Impact of Underwater Treadmill Training on Glycemic Control, Blood Lipids, and Health-Related Fitness in Adults With Type 2 Diabetes

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IN BRIEF A large number of adults with type 2 diabetes experience comorbidities that discourage physical activity and hinder regular participation in land-based exercise programs. An aquatic exercise program is an innovative exercise modality that incorporates combined aerobic and resistance exercise. The purpose of this study was to determine if an underwater treadmill walking program featuring gradual and progressive increases in walking speed and duration has a positive effect on glycemic control, metabolic health, cardiovascular function, body composition, and leg strength in middle-aged adults with type 2 diabetes.

The use of exercise as a therapeutic modality for type 2 diabetes has been shown to enhance insulin sensitivity and improve glycemic control (1). Current physical activity recommendations (2) for adults with type 2 diabetes include aerobic and resistance exercise, with the combination of both exercise modalities leading to better glycemic control compared to performing each activity mode separately (3–5). However, many adults with type 2 diabetes are overweight or obese and may experience reduced mobility because of osteoarthritis or other joint problems that limit physical activity and hinder participation in land-based endurance and resistance training (6).

An emerging therapy that may assist individuals with type 2 diabetes in overcoming barriers to active living is underwater treadmill training (UTT). A unique exercise mode that incorporates concurrent aerobic and strength training, walking on a treadmill placed in water improves cardiovascular health and provides resistance to strengthen the legs, while lowering vertical ground reaction forces (7). Compared to walking in a therapy or recreational pool, exercising on a treadmill immersed in a self-contained water tank enables walking speed to be controlled in a gradual and systematic manner, and caloric expenditure is similar to that measured during dry-land walking (8). The use of water as an unloading medium also reduces core weight and the weight of the legs, thus decreasing the strength needed to walk and support the body. From a health standpoint, the ability to increase energy expenditure is an important component in treating type 2 diabetes (9), since increased caloric output can lessen macrovascular and obesity-related complications and is linked to better glycemic control (9).

With an estimated prevalence of nearly 26 million adults with diabetes in the United States (10) and continued escalation of obesity rates and sedentary behavior in adults, it is important to explore the potential of innovative and user-friendly, activity-based interventions to improve the health and mobility of people with metabolic disease. Against this backdrop, the purpose of our study was to document the impact of UTT...
on glycemic control, blood lipids, and health-related fitness in adults with type 2 diabetes. Specifically, when compared to control measures, we hypothesized that, in this clinical population, a 12-week program of underwater treadmill walking would lead to 1) decreased levels of A1C, LDLs, total cholesterol, and triglycerides (TGs); 2) an increase in HDL concentration; and 3) improved cardiovascular function, body composition, and leg strength.

Research Design and Methods

Participants
Twenty-six adults with physician-diagnosed type 2 diabetes volunteered to participate in this study. The sample size for this study was determined based on an a priori sample size assessment with a medium power effect size of 0.70. Inclusion criteria were a diagnosis of type 2 diabetes for a minimum of 2 years, medical clearance to participate in an exercise program, and a sedentary lifestyle, defined as not performing regular aerobic activity (exercising less than two times a week for at least 20 minutes) or any type of resistance exercise in the 6-month period preceding the study (5). Exclusion criteria included having a myocardial infarction within 6 months before the start of the investigation, presence of unstable chronic medical conditions (e.g., respiratory disease, heart failure, renal disease, or hepatic disease), changes in oral hypoglycemic medication use 6 months before the beginning of the study, and diabetic-related myopathies or neuropathies that would prevent full completion of the aquatic walking program (5,11). This study was approved by the university institutional review board, and participants provided written informed consent. During the investigation, participants were asked to maintain their current medication use and refrain from engagement in structured exercise programming.

We used a single-center, 26-week, randomized treatment-control research design. After obtaining baseline measurements, participants were allocated randomly to either the treatment (UTT) group or the control group and stratified by sex. The treatment group performed UTT, during which participants were asked to maintain their current dietary patterns and avoid participation in a formal exercise training program, both of which were verified through email and phone calls. Participants in the control group were also instructed to maintain their current dietary and physical activity habits, and weekly emails and phone calls were made to confirm adherence to these requests.

Primary Health Outcomes

Glycemic Control and Blood Lipid Profile
Glycemic control was evaluated by measuring plasma levels of A1C, which reflect average blood glucose concentration over a 1- to 3-month period (12). Serum cholesterol and TG values were selected as primary blood lipid markers. A 10-mL venous blood sample was drawn from a forearm vein, and A1C was determined using immunoturbidimetry (Roche COBAS Integra 800, Indianapolis, Ind.; 1.5–3.0% coefficient of variation [CV]). HDL (2.8–3.9% CV), LDL (calculated), and TG levels (1.3–2.1% CV) were analyzed using spectrophotometry (Beckman Coulter AU5400, Brea, Calif.).

Cardiovascular Function
Measures of resting heart rate (RHR) and blood pressure were used as indicators of general cardiovascular health (13). After 10 minutes of seated rest in a dark quiet room (14), RHR was obtained by doubling the number of beats recorded from palpation of the radial pulse for 30 seconds and counting the first beat as zero (14). Two measures of RHR obtained over a 5-minute period were averaged to obtain mean RHR. Using the same adult sphygmomanometer and stethoscope, resting systolic blood pressure (RSBP) and resting diastolic blood pressure (RDBP) were recorded by the primary investigator at the brachial artery (13).

The 6-minute walk for distance (6MWFD) test, chosen as a measure of endurance performance, has been shown to reflect the ability of a person to perform a variety of daily life activities (15). This assessment was selected based on its reliability and safety when used by people with disease (15). Participants walked for 6 minutes around an oval course on an indoor collegiate track, were instructed to cover as much distance as possible within the prescribed time limit, and were given standardized encouragement during the test at equally spaced intervals. Total walking distance was recorded to the nearest foot using a calibrated measuring wheel and converted to meters.

Body Composition
Duplicate measures of body mass to the nearest 0.1 kg (without shoes) were obtained using a flat digital scale (SECA 869) and averaged to determine mean body mass. Standard procedures (16) were followed to measure skinfold thicknesses at seven body sites (abdomen, pectoral, suprailiac, mid-axillary, subscapular, quadriceps, and triceps) on the right side of the body. Using population- and sex-specific equations (14), body fat percentage was calculated from measures of average skinfold thickness at each body site. Duplicate measures of waist circumference, taken as the narrowest point between the iliac crest and the xiphoid process (17), were obtained using a Gulick tape measure and averaged to derive mean waist circumference (in centimeters).

Leg Strength
Concentric peak torque of the dominant leg quadriceps and hamstrings at 30° · second⁻¹ and 60° · second⁻¹ was assessed using a Biodex System III dynamometer. Contraction velocities were chosen to encompass the range of walking speeds used by adults (18). Participants were seated in an upright position and adjustable straps were

Clinical Diabetes Online Ahead of Print, published online May 2, 2018
placed around the upper body and dominant thigh to isolate the quadriceps and hamstring muscles and limit the amount of muscle activation in muscle groups that were not evaluated. Following three accommodation trials, three maximum voluntary sessions were completed in a randomized order at both contraction velocities, with a total of 30 seconds of rest interspersed between trials. The highest peak torque measured across testing sessions for each muscle group and individual velocity was recorded. Leg strength values were expressed in peak torque (ft-lbs), which is considered a representative indicator of strength for both knee flexion and knee extension (19).

**Treadmill Accommodation and UTT**

Before starting UTT, participants performed a walking accommodation session on a treadmill submerged in a water tank (Ferno, Wilmington, OH). In addition to a treadmill, the tank contained a control panel from which the treadmill was operated, a water reservoir with a water filtration system, a variable-speed motor, and two large Plexiglas windows that enabled participants to be monitored visually. The height of the water, which was set at 10 cm below the xiphoid process, was maintained for the duration of the training period (7). The walking accommodation session consisted of 5 minutes of walking at a speed eliciting 20% of heart rate reserve (HRR = [(220 – participant’s age – RHR) × % intensity desired] + RHR).

Study participants completed three UTT sessions per week on alternate days for a total of 12 weeks. Each training session consisted of three walking sessions separated by at least 5 minutes of rest on a flotation device. Water temperature was kept in a neutral range (29–31ºC) (20). During UTT, a gradual progression of exercise intensity and duration was implemented, based on water-based exercise training programs (6,21) and exercise guidelines published by the American College of Sports Medicine (17). Table 1 depicts the progression of walking intensity and duration used during UTT. Exercise heart rate was monitored continuously in each exercise session with a Polar heart rate monitor (Polar, Finland). Once a week, participants were verbally asked about physician visits, acute illnesses, and hypoglycemic events that occurred while engaged in UTT so that they could be documented (11).

**Statistical Analyses**

Descriptive statistics are presented as means ± SDs (Table 2). For each primary health outcome, the effectiveness of the UTT intervention was measured by quantifying the amount of change from baseline to post-training in the treatment group compared to change over the same time period in the control group. The 95% CIs for the amount of change were constructed to determine if a significant change occurred in each participant group, and one-way ANOVA was used to evaluate whether the amount of change for each primary health outcome differed between treatment and control groups. Partial eta squared values (\(\eta_p^2\)) were calculated as shown in Eq. 1 and used to quantify effect size. Significance level was set at \(\alpha\) level of 0.05 for all statistical analyses.

\[
\frac{SS_{\text{Effect}}}{SS_{\text{Error}}} = \frac{SS_{\text{Effect}}}{SS_{\text{Error}} + SS_{\text{Error}}}
\]

**EQ. 1**

**Results**

Adherence to the UTT program was 100%, with the participants completing all 36 (12 weeks × 3 sessions per week) UTT sessions. No UTT-related injuries were reported during the study, and no symptoms of hypoglycemia were reported during the walking sessions. Descriptive statistics and 95% CIs for change scores are reported in Table 3.

**Glycemic Control and Blood Lipid Profile**

ΔA1C was different for UTT and
control groups \( F(1, 24) = 37.18, P < 0.001, \eta^2_p = 0.61 \), such that A1C values decreased for the UTT group \( M = -0.67 \) but not for the control group \( M = 0.02 \). Likewise, \( \Delta \text{HDL} \) varied for UTT and control groups \( F(1, 24) = 10.13, P = 0.004, \eta^2_p = 0.30 \), with an improvement in HDL detected for the UTT group \( M = 6.15 \) but not the control group \( M = -1.46 \). While no group difference was observed in \( \Delta \text{LDL} \) and \( \Delta \text{TG} \) \( F(1, 24) = 0.68, P = 0.419, \eta^2_p = 0.03, \) and \( F(1, 24) = 2.25, P = 0.147, \eta^2_p = 0.09, \) respectively, the TG/HDL ratio was lower for the UTT group \( M = -1.06 \) compared to the control group \( M = 0.06 \) \( F(1, 24) = 4.37, P = 0.047, \eta^2_p = 0.15 \).

**Cardiovascular Function**

Differences in \( \Delta \text{RHR} \), \( \Delta \text{RSBP} \), and \( \Delta \text{RDBP} \) varied between UTT and control groups \( F(1, 24) = 9.00, P = 0.005, \eta^2_p = 0.28; F(1, 24) = 9.58, P = 0.005, \eta^2_p = 0.29; \) and \( F(1, 24) = 9.32, P = 0.005, \eta^2_p = 0.28, \) respectively. Follow-up analyses revealed decreases in RHR \( M = -8.00 \), RSDP \( M = -7.69 \), and RDBP \( M = -6.00 \) for the UTT group.

### TABLE 2. Participant Baseline Characteristics

|                          | n  | Mean ± SD |
|--------------------------|----|-----------|
| Age (years)              | 58.0 ± 5.0 |
| Sex (F/M)                | 16/10 |
| Height (m)               | 1.8 ± 0.2 |
| Body mass (kg)           | 91.2 ± 9.6 |
| Time since diabetes diagnosis (years) | 7.1 ± 4.6 |
| Number of current smokers | 3 |
| Percent taking diabetes medication | 70.4 ± 4.0 |
| Metformin users          | 15 |
| Metformin dosage (mg/day) | 1127 ± 280 |
| Sitagliptin users        | 3 |
| Sitagliptin dosage (mg/day) | 92 ± 14 |
| Participants who reduced medication use during the study | 2 |

### TABLE 3. Descriptive Statistics for Primary Health Outcomes

|                          | UTT Group (n = 13) | Control Group (n = 13) |
|--------------------------|-------------------|-----------------------|
|                          | Baseline Mean     | Change Mean           | 95% CI for Change Mean | Baseline Mean | Change Mean | 95% CI for Change Mean |
| Glycemic control (A1C, %) | 7.25              | -0.67                 | -0.91 -0.43            | 7.90          | 0.02        | -0.03 0.07          |
| Blood lipid profile      |                   |                       |                        |               |             |                   |
| HDL (mg/dL)              | 57.23             | 6.15                  | 1.20 11.11             | 43.38         | -1.46       | -3.07 0.15         |
| LDL (mg/dL)              | 101.77            | -1.15                 | -10.21 7.90            | 133.15        | 2.77        | -2.32 7.86         |
| TG (mg/dL)               | 163.69            | -11.62                | -28.67 5.44            | 215.15        | 0.69        | -4.69 6.08         |
| TG/HDL                   | 4.02              | -1.06                 | -2.18 0.05             | 5.69          | 0.06        | -0.31 0.43         |
| Cardiovascular function  |                   |                       |                        |               |             |                   |
| RHR (bpm)                | 74.00             | -8.00                 | -13.00 -3.00           | 82.00         | 3.00        | -3.00 9.00         |
| RDBP (mmHg)              | 82.00             | -6.00                 | -8.70 -3.30            | 81.08         | -0.46       | -3.35 2.42         |
| RSBP (mmHg)              | 128.62            | -7.69                 | -12.29 -3.09           | 129.08        | 0.15        | -2.91 3.21         |
| 6MWFD (m)                | 476.46            | 95.08                 | 64.18 125.98           | 508.92        | 0.77        | -6.60 8.14         |
| Body composition         |                   |                       |                        |               |             |                   |
| Body mass (kg)           | 94.96             | -2.99                 | -3.50 -2.48            | 102.70        | 0.73        | 0.01 1.44          |
| Body fat (%)             | 31.24             | -2.48                 | -2.94 -2.02            | 29.64         | 0.38        | -0.14 0.90         |
| Waist circumference (cm) | 104.89            | -4.15                 | -5.10 -3.21            | 115.54        | 0.80        | -0.04 1.64         |
| Leg strength (ft-lbs)    |                   |                       |                        |               |             |                   |
| Hamstring peak torque @ 30° · second−1 | 73.80         | 6.62                  | 2.46 10.77             | 87.37         | -0.51       | -2.91 1.89         |
| Hamstring peak torque @ 60° · second−1 | 52.87         | 7.99                  | 1.75 14.22             | 64.38         | 0.50        | -0.69 1.68         |
| Quadriceps peak torque @ 30° · second−1 | 70.00         | 3.51                  | -0.06 7.08             | 85.40         | 0.07        | -1.41 1.55         |
| Quadriceps peak torque @ 60° · second−1 | 50.70         | 7.83                  | 3.07 12.59             | 60.51         | 1.00        | 0.03 1.97          |

**Bold change indicates with 95% CIs that exclude 0.**
whereas no reductions were noted for the control group (RHR \( M = 3.31 \), 
RSBP \( M = 0.15 \), RDBP \( M = -0.46 \)). 
\( \Delta 6\text{MWFDF} \) also differed between UTT and control groups 
\([ F (1, 24) = 41.84, P < 0.001, \eta^2_\varepsilon = 0.64] \), such as 
that the UTT group displayed an improvement in 6MWFDF \( (M = 95.08) \), 
but no change was observed in the control group \( (M = 0.77) \).

**Body Composition**

Measures of \( \Delta \text{body mass, } \Delta \text{body fat} \), and \( \Delta \text{waist circumference} \) 
differed between UTT and control groups 
\([ F (1, 24) = 85.59, P < 0.001, \eta^2_\varepsilon = 0.78; F (1, 23) = 80.31, 
P < 0.001, \eta^2_\varepsilon = 0.78; \) and \( F (1, 24) = 72.74, P < 0.001, \eta^2_\varepsilon = 0.75, 
respectively]. Examination of body composition data indicated that body mass 
\( (M = -2.99) \), body fat percentage \( (M = -2.48) \), and waist circumference 
\( (M = -4.15) \) values were lower after UTT, while no change in body fat percentage 
\( (M = 0.38) \) or waist circumference \( (M = 0.80) \) was detected for participants in the control group. 
Additionally, body mass increased in the control group \( (M = 0.73) \).

**Leg Strength**

Differences in \( \Delta \text{hamstring peak torque} \) at \( 30^\circ \cdot \text{second}^{-1} \) and \( 60^\circ \cdot \text{second}^{-1} \) 
were noted for participants in the UTT and control groups 
\([ F (1, 24) = 10.45, P = 0.004, \eta^2_\varepsilon = 0.30, \) and \( F (1, 24) = 6.61, P = 0.017, \eta^2_\varepsilon = 0.22, \) 
respectively]. Strength values for the hamstring muscles at \( 30^\circ \cdot \text{second}^{-1} \) 
\( (M = 6.62) \) and at \( 60^\circ \cdot \text{second}^{-1} \) \( (M = 7.99) \) were higher for the UTT group, 
but no changes occurred in the control group \( (30^\circ \cdot \text{second}^{-1} M = -0.51; 60^\circ \cdot \text{second}^{-1} M = 0.50) \). 
\( \Delta \text{quadriceps peak torque at } 60^\circ \cdot \text{second}^{-1} \) was higher for the UTT group \( (M = 7.83) \) 
than the control group \( (M = 1.00) \) \( [F (1, 24) = 9.37, P = 0.005, \eta^2_\varepsilon = 0.28] \); 
however, both groups displayed a significant change in this variable. 
The \( \Delta \text{quadriceps peak torque at } 30^\circ \cdot \text{second}^{-1} \) was similar for UTT 
\( (M = 3.51) \) and control \( (M = 0.07) \) groups 
\([ F (1, 24) = 3.77, P = 0.064, \eta^2_\varepsilon = 0.14] \).

**Discussion**

In support of our study hypotheses, 
UTT resulted in better glycemic control, 
a healthier blood lipid profile, 
and improved cardiovascular function, 
body composition, and leg strength in a group of obese, middle-aged adults with type 2 diabetes. 
Secondary analyses also revealed that 
total caloric intake and relative macronutrient intake remained stable 
between control and treatment conditions \( (P < 0.05) \), 
thus emphasizing the singular impact of UTT on key health variables in men and women with type 2 diabetes.

Similar to results from an earlier investigation \( (22) \) documenting the safety and efficacy of UTT in this clinical population, no exercise-related injuries of adverse clinical events were recorded during 
the course of our study, and the adherence rate to the training protocol was 100%. 
The absence of injury and diabetic complications in the current study differs markedly from 
published findings indicating the presence of 5–10 hypoglycemic events and adverse rate events varying 
from 2% to 38% in studies of adults with type 2 diabetes who participated in 
traditional treadmill- and resistance-based exercise programs \( (5,11,23) \). 
Although speculative, the absence of hypoglycemic symptoms with UTT may be related to a 
shorter overall exercise duration while performing concurrent aerobic and resistance training in the water 
compared to the time spent participating in separate land-based endurance and strength exercise programs \( (4,5,24) \). 
A high rate of adherence to UTT in adults with type 2 diabetes may also be linked to 
fewer diabetic complications and a decrease in ground reaction forces acting on the lower extremities \( (25,26) \).

**Glycemic Control**

A1C level was reduced by 0.67% to 
a mean sample value below 7.0% after 
12 weeks of UTT. Compared to 
land-based investigations, the degree 
to which glycemic control was im-
proved after UTT is superior to the 
0.57% reduction in A1C observed af-
after 16 weeks of combined aerobic and 
resistance training performed on land 
\( (4,27) \) and within the range of values 
reported in meta-analyses showing an 
average decrease in A1C of 0.50–
0.80% among individuals with type 2 
diabetes who completed a minimum of 
12 weeks of land-based aerobic training 
or combined resistance and 
aerobic exercise \( (1,22,28) \). 
In view of evidence showing that a decrease in 
A1C of 0.70% represents a potential 
reduction of up to 76% in long-term 
complications from diabetes \( (29) \), 
the degree to which glycemic control 
was improved in our study is clinically significant. 
Moreover, the 0.67% reduction in A1C noted in the present 
study is similar to the improvement in 
glycemic control \( (0.60–0.80\%) \) 
typically observed after dietary intervention 
and long-term drug or insulin therapy \( (4) \). 
Potential mechanisms associated with reductions in A1C 
after UTT include upregulation of 
mitochondrial proteins \( (30) \), 
heightened glycogen synthase activity \( (31) \), 
increased glucose-4 transporter protein content 
and contractile protein content \( (31) \), 
a higher basal metabolic rate and elevation in absolute glucose 
uptake \( (32) \), and diminished regional 
visceral and intermuscular fat stores, 
which can directly influence insulin sensitivity \( (33) \).

**Blood Lipid Profile**

In our study, a 3-month period of 
UTT was linked to an increase in 
HDL \( (+6.15 \text{ mg/dL}) \) and a reduction 
in the TG/HDL ratio \( (-1.12) \). 
The increase in HDL level contrasts 
with data revealing no change in 
HDL cholesterol in middle-aged 
and older adults with type 2 diabetes 
who participated in an aquatic-based 
exercise programs \( (30,34) \). 
This discrepancy may be related to the longer training period and larger decrease in 
body mass \( (4.11 \text{ kg}) \) reported in our 
investigation compared to other 
water-based studies \( (26,35) \).
HDL concentration after endurance training have been attributed to an increase in the production and action of several enzymes that stimulate the reverse cholesterol transport system (36,37). While mean reductions in LDL and TG levels were observed, there was no significant change in either variable. These findings are comparable to those of Cuff et al. (3), who reported nonsignificant changes in LDL and TG levels after combined aerobic and resistance training in middle-aged postmenopausal women. The lack of significant reductions in LDL and TG in our study may have been due to the absence of a dietary intervention to supplement UTT. Despite the lack of change in TG and HDL concentrations, the TG/HDL ratio was lower after UTT. Reductions in the TG/HDL ratio have also been documented in other aquatic-based intervention studies featuring 8 weeks (26) or 12 weeks of supervised moderate-intensity exercise and are comparable to changes detected after extended periods of land-based aerobic or resistance training programs or combined aerobic and resistance training in adults with type 2 diabetes (28,34,35,38–41). From a clinical perspective, a decrease in the TG/HDL ratio is consistent with a lower risk of cardiovascular disease and metabolic abnormalities (30), as well as improved insulin action and sensitivity (42).

**Cardiovascular Function**

In the present investigation, resting measures of heart rate, systolic and diastolic blood pressure, and 6-minute walk for distance were used as descriptors of cardiovascular fitness and performance (6,43). Resting heart rate fell by 10% after UTT, which is in agreement with the findings of Bocalini et al. (20), who recorded a 10% decrease in resting measures of heart rate in healthy, sedentary older women after 12 weeks of water-based exercise. In our study, resting systolic and diastolic blood also decreased by an average of 8 and 6 mmHg, respectively, which is nearly identical to the 5- to 7-mmHg reduction in resting blood pressure seen in hypertensive adults after endurance training (44). Because hypertension is present in >60% of people with type 2 diabetes (45), and the risk of vascular complications is 66–100% higher in people with hypertension and type 2 diabetes compared to people with only one of these health conditions (37), the decrease in resting measures of systolic and diastolic blood pressure that occurred after participation in UTT may be of clinical benefit to this population.

The improvement in 6-minute walking distance after UTT was more than double the average gain in walking distance (46 m) achieved after combined aerobic and eccentric resistance training in middle-aged adults with type 2 diabetes (4). The lower baseline walking performance ($M = 476.5$ m) of our participants, compared to that reported in the investigation by Marcus et al. (4) ($M = 554.5$ m), may have been partially responsible for the larger magnitude of improvement seen after UTT. From a practical standpoint, the gain in walking distance after participating in water-based treadmill training would enable adults with type 2 diabetes to walk for longer periods of time without undue fatigue (38,46).

**Body Composition**

After engaging in UTT, body mass was reduced by an average of 2.99 kg, which is consistent with the recommended weekly weight loss standard for adults endorsed by the American College of Sports Medicine (17). This decrease in body mass is essentially identical to the average reduction of 3.00 kg measured by Cugusi et al. (35) in middle-aged men with type 2 diabetes who completed a 12-week supervised aerobic- and resistance-based aquatic exercise program and slightly lower than the 3.31-kg decrease in body mass recorded by Ho et al. (47) after 12 weeks of combined land-based aerobic and resistance exercise. One potential explanation for a lower body mass after UTT is the use of a lower water height compared to other studies, which would result in a higher exercise intensity because of reduced water buoyancy.

The magnitude of reduction in body fat percentage after UTT (2.5%) falls within the range of the 1.0–3.0% loss in body fat reported in studies incorporating land-based aerobic or resistance exercise in adults with type 2 diabetes (3–5,11,24) and is similar to reductions in relative fat after 16 weeks of shallow-water circuit training in overweight, postmenopausal women (48) and 8 months of shallow-water aquatic aerobic exercise performed by middle-aged, obese women (49). Likewise, the decrease in waist circumference after UTT is consistent with data obtained after 12 weeks of deep-water circuit training in older, overweight women (5 cm) (6) and 12 weeks of aquatic-based exercise in middle-aged men (6 cm) (35). From a health perspective, an improved body fat profile and a smaller waist circumference are correlated with reduced all-cause and cardiovascular mortality (50), less central adiposity, and greater insulin sensitivity (4).

**Leg Strength**

Significant gains in peak torque of 16% in the quadriceps at 60°·second$^{-1}$, 9% in the hamstrings at 30°·second$^{-1}$, and 15% in the hamstrings at 60°·second$^{-1}$ occurred after UTT. These findings align with recent data showing improved leg strength in middle-aged adults who performed 8 weeks of UTT (22) and are comparable to increases of 8% and 13% in knee extension flexion, respectively, observed in older and overweight women who participated in aquatic exercise interventions (6,38). During UTT, the constant movement of the lower limbs against water resistance provides a unique stimulus to improve muscle strength, a variable...
shown to be related to an enhanced glucose metabolic rate (51).

In conclusion, results from our study have demonstrated that UTT is a safe and effective multimodal training approach that can improve glycemic control, blood lipid profile, cardiovascular function, body composition, and leg strength in middle-aged adults with type 2 diabetes. The use of UTT may be a particularly appropriate treatment modality for adults with type 2 diabetes who have comorbidities or other medical issues that limit their ability to perform traditional land-based exercise protocols. In considering future research directions, additional work is needed to compare the efficacy of UTT to traditional land- and water-based exercise programs in older and younger adults with type 2 diabetes and prediabetes and document the potential association between improved glycemic control and reduction in inflammatory responses after UTT. From a practical standpoint, the use of smaller, commercially available treadmills that can be placed into existing pools located in clinical facilities and community fitness centers should also be explored as a cost-effective method of using UTT to treat larger groups of adults and children with type 2 diabetes, as well as individuals with arthritis, joint pain, and obesity who have difficulty performing land-based exercise programs.

Acknowledgments
The authors thank all of the participants for their time and participation in this study.

Duality of Interest
No potential conflicts of interest relevant to this article were reported.

Author Contributions
R.T.C. designed the study; acquired, analyzed, and interpreted the data; and wrote the manuscript. J.M.C. designed the study, interpreted the data, and reviewed the manuscript. D.W.M. designed the study, interpreted the data, wrote the manuscript, and reviewed the manuscript. R.T.C. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Previous Publication
A portion of this study was presented as an abstract at the Southeast American College of Sports Medicine regional conference in Greenville, SC, 16–18 February 2017, and at the American College of Sports Medicine national conference in Denver, CO, 30 May to 3 June 2017. The remaining portion of this study was published as an abstract at the 77th ADA Scientific Sessions in San Diego, CA, 9–13 June 2017.

References
1. Snowling NJ, Hopkins WG. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients. Diabetes Care 2006;29:2518–2527
2. American Association of Diabetes Educators. Diabetes and physical activity. Diabetes Educ 2012:38:129–132
3. Cuff DJ, Meneilly GS, Martin A, Ignaszewski A, Tidesley HD, Frohlich JJ. Effective exercise modality to reduce insulin resistance in women with type 2 diabetes. Diabetes Care 2003:26:2977–2982
4. Marcus RL, Smith S, Morrelli G, et al. Comparison of combined aerobic and high-intensity eccentric resistance exercise with aerobic exercise only for people with type 2 diabetes mellitus. Phys Ther 2008;88:1345–1354
5. Sigal RJ, Kenny GP, Boulé NG, et al. Effects of aerobic training, resistance training, or both on glycemic control in type 2 diabetes: a randomized trial. Ann Intern Med 2007;147:357
6. Jones LM, Meredith-Jones K, Legge M. The effect of water-based exercise on glucose and insulin response in overweight women: a pilot study. J Womens Health 1999;18:1653–1659
7. Alkurdi W, Paul D, Sadowski K, Dolny D. The effect of water depth on energy expenditure and perception of effort in female subjects while walking. International Journal of Aquatic Research and Education 2010;4:49–60
8. Hall J, Macdonald IA, Maddison PJ, O’Hare JP. Cardiorespiratory responses to underwater treadmill walking in healthy females. Eur J Appl Physiol 1998;77:278–284
9. Tuomilehto J, Lindström J, Eriksson JG, et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. N Engl J Med 2001;344:1343–1350
10. Centers for Disease Control and Prevention. National Diabetes Fact Sheet: National estimates and general information on diabetes and prediabetes in the United States. Atlanta, GA, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2011
11. Castaneda C, Layne JE, Munoz-Orians L, et al. A randomized controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. Diabetes Care 2002;25:2335–2341
12. Bennett CM, Guo M, Dharmage SC. HbA1c as a screening tool for detection of type 2 diabetes: a systematic review. Diabet Med 2007;24:333–343
13. Nagaya T, Yoshiha H, Takahashi H, Kawai M. Resting heart rate and blood pressure, independent of each other, proportionally raise the risk for type-2 diabetes mellitus. Int J Epidemiol 2010;39:215–222
14. Allison MA, Manson JE, Aragaki A, et al. Resting heart rate and coronary artery calcium in postmenopausal women. J Womens Health 2011;20:661–669
15. Enright PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. Am J Respir Crit Care Med 1998;158:1384–1387
16. Bloomfield J, Ackland T, Elliott B. Applied anatomy and biomechanics in sport. Hoboken, N.J., Blackwell Scientific Publications Press, 1994
17. American College of Sports Medicine. ACSM’s guidelines for exercise testing and prescription. Baltimore, MD: Lippincott, Williams, and Wilkins Press, 2013
18. Lanshammar K, Ribom EL. Differences in muscle strength in dominant and non-dominant leg in females aged 20–39 years: a population-based study. Physical Therapy in Sport 2011;12:76–79
19. Blain H, Vuillemin A, Teissier A, Hanesse B, Goullirn F, Jeandel C. Influence of muscle strength and body weight and composition on regional bone mineral density in healthy women aged 60 years and over. Gerontology 2001;47:207–212
20. Bocalini DS, Serra AJ, Murad N, Levy RF. Water-versus land-based exercise effects on physical fitness in older women. Geriatr Gerontol Int 2008;8:265–271
21. Stevens S, Morgan DW. Underwater treadmill training in adults with incomplete spinal cord injuries. J Rehabil Res Dev 2010;47:12–16
22. Connors R, Morgan D, Fuller D, Caputo J. Underwater treadmill training, glycemic control, and health-related fitness in adults with type 2 diabetes. International Journal of Aquatic Research and Education 2014;8:382–396
23. Yavari A, Najafipoor F, Aliasgarzadeh A, Niafar M, Mobasser M. Effect of aerobic exercise, resistance training or combined training on glycemic control and cardiovascular risk factors in patients with type 2 diabetes. Biology of Sport 2012;29:135–143
24. Maiorana A, O’Driscoll G, Goodman C, Taylor R, Green D. Combined aerobic and resistance exercise improves glycemic con-
trol and fitness in type 2 diabetes. Diabetes Res Clin Pract 2002;56:115–123
25. Rutledge E, Silvers W, Browder K, Dolny D. Metabolic-cost comparison between submaximal land and aquatic treadmill exercise. International Journal of Aquatic Research and Education 2007;1:118–133
26. Åsa C, Maria S, Katharina SS, Bert A. Aquatic exercise is effective in improving exercise performance in patients with heart failure and type 2 diabetes mellitus. Evid Based Complement Alternat Med 2012;1–8
27. Tan S, Li W, Wang J. Effects of six months of combined aerobic and resistance training for elderly patients with a long history of type 2 diabetes. J Sports Sci Med 2012;11:495–501
28. Kelley GA, Kelley KS. Effects of aerobic exercise on lipids and lipoproteins in adults with type 2 diabetes: a meta-analysis of randomized-controlled trials. Public Health 2007;121:643–655
29. Shenoy S, Arora E, Jaspal S. Effects of progressive resistance training and aerobic exercise on type 2 diabetics in Indian population. Int J Diabetes Metab 2009;17:27–30
30. Menshikova EV, Ritov VB, Fairfull L, Ferrell RE, Kelley DE, Goodpaster BH. Effects of exercise on mitochondrial content and function in aging human skeletal muscle. J Gerontol A Biol Sci Med Sci 2006;61:534–540
31. Christ-Roberts CY, Pratipanawatr T, Pratipanawatr W, et al. Exercise training increases glycogen synthase activity and GLUT4 expression but not insulin signaling in overweight nondiabetic and type 2 diabetic subjects. Metabolism 2004;53:1233–1242
32. Erikkson J, Taimela S, Eriksson K, Parviainen S, Peltonen J, Kujala U. Resistance training in the treatment of non-insulin-dependent diabetes mellitus. Int J Sports Med 1997;18:242–246
33. Wei Y, Chen K, Whaley-Connell AT, Stump CS, Ibdah JA, Sowers JR. Skeletal muscle insulin resistance: role of inflammatory cytokines and reactive oxygen species. Am J Physiol Regul Integr Comp Physiol 2008;294:F673–680
34. Balducci S, Zanusso S, Massarini M, et al. The Italian Diabetes and Exercise Study (IDES): design and methods for a prospective Italian multicentre trial of intensive lifestyle intervention in people with type 2 diabetes and the metabolic syndrome. Nutrition Metabolism and Cardiovascular Diseases 2008;18:585–595
35. Cugusi L, Cadeddu C, Nocco S, et al. Effects of an aquatic-based exercise program to improve cardiometabolic profile, quality of life, and physical activity levels in men with type 2 diabetes mellitus. Physical Medicine and Rehabilitation 2015;7:141–148
36. Durstine L, Haskell W. Effects of exercise training on plasma lipids and lipoproteins. Exerc Sport Sci Rev 1994;22:477–521
37. Hayashino Y, Jackson JL, Fukumori N, Nakamura F, Fukuhara S. Effects of supervised exercise on lipid profiles and blood pressure control in people with type 2 diabetes mellitus: a meta-analysis of randomized controlled trials. Diabetes Res Clin Pract 2012;98:349–360
38. Takeshima N, Rogers ME, Watanabe E, et al. Water-based exercise improves health-related aspects of fitness in older women. Med Sci Sports Exerc 2002;34:544–551
39. Look AHEAD Research Group. Reduction in weight and cardiovascular disease risk factors in individuals with type 2 diabetes: one-year results of the look AHEAD trial. Diabetes Care 2007;30:1374–1383
40. Arora E, Shenoy S, Sandhu JS. Effects of resistance training on metabolic profile of adults with type 2 diabetes. Indian J Med Res 2009;129:515–519
41. Balducci S, Leonetti F, Di Mario U, Fallucca F. Is a long-term aerobic plus resistance training program feasible for and effective on metabolic profiles in type 2 diabetic patients? Diabetes Care 2004;27:841–842
42. McLaughlin T, Reaven G, Abbasi F, et al. Is there a simple way to identify insulin-resistant individuals at increased risk of cardiovascular disease? Am J Cardiol 2005;96:399–404
43. Jurca R, Jackson AS, LaMonte MJ, et al. Assessing cardiorespiratory fitness without performing exercise testing. Am J Prev Med 2005;29:185–193
44. Johnson HM, Thorpe CT, Bartels CM, et al. Undiagnosed hypertension among young adults with regular primary care use. J Hypertens 2014;32:65–74
45. Stewart KJ. Role of exercise training on cardiovascular disease in persons who have type 2 diabetes and hypertension. Diabetes and Cardiovascular Disease 2004;22:569–586
46. Meredith-Jones K, Waters D, Legge M, Jones L. Upright water-based exercise to improve cardiovascular and metabolic health: a qualitative review. Complementary Therapies in Medicine 2011;19:93–103
47. Ho SS, Ravidelli-Bagatini S, Dhaliwal SS, Hills AP, Pal S. Resistance, aerobic, and combination training on vascular function in overweight and obese adults. Journal of Clinical Hypertension 2012;14:848–854
48. Volaklis KA, Spassis AT, Tokmakidis SP. Land versus water exercise in patients with coronary artery disease: effects on body composition, blood lipids, and physical fitness. Am Heart J 2007;154:561–566
49. Gappmaier E, Lake W, Nelson AG, Fisher AG. Aerobic exercise in water versus walking on land: effects on indices of fat reduction and weight loss of obese women. J Sports Med Phys Fitness 2006;46:564–569
50. Romero-Corrал A, Somers VK, Sierra-Johnson J, et al. Normal weight obesity: a risk factor for cardiometabolic dysregulation and cardiovascular mortality. Eur Heart J 2010;31:737–746
51. Andersen H, Poulsen PL, Mogensen CE, Jakobsen J. Isokinetic muscle strength in long-term IDDM patients in relation to diabetic complications. Diabetes 1996;45:440–445