Aquatic and land training on functional and glycemic outcomes in people with type 2 diabetes: preliminary data from Aquatic and Land Exercise for Diabetes randomized clinical trial

Treinamento aquático e terrestre em desfechos funcionais e glicêmicos de pessoas com Diabetes Tipo 2: dados preliminares do Aquatic and Land Exercise for Diabetes - ensaio clínico randomizado

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ABSTRACT

Introduction: People with type 2 diabetes (T2DM) exhibit poor adherence and discomfort associated with traditional exercise practices; therefore, alternative modalities such as aquatic exercise should be investigated. Objective: Investigating the effects of 11 weeks of combined training (aerobic and resistance) performed in different environments (aquatic and land-based) on functional and glycemic outcomes in patients with T2DM. Methods: These are preliminary data from a randomized controlled trial with two parallel groups. The study included adults and older adults of both genders, aged between 45 and 80 years, with T2DM. The training program was conducted three times per week on non-consecutive days, with participants assigned to combined training in either the aquatic (AQUA) or land-based (LAND) environment. Assessments were conducted at baseline and after 12 weeks, including the 6-minute walk test (6 MWT), Sit-to-Stand test (STS), Sit-and-Reach test using the Wells bench (Flex), Timed Up and Go at habitual (TUG-h) and maximal speed (TUG-m), and glycemic control markers (fasting glucose and insulin, HOMA-IR, and HbA1c). Results: A total of 37 individuals (18 women; 60.45 ± 8.72 years) participated in the study. Adherence to the training program was 87.1 ± 12.9% in the AQUA group and 81.8 ± 15.5% in the LAND group (p = 0.231). Both groups showed significant improvements in the 6MWT, TUG-h, TUG-m, and Flex tests (p < 0.001), while improvements in the STS were observed only in the AQUA group (p < 0.001). No significant changes were observed in glycemic control. Conclusion: Both aquatic and land-based combined training improved functional capacity in patients with T2DM, with specific gains in lower-limb strength observed only in the AQUA group. Furthermore, 11 weeks of training did not induce significant changes in glycemic control in this population.

Keywords: Type 2 diabetes mellitus; Combined training; Physical fitness; Aquatic exercise; Glycemic control.

RESUMO

Introdução: Pessoas com diabetes tipo 2 (DM2) apresentam baixa aderência e desconforto associado às práticas de exercício tradicionais, por isso, modalidades alternativas como exercício em meio aquático devem ser investigadas. Objetivos: Verificar os efeitos de 11 semanas do treinamento combinado (aeróbio e força) em diferentes meios (aquático e terrestre) sobre desfechos funcionais e glicêmicos de pacientes com DM2. Métodos: Dados preliminares de um ensaio clínico randomizado comparador, com dois grupos em paralelo. Participaram adultos e idosos com DM2 de ambos os gêneros, com idade entre 45 e 80 anos. O programa de treinamento foi aplicado três vezes por semana, em dias alternados, sendo realizado treinamento combinado no meio aquático (AQUA) ou terrestre (LAND). Foram avaliados, na linha de base e na 12ª semana, o desempenho nos testes: caminhada de 6 minutos (TC6M), Sentar e Levantar (SL), Sentar e Alcançar pelo Banco de Wells (Flex), TUG em velocidade habitual (TUG-h) e máxima (TUG-m) e controle glicêmico (glicose e insulina em jejum, HOMA-IR e HbA1c). Resultados: Participaram 37 pessoas (18 mulheres, 60,45 ± 8,72 anos). A aderência ao treinamento foi de 87,1 ± 12,9% no AQUA e 81,8 ± 15,5% no LAND (p = 0,231). Ambos os grupos apresentaram melhoras no TC6M, TUG-h, TUG-m e Flex (p < 0,001), enquanto apenas o AQUA apresentou melhoras no SL (p < 0,001). Não houve diferença significativa no controle glicêmico. Conclusão: Os treinamentos, aquático e terrestre melhoraram a capacidade funcional de pacientes com DM2, com destaque para melhora apenas no no AQUA na força dos membros inferiores. Ainda, 11 semanas não modificaram significativamente o controle glicêmico destes pacientes.

Palavras-chave: Diabetes melittus tipo 2; Exercício físico; Desempenho físico funcional; Controle glicêmico.

Introduction

Type 2 diabetes mellitus (T2D) is a chronic endocrine and metabolic disease characterized by absolute or relative insulin secretion deficiency, as well as decreased sensitivity of target organs to the hormone, with hyperglycemia (high blood glucose levels) as its main clinical feature[1]. The treatment of T2D involves the adoption of healthy eating habits, lifestyle modifications, and pharmacological approaches[2]. In this context, exercise, in addition to being recognized as an important preventive strategy[3], is widely recommended as a cost-effective therapeutic strategy for disease management, as it reduces insulin resistance by improving glucose uptake by skeletal muscles[4-6]. Accordingly, adaptations resulting from regular exercise contribute to reductions in glycated hemoglobin (HbA1c) levels, which represent the primary therapeutic target in the treatment of T2D[3].

In this regard, exercise has been shown to reduce HbA1c levels by approximately 0.5% to 0.7%, magnitudes comparable to those achieved with hypoglycemic medications[3,7]. Combined training (aerobic and resistance) has been emphasized in clinical guidelines, as it integrates the benefits of both modalities. The exercise prescription guidelines of the American College of Sports Medicine recommend combined training for overall health improvement in individuals with metabolic diseases[3,8], and studies indicate that combined training is as effective as, or even more effective than, aerobic or resistance training alone in reducing HbA1c levels[9-11].

As a chronic condition, T2D is also associated with accelerated metabolic aging, leading to functional decline[12], reduced muscle strength[13], impaired functional mobility[14], and decreased cardiorespiratory capacity[15,16]. These functional limitations compromise a wide range of activities, negatively affecting independence in activities of daily living[17]. In this context, physical exercise has been associated with improvements in functional outcomes in individuals with T2D[18-20].

Despite the robust literature on the beneficial effects of exercise, most studies involving individuals with T2D have focused on land-based training environments. However, land-based exercise often imposes considerable stress on the musculoskeletal system, which can be attenuated in an aquatic environment due to buoyancy, allowing exercises to be performed with reduced ground reaction forces[21]. In addition to this biomechanical advantage, aquatic exercise may combine the general benefits of physical training with specific effects of water immersion, which can induce acute neuroendocrine adjustments, such as sympathetic nervous system suppression and reduced activation of the renin–angiotensin system.

In recent years, clinical trials and systematic reviews have demonstrated the benefits of aquatic training for functional capacity, glycemic control, and quality of life in individuals with T2D[22-26]. Nevertheless, although aquatic training shows promising results, the few studies that have compared water-based and land-based training in this population have predominantly focused on aerobic exercise. To date, there are no consistent studies evaluating the effects of combined training across different environments[25,26]. Therefore, the aim of this study was to investigate the effects of 11 weeks of combined training (aerobic and resistance) performed in different environments (aquatic and land-based) on functional and glycemic outcomes in patients with T2D.

Methods

Study Design

This study reports preliminary and mid-term (11-week) functional and glycemic outcomes from a randomized, comparative, single-center, two-arm parallel clinical trial with a superiority hypothesis, registered under the acronym ALED (Aquatic and Land Exercise for Diabetes). It should be noted that the present manuscript addresses only a subset of the outcomes investigated in the overarching project. The study was conducted at Sports Center of the Federal University of Santa Catarina, approved by the Human Research Ethics Committee of the host institution (protocol number 6.735.640) and was registered in the Brazilian Clinical Trials Registry (RBR-10fwqmfy). All participants provided written informed consent. Further details of the study design and methodology can be found in the published protocol article[27].

Participants

Participants were selected non-randomly, on a voluntary basis, using the following eligibility criteria: adults and older adults with T2D, of both gender, aged between 45 and 80 years, with a confirmed medical diagnosis of T2D (HbA1c: 6.5–10%) and/or use of hypoglycemic drugs (except exogenous insulin); exempt from regular exercise (defined as performing any type of physical training for at least 20 minutes on two or more days per week) for at least three months; absence of uncontrolled hypertension, autonomic neuropathy,

severe peripheral neuropathy, severe proliferative and non-proliferative retinopathy, uncompensated heart failure, peripheral amputation, chronic renal failure; joint and/or muscle impairments that prevent physical exercise; and body mass index ≥ 40 kg/m².

Randomization

Participants were randomly assigned in blocks, in a 1:1 ratio, stratified by gender and HbA1c level, to one of two combined training groups: water-based (AQUA) and land-based (LAND). The allocation list was concealed from all outcome assessors. The randomization process was performed using the online software www.randomizer.org by a researcher not involved in the other study procedures.

Intervention

The training programs (water- and land-based) lasted 11 weeks, with three sessions per week on non-consecutive days (Mondays, Wednesdays, and Fridays) in the evening. The combined training was carried out in an aquatic environment through hydrogymnastics, and in the land-based program through walking/running on a treadmill and resistance training. The training sessions lasted a maximum of 60 minutes, consisting of a 5-minute warm-up, 30 to 47 minutes of main training (aerobic and resistance training), and 5 to 10 minutes of cool-down (stretching for the main muscle groups).

The first week of the intervention was dedicated to familiarizing participants with the environment, exercises, and scales used during training. The three sessions were conducted at the same time and with the same expected duration, with special attention given to instructing participants on proper exercise execution, familiarizing participants in the AQUA group with the aquatic environment and identifying the target zone of the prescribed rate of perceived exertion (RPE) and the maximum number of repetitions for strength exercises in the LAND group. Initial familiarization with the Borg Scale was conducted through oral explanation and practical experimentation at different exercise intensities.

The intervention was supervised by physical education professionals, with a ratio of two professionals for every four participants. Aerobic training was prescribed using the continuous method and monitored using the RPE scale (Borg 6–20 points), with the target zone varying according to the mesocycle. Resistance training consisted of exercises targeting the main muscle groups, using multiple sets, and intensity

(exercise load) was modulated by water resistance in the aquatic environment and by equipment load in the terrestrial environment. Participants were instructed to perform movements at maximum speed (RPE 19) in the aquatic environment and to remain within the target zone of maximum repetitions in the terrestrial environment. Both training programs were similar in volume and intensity, with one progression in volume and another in intensity throughout the periodization (Figure 1).

Aerobic training in the aquatic environment consisted of five exercises: backward running, front kick, backward lift, front slide, and stationary running, accompanied by upper limb movements. Resistance training consisted of two exercise blocks: block 1 (horizontal shoulder flexion and extension, unilateral hip flexion and extension with knee flexion and extension); and block 2 (horizontal shoulder flexion and extension crossing the front and unilateral knee flexion and extension), progressing from one set of 30 seconds to three sets of 20 seconds per exercise, with a 1-minute rest between sets and blocks and 10 seconds between exercises. Aerobic training on land was performed on a treadmill and followed the same periodization as the AQUA group. Resistance training consisted of four exercises (rowing machine, horizontal leg press, chest fly machine, and seated knee flexion machine), initially performed with one set of 12 to 15 repetitions and progressing to two sets of 10 to 12 repetitions per exercise, with a 1-minute rest between sets and exercises. Figure 1 provides further details regarding the progression of the training program.

Outcome assessment

The primary outcome, the 6-Minute Walk Test (6MWT), and secondary outcomes, including other functional capacity tests and glycemic control indicators, were assessed before participant allocation and after 11 weeks of training. Assessments were performed by experienced evaluators who were blinded to participant allocation. The primary and secondary endpoints of the present study are not the same as those of the main project, which has HbA1c level as its primary outcome. Functional capacity outcomes were assessed at the Sports Center of the Federal University of Santa Catarina, while blood samples were collected and analyzed by specialized professionals at a clinical analysis laboratory. To participant characterization, data on personal identification, demographic and life-
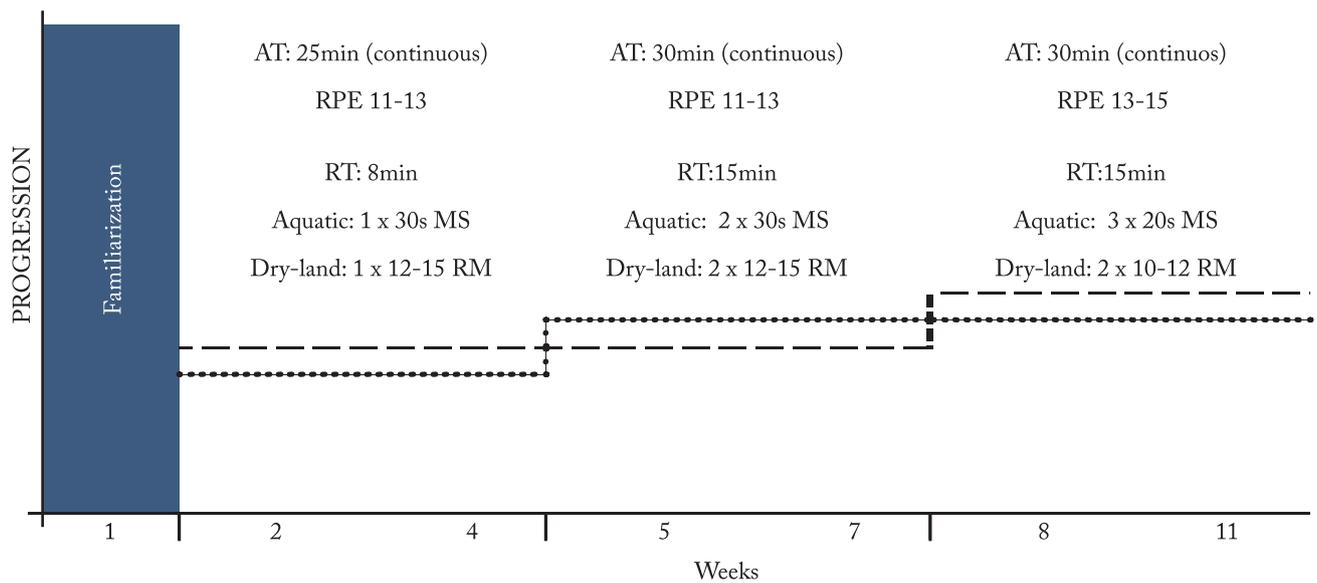
Figure 1 – Structure of combined aquatic and land training over 11 weeks.
····: progression in duration; ---: progression of intensity and density; AT: aerobic training; Min: minutes; MS: maximum speed; RPE: rating of perceived exertion (Borg 6-20); RM: repetitions maximum; RT: resistance training; S: seconds; x: sets.

style characteristics, and health status were collected through interviews.

To assess functional capacity, flexibility (Flex) was measured using the Sit-and-Reach test[28]; lower limb strength and endurance were measured using the 30-second Sit-to-Stand (STS) test[29]; functional mobility was assessed using the Timed Up-and-Go test[30] at usual speed (TUG-u) and maximum speed (TUG-m); and cardiorespiratory fitness was evaluated using the 6MWT[29]. The tests were performed in the order listed. Flexibility was assessed in three attempts, with the highest value recorded. All tests were conducted after explanation and demonstration by the evaluator. The TUG test was performed in two attempts, with the lowest value recorded. The 6MWT and the STS test were performed in a single attempt.

To assess glycemic control and insulin resistance indicators, venous blood samples were collected after an 8- to 12-hour fast at a clinical laboratory by trained professionals. Samples were processed and stored according to laboratory standards for subsequent analysis of the following parameters:

- HbA1c: measured by high-performance liquid chromatography (HPLC) and expressed as a percentage (%);
- Fasting blood glucose: determined by a colorimetric enzymatic method (glucose oxidase), with values expressed in mg/dL;
- Fasting insulin: quantified by chemiluminescence,

with results expressed in μU/mL.

Based on fasting blood glucose and insulin values, the Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) index was calculated using the following formula:

$$\text{HOMA-IR} = [\text{fasting blood glucose (mmol/L)} \times \text{fasting insulin (μU/mL)}] / 22.5.$$

All laboratory procedures followed current technical and biosafety standards. Blood analyses were performed in a certified laboratory with internal and external quality control.

Adherence to the training program, as well as the monitoring of adverse events, was assessed throughout the 11-week intervention. To this end, attendance at training sessions was recorded, and dropouts and reasons for dropout were documented. Adverse events were collected weekly using a standard questionnaire, completed every Friday and referring to the previous seven days. The questions aimed to identify general adverse events related to participants' health, as well as to determine whether these events were associated with the training program.

Participants were also instructed to maintain their usual eating habits and medication use after the start of the study. Data on eating behavior were collected at baseline and after 24 weeks but will be analyzed only after completion of the trial with the full sample.

Statistical Analysis

The sample size calculation for the 24-week study considered a significance level of 5%, statistical power of 80%, and an effect size (f) of 0.129, which corresponds to a difference of –0.4% in HbA1c for the AQUA group compared with the LAND group, with a 1:1 allocation ratio between groups. Thus, the sample size was calculated to require a minimum of 25 participants per group. Considering a sample loss similar to that reported by Delevatti et al.[21] (30%), the objective was to recruit 32 participants per group, totaling 64 participants in the study. The sample size was determined using the G*Power software, version 3.1.6 (University of Düsseldorf, Düsseldorf, Germany).

The normality and homogeneity of continuous variables used for sample characterization were tested using the Shapiro–Wilk and Levene tests, respectively. Continuous variables classified as normally distributed are presented as mean and standard deviation, whereas non-normally distributed variables are presented as median and interquartile range. Categorical variables characterizing the sample are presented as absolute frequency (n) and relative frequency (%). For comparisons between groups, the independent t-test or its nonparametric equivalent was used for continuous variables, and Fisher's exact test was used for categorical variables.

Outcomes are presented as mean and standard error. Analyses were performed using generalized estimating equations, adopting the intention-to-treat (ITT) principle and the Bonferroni post hoc test. The ITT analysis included all participants who completed baseline assessments, regardless of attendance at training sessions or participation in the 12-week assessments. Data were analyzed using the SPSS statistical package, version 23.0, and the significance level was set at 5%.

Results

Thirty-seven participants started the study (AQUA = 19; LAND = 18), and 32 participants completed the intervention, with a sample loss of 5% in the AQUA group (n = 1) due to family problems and 22% in the LAND group (n = 4), including three due to health problems unrelated to exercise and one due to personal reasons (p = 0.132). The analysis was performed with the 37 participants who completed the baseline assess-

Table 1 – Sample characterization (n = 37)

	Aquatic (n = 19)	Land (n = 18)	p-value
Demographics			
Age (years)	58.00 [52.00; 72.00]	61.50 [50.75; 68.25]	0.647
Gender (female/male)	9/10	9/9	0.139
Duration of type 2 diabetes mellitus (years)	10.00 ± 6.10	12.66 ± 7.90	0.260
Marital status (married/common-law union) n (%)	10 (52.6)	13 (72.2)	0.366
Education (completed higher education) n (%)	5 (27.8)	9 (47.4)	0.171
Body mass index	30.34 ± 4.67	28.62 ± 3.28	0.265
Diseases, n (%)			
Hypertension	11 (57.9)	10 (55.6)	0.885
Dyslipidemia	8 (42.1)	14 (77.8)	0.271
Coronary artery disease	2 (10.5)	0 (0.0)	0.157
Medications, n (%)			
Sodium–glucose co-transporter 2 inhibitor	6 (31.8)	8 (44.4)	0.420
Thiazolidinedione	1 (5.3)	1 (5.6)	0.743
Biguanide	18 (94.7)	16 (88.9)	0.604
Sulfonylurea	4 (21.1)	6 (33.3)	0.476
Dipeptidyl peptidase-4inhibitors	2 (10.5)	0 (0.0)	0.486
Glucagon-like peptide-1 receptor agonist	1 (5.3)	0 (0.0)	>0.999
Statin	9 (47.4)	13 (72.2)	0.124
Thyroid-stimulating hormone	2 (10.5)	4 (22.2)	0.405
Angiotensin-converting enzyme inhibitors	3 (15.8)	4 (22.2)	0.693
Angiotensin II receptor antagonists	6 (31.6)	7 (38.9)	0.642
Beta-blocker	4 (21.1)	2 (11.1)	0.660
Calcium channel blocker	2 (10.5)	3 (16.7)	0.660
Diuretic	4 (21.1)	6 (33.3)	0.476

ments, in accordance with the ITT principle. Overall, the sample consisted of 18 women (48.65%), diagnosed with T2D for more than nine years, and most participants used medications from the biguanide and statin classes (Table 1).

Adherence to the training program was 87.07 ± 12.86% in the AQUA group and 81.81 ± 15.54% in the LAND group, with no difference between groups (p = 0.231). No serious adverse events were reported by the participants.

Functional tests conducted pre- and post-intervention revealed a time effect, indicating significant improvements in both groups in the 6MWT (p <0.001), Flex (p <0.001), TUG-u (p <0.001), and TUG-m (p <0.001), and a significant improvement only in the AQUA group in the STS test (p <0.001) (Table 2). No differences were observed in HbA1c, fasting glucose, insulin, or HOMA-IR after 11 weeks of training (Table 3).

Discussion

The present study aimed to verify the effects of 11 weeks of combined training performed in different environments (water- and land-based) on functional and glycemic outcomes in patients with T2D. These

are preliminary data from the ALED clinical trial, and the main findings demonstrate improvements in functional capacity in both training groups, with superior effects in the STS test for the AQUA group. On the other hand, no significant changes in glycemic control variables were observed.

The positive results observed in most functional capacity outcomes in both groups were expected and are consistent with findings reported in the literature demonstrating the benefits of combined training in different environments in adults and older adults[9,10,25,26]. It is noteworthy that there were no differences in the magnitude of improvement between groups, with similar gains in the 6MWT, TUG-u, TUG-m, and Flex tests. Somewhat unexpectedly, the AQUA group showed superiority in lower limb muscle strength and endurance, as assessed by the STS test.

The superiority of the AQUA group in the STS test suggests that aquatic training prescribed at maximal movement speed, as applied in the present study, may promote greater gains in muscle strength and endurance than traditional land-based strength training in individuals with T2D. This finding may be explained primarily by training specificity and similarity to the

Table 2 – Effects of 11 weeks of combined training on functional capacity of people with type 2 diabetes mellitus (Aquatic = 19; Land = 18)

	Group	Baseline	11 weeks	Mean difference (95% IC)	p-value (group)	p-value (time)	p-value (g*t)
6-minute walk test (meters)	Aquatic	547.75 ± 16.67	578.05 ± 19.30	30.30 (7.09; 53.52)	0.167	<0.001	0.938
	Land	518.06 ± 13.16	547.21 ± 15.59	29.15 (11.93; 46.39)			
Sit-to- Stand (repetitions)	Aquatic	14.40 ± 0.66	17.74 ± 0.92*	3.34 (2.13; 4.54)	0.450	<0.001	<0.001
	Land	14.35 ± 1.00	15.86 ± 1.16	1.51 (-0.40; 3.05)			
Timed-up-and-go at usual speed (seconds)	Aquatic	9.78 ± 0.46	8.11 ± 0.32	-1.67 (-2.19; -1.13)	0.952	<0.001	0.282
	Land	9.49±0.42	8.34 ± 0.27	-1.15 (-1.92; -0.37)			
Timed-up-and-go at maximum speed (seconds)	Aquatic	6.75±0.31	6.05 ± 0.26	-0.70 (-0.95; -0.44)	0.948	<0.001	0.327
	Land	6.67 ± 0.24	6.18 ± 0.20	-0.49 (-0.86; -0.11)			
Flex (centimeters)	Aquatic	15.12 ± 1.95	17.44 ± 2.06	2.32 (0.70; 3.93)	0.545	<0.001	0.261
	Land	12.50 ± 2.29	16.32 ± 2.58	3.82 (1.77; 5.85)			

* different from pre-intervention (p < 0.001); g*t: group/time interaction.

Table 3 – Effects of 11 weeks of combined training on glycemic control in people with T2D. (Aquatic = 19; Land =18)

	Group	Baseline	11 weeks	Mean Difference (95% IC)	p-value (group)	p-value (time)	p-value (g*t)
Glycated hemoglobin (%)	Aquatic	7.85 ± 0.26	7.80 ± 0.22	-0.05 (-0.30; 0.20)	0.300	0.160	0.337
	Land	7.63 ± 0.23	7.37 ± 0.21	-0.26 (-0.61; 0.09)			
Glucose (milligrams per deciliter)	Aquatic	155.42 ± 9.21	163.89 ± 8.63	8.46 (-2.47; 19.39)	>0.999	0.954	0.072
	Land	164.17 ± 9.93	155.13 ± 12.32	-9.04 (-24.67; 6.61)			
Insulin (microunits per milliliter)	Aquatic	18.86 ± 2.45	21.22 ± 2.86	2.36 (-1.86; 8.89)	0.554	0.582	0.458
	Land	23.78 ± 6.39	23.43 ± 2.45	-0.35 (-6.12; 6.58)			
Insulin resistance	Aquatic	7.31 ± 1.04	8.50 ± 1.24	1.19 (-0.30; 2.68)	0.524	0.904	0.269
	Land	10.20 ± 3.05	8.72 ± 1.71	-1.48 (-5.97; 3.01)			

g*t: time/group interaction.

test performed, which involves a substantial muscle power component. Additionally, it should be noted that the LAND group included only one strength exercise targeting knee and hip extensors (leg press), whereas the AQUA group performed two exercises involving these muscle groups. As this was a combined training program, it is also necessary to consider the potential influence of the aerobic component on muscle strength. While land-based aerobic training was performed on a treadmill without incline and therefore with minimal resistance, training in the aquatic environment required lower limb movements in multiple planes against water resistance, which is substantially greater than air resistance.

Regarding functional improvements observed in both groups, the improvement in the 6MWT is particularly noteworthy. The AQUA group showed an average increase of 30.30 ± 11.84 meters, while the LAND group demonstrated an average increase of 29.16 ± 8.79 meters. The 6MWT is a submaximal exercise test widely used to assess functional exercise capacity in clinical populations, and studies indicate that improvements between 14.0 and 30.5 meters can already be considered clinically relevant[32], being associated with improved quality of life and reduced mortality.

The absence of a significant reduction in HbA1c levels may be related to the relatively short duration of the intervention (11 weeks). Evidence suggests that exercise interventions lasting less than 12 weeks tend to have limited effects on glycemic control in individuals with T2D, particularly in samples with variability in medication use and baseline HbA1c values between 6.5% and 8.0%[33,34]. Systematic reviews and meta-analyses indicate that most studies reporting significant reductions in HbA1c employ interventions lasting longer than 12 weeks, with longer durations being associated with more consistent improvements in HbA1c and fasting glucose[35-37]. One possible explanation is the approximately 120-day lifespan of red blood cells, suggesting that training programs need to exceed 11 weeks to elicit measurable changes in HbA1c.

In addition to intervention duration, the magnitude of glycemic responses may also be related to exercise volume and intensity. Evidence suggests that weekly exercise volumes exceeding 170 minutes are associated with more pronounced improvements in insulin sensitivity and glycemic control, regardless of the exercise modality used[38]. Furthermore, programs incorporating higher intensities, such as high-load resistance training

or interval aerobic exercise, tend to promote greater reductions in insulin and HOMA-IR levels, particularly when performed for at least 12 weeks[39]. In the present study, although progression in both volume and intensity was implemented, the training stimulus remained within a moderate range for most participants. This may have been sufficient to induce functional adaptations but not substantial metabolic changes. Higher-intensity training modalities, such as high-intensity interval training or high-load resistance training, have been associated with more significant improvements in insulin resistance, even with lower total training volume[40].

Although the proposed training program allowed for progression in volume and intensity, particularly in the aerobic component, which is essential for improving HbA1c levels, variability in medication use among participants may have limited the detection of exercise-induced effects in a short-term intervention, as the effects of exercise may be masked or potentiated by pharmacological adjustments[34,35]. Thus, studies suggest that in heterogeneous populations regarding medication use, longer interventions are required to observe independent effects of exercise on glycemic control.

From a practical perspective, the findings suggest that combined training performed in different environments is feasible and effective in promoting relevant functional improvements in adults with T2D, regardless of the environment. For individuals with osteoarticular limitations or low physical fitness, the aquatic environment represents an accessible and comfortable alternative, yielding functional outcomes comparable to those of land-based training and, in some aspects, superior, in addition to demonstrating good adherence and lower dropout rates. However, to optimize metabolic effects—particularly on insulin resistance and HbA1c—training programs with higher intensity and/or longer duration should be considered.

As a limitation, the present study has a small sample size; however, these data represent a preliminary analysis from a larger project designed to evaluate at least 25 participants per group over a 24-week period. Strengths of the study include being the first clinical trial to compare combined training performed in different environments (aquatic and land-based) using similar periodization while assessing different outcomes in patients with T2D.

Future studies should investigate the effects of exercise in different environments using equivalent prescriptions in other chronic diseases, beyond T2D.

In conclusion, the findings of this study, which consists of preliminary data from the ALED clinical trial, suggest that 11 weeks of combined aquatic training is superior to combined land training in lower limb muscle strength and endurance and that both modalities (aquatic and land) promote improvements in cardiorespiratory fitness, functional mobility, and flexibility in people with T2D. Furthermore, 11 weeks of combined training in different environments does not appear to be sufficient to modify markers of glycemic control and insulin resistance in people with T2D.

Conflict of interest
The authors declare no conflict of interest.

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Author's contributions
Danielevicz A: Methodology; Data and experiment validation; Data analysis; Research; Supervision; Original manuscript writing; Approval of the final manuscript version. Leonel LS: Conceptualization; Methodology; Data and experiment validation; Supervision; Original manuscript writing; Approval of the final manuscript version. Wolin IAV: Methodology; Data and experiment validation; Supervision; Data presentation design; Original manuscript writing; Approval of the final manuscript version. Constantini MI: Data and experiment validation; Supervision; Original manuscript writing; Approval of the final manuscript version. Benitez HO: Data and experiment validation; Writing - revision and editing; Approval of the final manuscript version. Diesel M: Methodology; Data and experiment validation; Data analysis; Data curation; Writing - revision and editing; Approval of the final manuscript version. Freitas CLR: Methodology; Data and experiment validation; Research; Supervision; Writing - revision and editing; Approval of the final version of the manuscript. Delevatti RS: Conceptualization; Methodology; Data and experiment validation; Research; Supervision; Drafting of the original manuscript; Drafting - revision and editing; Approval of the final version of the manuscript.

Declaration regarding the use of artificial intelligence tools in the article writing process
The authors used Chat GPT Translate artificial intelligence tools to assist in the translation process of the manuscript.

Availability of research data and other materials
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