compared specifically the effect of the two exercise modes on 6MWD in T2DM patients. These findings demonstrate the need more research of this topic.

Figure 5. Effect of AE on RSBP



A. RSBP in AE vs Ctrl

Study or Subgroup	AE Mean	AE SD	AE Total	Ctrl Mean	Ctrl SD	Ctrl Total	Weight	Mean Difference IV, Random, 95% CI
Eduardo 2020	130.8	17	13	123.5	12	12	24.6%	7.30 [-4.17, 18.77]
Nuttamonwarakul 2012	115.2	13.4	20	116.5	9.9	20	35.6%	-1.30 [-8.60, 6.00]
Ryan 2019	121	6	13	129	9	13	39.8%	-8.00 [-13.88, -2.12]
Total (95% CI)			**46**			**45**	**100.0%**	**-1.85 [-9.75, 6.05]**

Heterogeneity: Tau² = 31.82; Chi² = 6.00, df = 2 (P = 0.05); I² = 67%
Test for overall effect: Z = 0.46 (P = 0.65)

B. RSBP in AE vs LE

Study or Subgroup	AE Mean	AE SD	AE Total	LE Mean	LE SD	LE Total	Weight	Mean Difference IV, Fixed, 95% CI
Nuttamonwarakul 2014	112.7	11.2	10	112.2	10.7	9	5.0%	0.50 [-9.35, 10.35]
Rodrigo 2015	124	4.4	11	121.8	5.4	10	27.2%	2.20 [-2.04, 6.44]
Suntraluck 2017	133	4.3	15	132	3	14	67.8%	1.00 [-1.68, 3.68]
Total (95% CI)			**36**			**33**	**100.0%**	**1.30 [-0.91, 3.51]**

Heterogeneity: Chi² = 0.25, df = 2 (P = 0.88); I² = 0%
Test for overall effect: Z = 1.15 (P = 0.25)

C. RSBP in pre- vs post-AE

Study or Subgroup	pre-AE Mean	pre-AE SD	pre-AE Total	post-AE Mean	post-AE SD	post-AE Total	Weight	Mean Difference IV, Fixed, 95% CI
Chagas 2020	128.6	22	13	130.8	17	13	1.8%	-2.20 [-17.31, 12.91]
Conners 2019	129	7	13	121	6	13	16.1%	8.00 [2.99, 13.01]
Cugusi 2014	130.66	17.45	18	125.44	12.65	18	4.1%	5.22 [-4.74, 15.18]
Delevatti 2016	130	3.9	11	124	4.4	11	33.6%	6.00 [2.53, 9.47]
Johnson 2018	129.2	14.7	18	127.9	15.5	18	4.2%	1.30 [-8.57, 11.17]
Nuttamonwarakul 2012	117.6	15	20	115.2	13.4	20	5.2%	2.40 [-6.42, 11.22]
Nuttamonwarakul 2014	114.1	11.7	10	112.7	11.2	10	4.0%	1.40 [-8.64, 11.44]
Suntraluck 2017	140	5.7	15	133	4.3	15	31.0%	7.00 [3.39, 10.61]
Total (95% CI)			**118**			**118**	**100.0%**	**5.89 [3.87, 7.90]**

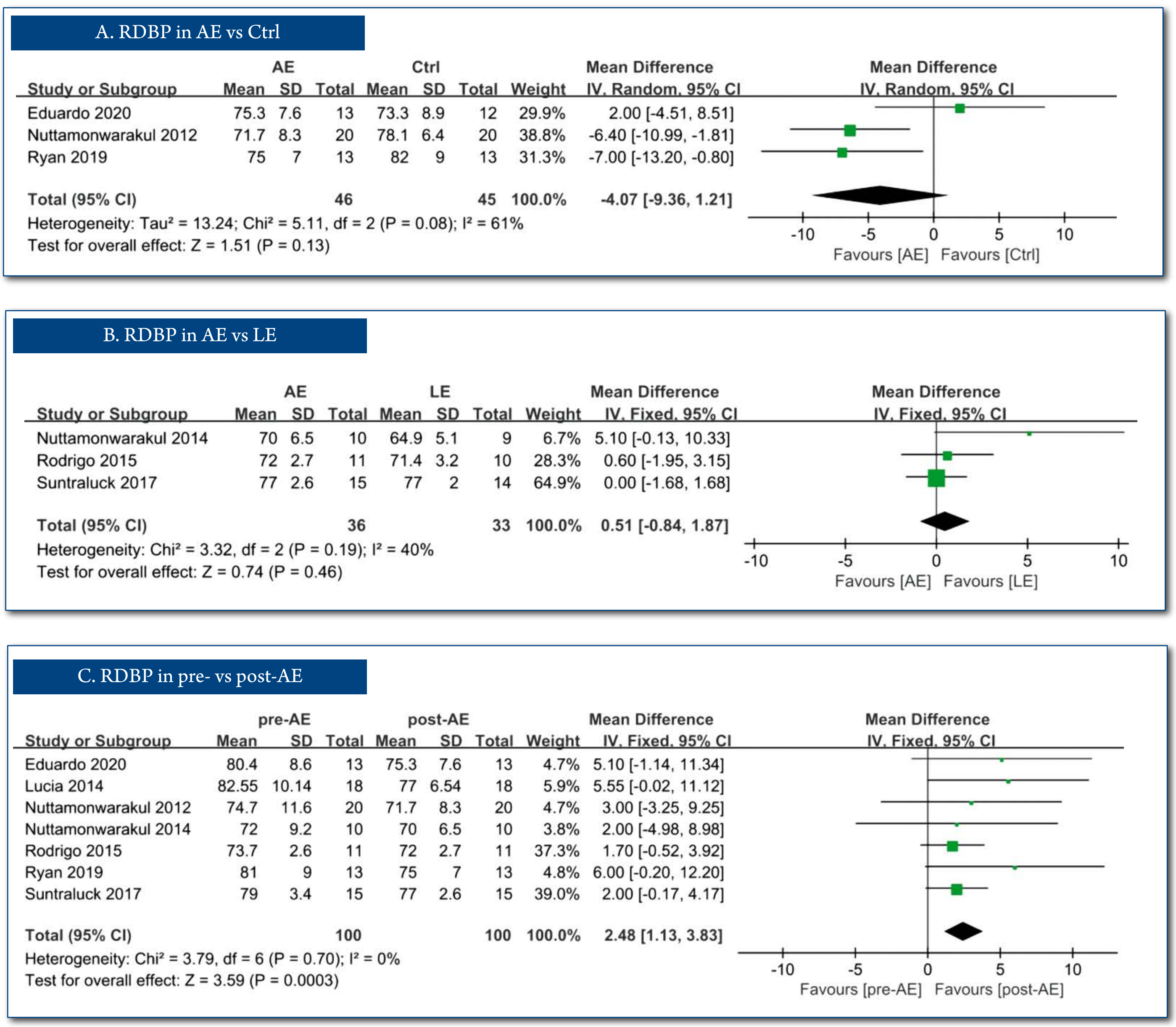
Heterogeneity: Chi² = 4.37, df = 7 (P = 0.74); I² = 0%
Test for overall effect: Z = 5.73 (P < 0.00001)

VO_{2max} is one of the commonly used indexes to predict cardiopulmonary function. It is affected by cardiac output, pulmonary diffusion capacity, blood oxygen carrying capacity, and other factors [28]. Increased VO_{2max} often indicates better cardiac function and exercise tolerance [29]. Exercise may improve VO_{2max}, because it stimulates the body's central (oxygen transport) and peripheral (oxygen utilization) adaptations to higher oxygen consumption [30]. When people enter the water, hydrostatic pressure increases cardiovascular challenges and respiratory work [31]. In addition, it counteracts the inspiratory muscles, compresses the abdomen, and raises the diaphragm [8]. Therefore, it was believed that VO_{2max} during movement in water, especially in deep water, was lower than that on land [8]. Some researchers held that VO_{2max} was more improved by AE than LE [25, 26]. However, there is no overwhelming evidence which sport is more effective. Previous reviews showed that AE may increase VO_{2max} by 5 to 42% [8], while LE was reported to increase VO_{2max} by 4.2 to 13.4% [32]. The current study found that VO_{2max} in people with T2DM was increased in post-AE as compared with pre-AE and Ctrl. No difference in the improvement of VO_{2max} was found in AE vs LE. The effect of AE on VO_{2max}, especially compared to LE, should be further confirmed.

As a simple and noninvasive measurement method, heart rate is closely related to cardiac structure and function. In general, moderately low RHR indicates effective heart function and cardiovascular health [33]. Regular exercise reduces RHR due to its potential capability to restrain sympathetic activity and increase parasympathetic activity, increase stroke volume and improve myocardial oxygen uptake [34]. When performing exercise in water, the heart rate was believed to be lower than that on land under the same exercise intensity, mainly due to the greater stroke volume of heart when body entered the water [8]. A previous review stated that heart rate was lower in water than that on land, but the difference of RHR after exercise was not described [35]. In another meta-analysis, RHR was decreased after both AE and LE, but it was uncertain which kind of exercise was more effective [4]. Similar results were obtained in people with T2DM in our study. RHR declined in post-AE when compared with pre-AE and Ctrl. Also, AE showed no greater advantage in reducing RHR when compared to LE. It is worth noting that, among the three trials designed as AE vs LE in our review, there was one study [20] that suggested that AE is more beneficial. However, whether or not AE is more favorable still requires more study.

Blood pressure is another common index closely related to cardiovascular function. Elevated blood pressure is an important factor leading to cardiovascular events [36]. There seems to be no doubt that exercise can reduce blood pressure. In addition to the possible effect of weight loss, exercise may decrease ventricular wall thickness, reduce arterial stiffness and improve endothelial function [37]. As mentioned earlier, the way the cardiovascular system functions changes when the body is immersed in water. The majority of studies suggested that AE is more conducive to lowering blood pressure than LE after both acute [38–40] and long-term exercise [41]. However, in our study, AE did not show a greater advantage in reducing blood pressure in T2DM patients. A previous meta-analysis on the effect of water sports on blood pressure only compared the antihypertensive effect of AE with that

Figure 6. Effect of AE on RDBP



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of a non-intervention control group instead of with LE [42]. Whether the antihypertensive efficacy of AE is greater requires further investigation. Also, consistent with previous studies, in this study RSBP and RDBP declined post-AE as compared to pre-AE. A similar result should have been obtained for AE vs Ctrl. However, no difference in blood pressure was found after completion of the two different interventions. The reason for that outcome might be partly due to the differences in basic levels between the two groups.

Conclusions and limitations

In this review, we found that VO_{2max} of patients with T2DM was increased by AE, while RHR, RSBP, and RDBP decreased after AE. There was no difference in the above changes when AE was compared to LE. It seemed that AE, like LE, might be beneficial to cardiovascular health in patients with T2DM. However, we failed to provide sufficient evidence to prove that participation in AE could improve 6MWD in the T2DM population. In addition, as shown in Table 1, there were differences among the studies in the temperature and depth of water and in the type and intensity of water movement. These factors might lead to alternative results [43]. Perhaps a more detailed experimental design could solve this problem.

Authors' contributions

All authors contributed significantly to the project. They have read and approved the final version of the manuscript.

No conflict of interest is reported.

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