The effects of water-based exercise training in people with type 2 diabetes

Anna S. Scheer

Dr. Louise H. Naylor* 2,3

Associate Professor (Metabolic Medicine) Seng K. Gan4

Dr. Jonathon Charlesworth5

Dr. Nat Benjanuvatra2

Winthrop Professor Daniel J. Green2

Associate Professor Andrew J. Maiorana* 1,3

1. School of Physiotherapy and Exercise Science, Faculty of Health Science, Curtin University, GPO Box U1987, Perth, Western Australia, Australia, 6845

2. School of Human Sciences, Faculty of Science, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia, 6009

3. Advanced Heart Failure and Cardiac Transplant Service, Royal Perth Hospital, GPO Box X2213, Perth, Western Australia, Australia, 6847

4. Medical School, Faculty of Health and Medical Sciences, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia, 6009

5. Sports Medicine Glengarry, Suite 1/64 Arnisdale Road, Duncraig, Western Australia, Australia, 6023

Corresponding author: Associate Professor Andrew Maiorana

Telephone: +61 8 9266 9225, Fax: +61 8 9266 3699, Email: A.Maiorana@curtin.edu.au

* Dr Naylor and Associate Professor Maiorana have transferred from Royal Perth Hospital to the Advanced Heart Failure and Cardiac Transplant Service and Allied Health Departments, Fiona Stanley Hospital, Murdoch, Western Australia, Australia
Abstract:

Purpose: To investigate the effects of 8 weeks of upright water-based exercise training in people with type 2 diabetes.

Methods: Thirteen participants with type 2 diabetes (54% male; 60.9 ± 9.6 years, mean ± standard deviation) completed eight weeks of upright water-based exercise training at a moderate intensity (60-80% of exercise test-derived maximum heart rate), for one hour, three times a week (TG). Fourteen participants (64% male; 63.9 ± 9.8 years) acted as a control group (CG) who maintained their usual activities. Pre- and post-intervention, participants performed cardiopulmonary exercise testing to determine VO₂peak and one-repetition maximum testing to assess muscular strength. Blood profiles were assessed with standard assays. Body mass index and waist:hip ratio were employed as measures of anthropometry. Endothelium dependent (brachial artery flow mediated dilation (FMD)) and independent (GTN mediated) function were assessed using vascular ultrasound.

Results: Water-based training increased VO₂peak (18.5 ± 4.3 to 21.5 ± 5.4 ml.kg⁻¹.min⁻¹) (p=0.002), overall muscle strength (123 ± 44 to 139 ± 43kg) and leg strength (92 ± 28 to 104 ± 29kg), compared with the CG (p=0.001). The effect on pectoral strength (31 ± 17 to 35 ± 16kg) was not significantly different to the CG (24 ± 12 to 26 ± 14kg) (p=0.08). No change was observed in anthropometry, blood profiles, or GTN mediated vascular function. FMD was increased following training (6.1 ± 2.4 to 6.5 ± 3.0%), compared with controls who demonstrated a slight decrease (6.2 ± 1.6 to 5.4 ± 1.6%) (p=0.002).

Conclusion: Water-based circuit training was well tolerated and appears to be an effective exercise modality for improving aerobic fitness, strength and vascular function in people with type 2 diabetes.
Key Words: hydrotherapy, aquatic exercise, aerobic capacity, muscle strength, endothelial function

Introduction

Type 2 diabetes is a rapidly growing global health problem, associated with increased risk of cardiovascular diseases and premature mortality (1-3). Exercise training is an important component of comprehensive diabetes management (4); traditional exercise interventions have been shown to improve a range of physiological outcomes in type 2 diabetes including aerobic fitness, muscular strength, anthropometry, glycaemic control and vascular endothelial function (5-8). Moreover, exercise training has been associated with improved insulin sensitivity and reduced mortality (9, 10).

While the benefits of exercise in type 2 diabetes are well established, more than two thirds of people with type 2 diabetes do not achieve the recommended level of physical activity (11). A myriad of reasons may underlie the suboptimal participation in exercise by people with type 2 diabetes, including common comorbidities such as obesity and arthritis which may result in pain or discomfort during exercise (12), and reduce exercise self-efficacy (13). Over two thirds of people with type 2 diabetes are classified as obese (14) and over half have comorbid arthritis (12), both of which can inhibit the ability to carry out land-based physical activity (13, 15).

Providing alternative exercise options that are safe and efficacious for people with type 2 diabetes and comorbid obesity and/or arthritis may help encourage more people with type 2 diabetes to engage in ongoing exercise. Water-based exercise may provide an alternative option in this context due to the physical properties of water immersion, including the effects...
of buoyancy and hydrostatic pressure, which reduce the weight-bearing load on lower limb joints and may help to relieve joint swelling (16). These factors result in it being well tolerated in obese individuals (17) and may help to reduce the fear of pain reported by patients with type 2 diabetes and arthritis, with land-based exercise (12).

Furthermore, the characteristic physiological effects of upright water immersion, including an increase in central blood volume, cardiac output and pulse pressure (18-20), may facilitate vascular adaptations by augmenting vascular shear stress, a potent mediator for exercise-induced improvement in endothelial function (21), during aquatic exercise.

The aim of this study was to evaluate the effects of an eight-week water-based circuit training program on aerobic fitness, muscular strength, anthropometry, glycaemic control, lipid profiles and vascular function in people with type 2 diabetes.

Methods

Participants

Participants were recruited from the community using local media advertising. Eligibility for both groups in the study included a diagnosis of type 2 diabetes, managed through oral medication or diet, not currently undertaking structured exercise and being over 18 years of age. Exclusion criteria were insulin use, established cardiovascular disease, hypercholesterolaemia (total cholesterol >5.9mmol/L), untreated hypertension (140/90mmHg), diabetic retinopathy or ulcers. The study was performed with participants on their usual medications, which were not changed during the study. Participants were allocated to either an eight week water-based exercise training group (TG) or control group (CG), who
maintained their usual activities for eight weeks. This study received institutional ethics
approval and participants provided written, informed consent.

Assessments
Participants underwent the assessments, conducted by a blinded assessor, at baseline and
following the eight week study period. The primary outcome measure was aerobic capacity,
with secondary outcome measures including anthropometric measurements, blood profiles,
muscular strength and vascular function.

Aerobic Capacity
Exercise testing was undertaken using an electronically-braked cycle ergometer (Lode,
Groningen, Netherlands). Initial resistance was set at 20, 40 or 60 watts depending on the
participant’s exercise history and reported exercise tolerance and increased in 20W
increments at three minute intervals until volitional exhaustion or until the participant was
unable to maintain a cadence of at least 50 revolutions per minute. Heart rate and rhythm
were measured continuously with a 12 lead electrocardiogram (Cardiosoft, GE Marquette,
UK). Blood pressure was measured manually with a mercury sphygmomanometer and rating
of perceived exertion was assessed using the Borg Category Scale in the final 30 seconds of
each stage and at peak exercise. This test was conducted by an experienced exercise
physiologist, who has conducted over 1000 cardiopulmonary exercise tests previously in
clinical cohorts.
Oxygen consumption (VO₂) during exercise was calculated from minute ventilation (Vₑ),
measured using mass flow ventilometry, and simultaneous mixing chamber analysis of
expired gas fractions (Vmax, Sensormedics, Yorba Linda, USA). Gas analysers and flow
sensors were calibrated before each test, according to standard operating procedures. VO₂peak
and VCO₂peak were averaged over 40 seconds during the final minute of exercise prior to volitional exhaustion and expressed in L.min⁻¹ and relative to body weight (ml.kg⁻¹.min⁻¹).

**Anthropometric Measurements**

Body weight (AND HW 200KGL scales, Australia) and height were measured to derive body mass index (BMI). Waist and hip circumference were measured in triplicate using an anthropometric steel tape (Lufkin, USA), with the median scores recorded for analysis and used to calculate waist: hip ratio.

**Blood Profiles**

Plasma glucose, glycated haemoglobin (HbA₁C), serum insulin, total cholesterol, high density lipoprotein (HDL), low density lipoprotein (LDL) and triglycerides were assessed by antecubital venous blood samples. Samples were collected after an overnight fast and analysed by the pathology service at a National Association of Testing Authorities, Australia approved pathology service.

**Muscular Strength**

The one repetition maximum (1RM) technique was used to assess lower (dual leg press) and upper (pectoral deck) body muscular strength employing pin-loaded machine-stack weights (Pulsestar, Cheshire, England). Participants were familiarised to the tests, including being instructed in correct lifting technique and to avoid the Valsalva manoeuvre. After a general warm up and stretching, six repetitions of a submaximal weight, estimated at less than 50% of the 1RM, were performed. The weight was progressively increased with minimum of 2.5kg increments until a maximal load was achieved that could be lifted through one full repetition only, with good technique and without breath-holding. Rest periods between lifting
attempts were standardised to two minutes between lifts and machine settings were recorded for reproducibility at follow-up assessment.

Brachial artery vascular function

Brachial artery flow mediated dilation (FMD) and glyceryl trinitrate (GTN) mediated dilation were assessed in accordance with the guidelines for ultrasound assessment of FMD produced by Corretti et al (22). High resolution vascular ultrasound imaging was performed in a quiet, temperature controlled room. Assessments were performed ≥ 6 hours after fasting, ≥ 8 hours after consuming vitamins or caffeine and ≥ 24 hours after strenuous exercise. Baseline and follow-up assessments for individuals were conducted at the same time of day to exclude diurnal variation. Prior to testing, participants were rested in the supine position for 20 minutes, with their arms supported and abducted to approximately 80°. A multi-frequency 5-12MHz linear array wideband probe was used with a high resolution ultrasound scanning machine (T3000, Terason, Burlington, Massachusetts). B-mode longitudinal images of the vessel were always taken at an insonation angle <60 °. For FMD determination, baseline images were taken during the final minute of rest. Vessel response to an ischaemic stimulus was then assessed using a rapid inflation/ deflation cuff (AG 101 Hokanon, Bellevue, Washington), inflated to 220mmHg for five minutes. The cuff was positioned distal to the olecranon process and recordings were taken for 30 seconds before, and for five minutes after, cuff deflation. After a 20 minute rest, glyceryl trinitrate (GTN) mediated dilation of the brachial artery was examined through administering a sublingual dose of GTN (400μg). The brachial artery was imaged for one minute before the GTN dose and from minute 3 to minute 8 after dose administration.

Custom designed edge-detection software was used by a blinded examiner for image analysis. This method has previously been described in detail (23, 24), and found to have less
examiner variability than manual methods (23). Briefly, this software automatically determined arterial diameter and vessel wall thickness by assessing the pixel density of ultrasound images in a region of interest, which was selected by the examiner. FMD and GTN mediated dilation are expressed in terms of percentage change from baseline.

**Exercise Training Intervention**

Training was performed 3 times per week in a heated community pool, with an average water temperature of 30 degrees Celsius. Training sessions consisted of 50 minutes of a water-based circuit training program and 5 minute warm up and cool down of light aerobic activities and stretching of the major muscle groups.

The circuit program consisted of 16 exercises: eight aerobic stations (running, walking, high knee marching and heel flicks each performed twice), alternating with eight resistance stations (right and left; knee flexion/extension, hip flexion/extension, hip abduction/adduction and bilateral pectorals and shoulder flexion/extension). Participants exercised at each station for 60 seconds, with an active recovery period of 20 seconds between stations to encourage aerobic conditioning. The participants completed 2 full circuits in each session and then undertook part of a third circuit. The stations in the final circuit were alternated at each session to ensure all muscles received a consistent training stimulus.

Resistance was applied during the exercise circuit using custom designed sets of double-sided Perspex paddles (one sheet on either side of the limb, secured with Velcro) and adjusted for each participant (see Supplemental Digital Content 1). The upper limb paddles were positioned over the hands and the leg paddles were placed over the lower leg, starting a few centimetres above the ankle joint. Paddles were orientated on the limbs in accordance with the direction of the exercise to optimise resistance and were only used during the relevant resistance exercise. Paddle dimensions ranged from 15 cm x 20 cm to 25 cm x 30 cm. Paddle
size and repetition speed were altered as training progressed to maintain a moderate exercise intensity. This was guided by a rating of perceived exertion of 12-15 on the Borg Category Scale and a heart rate of 60-80% of the maximum heart rate achieved during the baseline exercise test, with exercise intensity being increased through the desired range as training progressed.

Sample Size
Sample size was calculated based on VO\textsubscript{2peak} data from an 8 week land-based circuit training program in people with type 2 diabetes (7). Assuming 80% power and a 5% level of significance, 11 participants would be required to complete the study (effect size of 1.7ml.kg.min\textsuperscript{-1}, standard deviation of 1.4ml.kg.min\textsuperscript{-1}), with the aim of recruiting 14 participants to the training group to allow for an approximate 20% drop out rate seen in previous studies. Recruitment was ceased once the training group had reached the required number.

Data Analysis
Data was analysed using IBM SPSS software for Windows. Baseline differences were assessed with independent \textit{t}-Tests. A per-protocol, 2-way mixed models ANOVA was used to examine group x time interactions (simple main effects), with main effects examined if no significant interaction was seen, \textit{p}<0.05 was considered statistically significant.

Results
Of the 82 potential participants screened for the study, 35 were allocated to the TG or CG. Fourteen participants commenced the TG, with 13 of these completing the program. Twenty-one participants in the CG commenced the study, with 14 completions (six participants
withdraw and one undertook an exercise program outside the study) (Figure 1).

There were no significant differences in sex or age between participants in the TG and CG at baseline. There was a similar profile between groups for diabetes management and for non-diabetes medication (Table 1).

The training program was well tolerated by participants, with no injuries or adverse responses to exercise occurring. Thirteen participants attended at least 80% of training sessions, with the remaining participant withdrawing due to an unrelated medical issue (cancer diagnosis).

Anthropometric characteristics of participants completing the study are presented in Table 2. BMI was the only outcome measure that significantly differed between groups at baseline (p=0.027). There were no significant between-group differences over time for any of the anthropometric or blood profile results. Waist circumference reduced from 114.1 ± 13.3 to 111.8 ± 13.6cm with training, however this was not significantly different when compared to the control group (p=0.213). In the control group HDL-cholesterol increased from 1.16 ± 0.37 to 1.24 ± 0.39mmol/L, but this was not significantly different to the training group (p=0.112). One CG participant did not complete the anthropometric assessment due to non-attendance. One CG and two TG participants failed to complete blood testing (all results), an additional two TG and two CG participants had fasting plasma glucose samples that were unable to be used due to laboratory processing issues.

Aerobic capacity was significantly improved with exercise training (Table 3). Training increased VO_{2peak} by 16% (p=0.002), exercise duration by 19% (p=0.003), and ventilatory threshold by 17% (p=0.045). There was no significant time x group interaction for peak heart rate, systolic or diastolic blood pressure, respiratory exchange ratio or rating of perceived
exertion. One TG and three CG participants were not included in the analysis for the exercise
tests, as the exercise test either did not achieve the criteria for a maximal effort (respiratory
exchange ratio at baseline was 0.87, n=1 CG), participants failed to attend the laboratory (n=2
CG), or due to technical issues (n=1 TG).

Overall muscular strength (summed strength test data) was significantly improved with
training (123 ± 44 to 139 ± 43kg) compared to the control condition (107 ± 45 to 108 ± 46kg)
(p=0.001). Lower body muscular strength significantly improved by 13% with training (TG:
92 ± 28 to 104 ± 29kg; CG: 83 ± 33 to 82 ± 33kg, p=0.001), but the measured difference of
13% in upper body strength in the TG did not achieve significance (TG: 31 ± 17 to 35 ±
16kg; CG: 24 ± 12 to 26 ± 14kg, p=0.075) (Figure 2). One TG and two CG participants did
not undergo strength assessment due to musculoskeletal limitations.

The percentage change in flow mediated dilatation in the TG (6.1 ± 2.4 to 6.5 ± 3.0%), was
significantly different to the CG (6.2 ± 1.6 to 5.4 ± 1.6%). Individual and group change
scores are presented in Figure 3. Ten TG participants and 12 CG participants were included
in this analysis due to inadequate scan data for analysis due to artefact (n=2 TG, n=2 CG), or
recording failure (n=1 TG).

There was no significant difference in the percentage change for GTN mediated dilation
between groups (17.8 ± 4.1 to 18.0 ± 4.9% in the TG and 17.0 ± 5.7 to 16.9 ± 5.9% in the
CG, p=0.404). Twelve participants from the TG and nine participants from the CG were
used in the GTN analysis, due to participant contraindications for testing (n=5 CG), or
insufficient scan data for analysis (n=1 TG).
Discussion

The primary findings from this study were that water-based circuit training was effective for improving aerobic capacity, muscle strength and vascular endothelial function. These adaptations are likely to translate to improved tolerance of endurance and strength-related tasks of daily living and provide support for the prescription of water-based exercise as an alternative exercise option for people with type 2 diabetes. However, there was no significant effect of training on anthropometric parameters or glycaemic control.

The improvement in aerobic capacity observed in the study is of a similar magnitude to that observed during similar duration and intensity gym-based exercise (7, 9) and longer duration aquatic exercise programs (25, 26). This has important clinical relevance because low aerobic capacity is associated with increased all-cause mortality in people with type 2 diabetes, independent of age, baseline cardiovascular disease, hypertension, glycaemic control and family history (10). Furthermore, in middle aged to older men, VO$_{2\text{max}}$ decreases significantly as a consequence of ageing (27). Slowing that decline by just 1 ml.kg$^{-1}$.min$^{-1}$ per decade has been associated with a relative risk reduction of nine percent in all-cause mortality (27).

These previous studies highlight the importance of maintaining aerobic capacity in individuals with type 2 diabetes and emphasise the significance of having evidence-based alternative exercise options to increase participation in exercise.

Water-based circuit training also resulted in a significant increase in overall and leg strength, comparable to our previous finding following eight weeks of gym-based circuit training (7). The improvement in strength was observed during a land-based assessment, suggesting that gains from water-based training are transferable to land-based activities. This observation supports the use of water-based exercise, involving resistance, for muscle conditioning, and is
particularly relevant to people with type 2 diabetes who have co-morbidities that might limit traditional gym-based exercise circuits or who are not comfortable in a gym environment. Over half of people with type 2 diabetes have comorbid arthritis (12) and the presence of arthritis in people with type 2 diabetes has been associated with reduced overall physical activity (12) and reduced self-efficacy for strength training (13). Improved muscular strength has been associated with enhanced physical function (28), which may increase daily activities with associated benefits over time to glycaemic control (4, 26) and quality of life (17, 26).

Whilst no change was observed in overall weight or body mass index, a 2.3cm reduction (NS) in waist circumference was evident in the TG. Previous studies of water-based exercise conducted over 12 weeks have resulted in a 5cm reduction in waist circumference in overweight or diabetic populations (26, 29), suggesting there may be additional benefits on central adiposity from longer duration training programs. Obesity is a common comorbidity in people with type 2 diabetes, with a large cohort study in an American population finding over 60% of people with type 2 diabetes were obese, with a mean BMI of 34.5kg/m² and mean waist circumference falling between 110-115cm for men and women (14), similar to the sample in this study. An increased hazard ratio of 1.07 to 1.09 has been found for every 5cm increase in waist circumference above guideline levels in a large cohort analysis (30), highlighting the importance of training programs of extended duration for addressing this risk factor.

Although HbA1c tended to improve in the TG compared with controls (p=0.07), there were no statistically significant interaction effects for any measure of glycaemic control following the eight week intervention. This contrasts with findings of improved glycaemic control following similar intensity and duration gym-based circuit training by our group (7).
conflicting results may be explained in part by the poorer glycaemic control at baseline in the
gym-based study (baseline HbA1c was 8.5%, compared with 7.3% in the current study), as it
appears patients with greater metabolic disturbance have the greatest improvement in
glycaemic control with exercise training (31). Alternatively, the lack of effect may reflect
differences in the muscle contractions or blood flow occurring in water versus on land, and
associated movement of glucose transporters (GLUT4). A meta-analysis that compared
water-based training with a control group in type 2 diabetes reported improved glycated
haemoglobin, however the majority of studies included in the analysis were of at least 12
weeks duration, with the two studies of eight weeks duration showing variable results (32).
This suggests that longer duration water-based training programs may be required to achieve
a significant improvement in glycaemic control. The smaller sample size of the fasting
plasma glucose analysis, compared to the HbA1c analysis may explain some of the variability
between these values, or reflect the different time course of these tests.

Impaired endothelial function has been associated with micro and macrovascular pathology
in people with type 2 diabetes (33, 34), which can have serious consequences for
cardiovascular health. Therefore, the improvement in endothelial function observed with
training (particularly compared with a decrease in the control group) is a clinically important
finding. The relatively modest effect observed in the current study compared with a previous
eight week gym-based study and 12 week water-based study in people with type 2 diabetes,
may reflect the higher baseline endothelial function in the current cohort (6, 25). We have
previously found that baseline FMD% is a predictor of the training effect, with individuals
who have a lower a priori endothelial function having a greater “reserve for improvement”
(35). Furthermore, the water-based training study by Suntraluck et al (2017) differed from
our study in that it investigated the effects of water-based cycling in the popliteal artery (25),
which may have prompted a greater adaptation in endothelial function, given the cycling-based intervention would have specifically targeted the muscle beds being supplied by the artery and may have increased the shear stress stimulus on the artery during training. In the current study, we examined brachial artery endothelial function, utilising blinded analysis and edge-detection and wall tracking software that is independent of investigator bias, in response to a training intervention that involved predominantly the legs, therefore the smaller change in FMD may reflect different analytical approaches, a lower localised training load, or that there is only a relatively modest systemic effect of water-based exercise involving the lower limbs.

Study Limitations

This study was limited by a relatively small sample size, which may have compromised the power to identify statistically significant changes in some physiological parameters that showed a tendency to improve (e.g. HbA1c). Furthermore, some disparity between groups at baseline (VO2peak, waist girth, BMI), whilst not statistically significant (with the exception of BMI), may have influenced the response to training in the respective groups. A further limitation is the relatively short duration of the training program (eight weeks) as highlighted above. A longer duration of training may also have increased the potential for change in anthropometric measures (36) and indices of glycaemic control (37). However, we found that water-based exercise led to an improvement in the clinically and functionally important outcomes of cardiorespiratory fitness, muscle strength, and endothelial function, highlighting that these parameters of fitness adapt rapidly with this mode of exercise. This study was not randomised in its final form, due to the high drop-out rate from the control group in patients who were randomised in the initial blocks. To ensure roughly even numbers completed the study, latter participants were allocated to a group. While this is a limitation, the absence of a
difference in characteristics at baseline, and the stability of the control group’s outcomes, indicate they still form an appropriate comparator group. Finally, results of this study cannot be extrapolated to the sub-group of patients with type 2 diabetes medicated with insulin, as these individuals were excluded from our study, nor can they be extrapolated to patients with co-morbid cardiovascular disease, as this was also an exclusion.

Conclusion

Eight weeks of water-based exercise improved aerobic capacity and muscular strength in people with type 2 diabetes. Engaging patients with type 2 diabetes in exercise can be challenging, and low exercise adherence is often compounded by comorbidities such as arthritis and obesity which occur in a high proportion of patients. The reduced weight-bearing nature of water-based exercise may help to overcome this barrier and engage more people with type 2 diabetes in exercise. This short duration program provides insight into the potential benefits of water-based exercise and highlights the need for further research into developing water-based exercise programs for people with type 2 diabetes.

Acknowledgements

We thank Mr. Peter McKinnon for his assistance with the statistical analysis. Dr. Louise Naylor was supported by the BrightSpark Foundation Company Ltd, Subiaco, Western Australia. Professor Danny Green is an NHMRC Principal Research Fellow (APP1080914). Financial support for this project was provided by Curtin University. None of the authors report any conflicts of interest. The results of the present study do not constitute endorsement by ACSM. The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.


Figure Captions

Figure 1: CONSORT diagram of participant flow through study

Figure 2: The effects of 8 weeks of water-based training or control period on muscular one repetition maximum strength. Figure A- leg muscle strength, Figure B- pectoral muscle strength

Figure 3: Plot of change in flow mediated dilation over 8 weeks. Circles indicate participants’ individual results, black bars indicate the average change for the groups.

Supplemental Digital Content

Supplemental Digital Content 1.doc