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Efficacy of Aerobic and Combined Aerobic-Resistance Exercise on Cardiometabolic Risk Factors in Adults With Type 2 Diabetes: A Randomized Clinical Trial

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ABSTRACT

Aim: The prevalence of type 2 diabetes (T2D) is rising, posing serious public health challenges. While evidence from experimental settings shows that combined aerobic and resistance training improves cardiometabolic health in T2D, data from real-world primary care—especially Mediterranean populations—remain limited. This trial assessed the effects of two 9-month supervised exercise interventions on cardiometabolic outcomes in T2D primary care patients in the Mediterranean region of Catalonia, Spain.

Methods: In this community-based, parallel-group trial within the “Pas a Pas” project, 273 primary care patients with T2D (mean age 68 ± 8.5 years) were randomized to 9-month exercise programs: aerobic training ($n = 69$), combined aerobic and resistance training ($n = 77$), or control ($n = 127$). Exercise groups attended two weekly 60-min supervised outdoor sessions using public parks. Primary outcomes were 9-month changes in fasting glucose and HbA1c; secondary outcomes included adiposity measures, lipid profile, and blood pressure. Multivariable-adjusted regression models were applied.

Results: After 9 months, combined training significantly reduced fasting glucose and HbA1c, while aerobic training showed no meaningful change. Combined training was more effective than controls and aerobic training in maintaining or improving glycemic levels. Fasting glucose worsened in the aerobic group versus controls. Both exercise groups reduced body weight and BMI, but only the combined group exceeded controls. Additionally, combined training improved LDL cholesterol and both systolic/diastolic blood pressure.

Conclusions: While both interventions improved weight-related outcomes, combined aerobic and resistance training showed superior benefits in glycemic control and cardiometabolic risk. These findings support integrating structured, multicomponent exercise programs within primary care for T2D management.

Trial Registration: ClinicalTrials.gov identifier: NCT02767739

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1 | Introduction

Type 2 diabetes (T2D) is one of the fastest-growing global health emergencies [1]. In Spain, its prevalence has nearly doubled in recent years—from 6.8% in 2017 [1] to 13.1% in 2024 [2]—making it the country with the fifth-highest T2D rate in Europe. T2D now represents over 96% of all diabetes cases nationwide [2]. This sharp rise highlights the growing challenge of managing the disease and underscores an escalating public health concern. T2D is not only closely linked with an increased risk of morbidities—such as hypertension, dyslipidemia, metabolic syndrome, and cardiovascular disease (CVD)—but also further exacerbates the burden on the Spanish healthcare system [3]. Individuals with T2D have four times greater cardiovascular risk compared to those without diabetes, with the risk increasing with worsening glycemic control, making a substantial contribution to global CVD mortality [4]. Given this, effective treatment and prevention strategies are urgently needed to manage T2D and mitigate the progression of its complications among individuals already affected by the disease—before it is too late.

In this context, exercise is recognized as a cornerstone of T2D management—alongside nutritional and pharmacological therapies—particularly for its role in reducing cardiometabolic risk, as endorsed by the American Diabetes Association (ADA) [5]. Aerobic exercise, involving continuous, rhythmic movements such as walking, jogging, or cycling, is well established for improving glycemic control (e.g., HbA1c and fasting glucose) and insulin sensitivity in individuals with T2D, as supported by a growing body of epidemiological and clinical evidence [6–9]. Additionally, robust evidence highlights its benefits for blood pressure and lipid regulation in this population [10]. Accordingly, current ADA guidelines recommend at least 150 min per week of moderate-intensity aerobic activity for individuals with T2D [11].

In recent years, resistance exercise—also known as strength training and performed using free weights, machines, body weight, or resistance bands—has gained recognition as a complementary strategy to improve muscular and metabolic health, particularly among older adults [12]. Globally, resistance training has seen a rise in popularity due to its versatility and efficiency in improving functional capacity [13]. This trend is also reflected regionally, specifically in Southern Europe, where resistance training has been widely established as a crucial component in every physical exercise program, with recent evidence highlighting the effectiveness of integrating this modality into “hybrid-type” sessions [14, 15]. Increasing evidence supports its effectiveness in reducing cardiometabolic risk in patients with T2D, showing improvements in waist circumference, high-density lipoprotein cholesterol (HDL-c), triglycerides, fasting glucose, insulin, and HbA1c, compared with a non-exercise standard treatment [16, 17]. Specifically, meta-analyses have shown that moderate-to-high intensity training and combined approaches have demonstrated great efficacy in improving muscle mass and insulin sensitivity while reducing visceral fat in patients with T2D and obesity [18–20]. In this regard, our research group previously observed that aerobic exercise alone was not effective in patients with T2D [21]. In fact, the community-based “Pas a Pas” walking intervention program, which did not include resistance training, yielded beneficial health outcomes in patients with hypertension or dyslipidemia but not in those with

T2D, where glucose levels were elevated in the intervention group. These findings suggested that aerobic exercise alone may be inadequate for optimizing glycemic outcomes in patients with T2D, emphasizing the importance of integrating resistance exercise to maximize patient outcomes.

Reflecting this, current guidelines from the ADA and the American College of Sports Medicine advocate for the inclusion of resistance training—typically 2 to 3 nonconsecutive sessions per week—alongside aerobic exercise [5, 6]. This combined approach is based on the premise that resistance and aerobic modalities may offer additive or even synergistic benefits on cardiometabolic health-related outcomes, surpassing the effects of either modality alone [16, 17].

In overweight or obese adults with T2D, combined aerobic and resistance training has consistently shown superior benefits compared to single-modality exercise. A meta-analysis of randomized controlled trials (RCTs) demonstrated that this combined approach led to greater improvements in glycemic control, blood pressure, and lipid profiles—specifically through reductions in triglycerides, total cholesterol, and low-density lipoprotein cholesterol (LDL-c) and increases in HDL-c [22]. These results were further corroborated by a recent 2024 meta-analysis of 20 RCTs (sample sizes 16–169; durations 8–60 weeks), which compared the effectiveness of different exercise modalities on cardiometabolic health. The analysis confirmed that combined training was the most effective intervention for improving BMI, systolic and diastolic blood pressure, and HbA1c when compared to standard care [23].

Despite substantial evidence supporting the benefits of multi-component physical activity (PA) for weight management and cardiometabolic risk reduction, most studies have been conducted under controlled experimental conditions [22, 23]. Evidence from real-world primary care settings—where interventions should be feasible, sustainable, and scalable—is still scarce. While previous meta-analyses have established the superiority of combined training, a critical question remains regarding whether these benefits are replicable and sustainable when implemented through primary care services using existing community infrastructure, such as public parks and fixed outdoor equipment. To our knowledge, only one primary care-based RCT has compared aerobic exercise versus combined aerobic–resistance training among patients with T2D [24]; however, it employed vigorous-intensity aerobic exercise rather than the moderate intensity recommended by clinical guidelines [5] and did not assess long-term cardiometabolic outcomes [17]. Moderate-intensity aerobic exercise is the most recommended by international clinical guidelines for older populations, especially those with T2D, and this implementation allows for a realistic assessment of the outcomes achievable within standard primary care in real-world settings [5]. This evidence gap is particularly relevant in Mediterranean populations, where region-specific lifestyle and environmental factors may influence intervention effectiveness. In Spain, the situation is especially concerning, given the high and rising prevalence of T2D and cardiovascular risk [4]. To date, only one small RCT conducted in Spanish primary care has assessed the cardiometabolic impact of exercise in adults with T2D—and it focused exclusively on aerobic training [25]. Further research in Mediterranean populations is crucial to evaluate the effects of both exercise modalities in

routine clinical settings and to determine their impact on cardiometabolic health in real-world practice.

Accordingly, this trial aimed to assess the effects of two 9-month supervised intervention programs—aerobic exercise and combined aerobic-resistance training—on cardiometabolic outcomes (glucose metabolism, adiposity, lipid profile, and blood pressure) in adult patients with T2D within the primary healthcare setting in the Mediterranean region. Through the evaluation of these clinical parameters, we aimed to capture the potential for clinically meaningful risk reduction, as these markers are established predictors of long-term diabetes complications and overall cardiovascular prognosis.

2 | Methods

2.1 | Study Design

This study is a secondary analysis of participants with T2D from the community-based “Pas a Pas” project, which was implemented over two consecutive study periods (2011–2015 and 2016–2019), each conducted as a parallel-group RCT. The first study period evaluated a 9-month supervised aerobic exercise program, whereas the second, conducted as a continuation of the Pas a Pas project, evaluated a 9-month supervised combined aerobic and resistance exercise program, with findings on kidney health previously reported [26]. Both study periods were conducted using the same eligibility criteria, recruitment procedures, follow-up duration (9 months), and outcome assessment methods, providing a consistent methodological framework for comparing the two exercise strategies. The study was conducted within the same primary care setting, and T2D management followed standardized regional clinical practice guidelines throughout both study periods. The study protocol was approved by the Ethics Committee of the Institut d’Investigació en Atenció Primària (IDIAP) Jordi Gol (approval ID: P11/67; May 5, 2011). All participants provided written informed consent. The trial was conducted in accordance with the principles of the Declaration of Helsinki and followed the CONSORT reporting guidelines.

The original “Pas a Pas” RCT was retrospectively registered at ClinicalTrials.gov on May 4, 2016. Recruitment for the first study period had already started in 2011 before trial registration.

2.2 | Participants and Randomization

Prior to the intervention, healthcare professionals at participating primary care centers were asked to identify and invite eligible adult users to join the study. Individuals who expressed interest underwent an initial screening to assess eligibility. Eligible participants were adults (38–93 years) with a confirmed diagnosis of T2D attending primary care who provided written informed consent. Exclusion criteria included a recent episode of ischemic heart disease (< 6 months), acute arthritis limiting mobility, or lung or heart disease with dyspnea on mild to moderate exertion that could interfere with the exercise program. Participants who met the eligibility criteria were randomly assigned using a computer-generated randomization sequence to either the aerobic training or control group (3:1 ratio) or to the combined aerobic and resistance training or control group (1:1.5 ratio).

A total of 573 participants were recruited from four primary care centers and enrolled across two time periods: 387 individuals in the first trial (2011–2015) targeting aerobic exercise and 186 in the second trial (2016–2019) focusing on a combined aerobic and resistance training program. For the current analysis, only participants with a confirmed diagnosis of T2D were included, resulting in a final sample size of 273 individuals: 69 in the aerobic-only group, 77 in the combined aerobic and resistance group, and 127 in the control group (Figure 1).

2.3 | Intervention

Based on international PA recommendations [27], two 9-month supervised exercise interventions were implemented in two different time periods. For the aerobic exercise intervention, participants assigned to the aerobic group took part in two supervised brisk walking sessions, each lasting 60 min (totaling 120 min/week or approximately 396 METs/min/week), along with socio-cultural activities once a month. Walking sessions included a warm-up period and followed preset circuits averaging 5 km in and around the city of Reus, Spain. Group sizes ranged from 15 to 30 participants. Socio-cultural activities were designed to promote social cohesion and included visits to museums, libraries, cultural exhibitions, local landmarks, and dance classes. For the combined aerobic and resistance training intervention, participants assigned to the exercise group followed the same aerobic program as those that participated in the aerobic exercise intervention; however, each session incorporated a resistance training component. These strength-based exercises were performed in outdoor public parks using fixed fitness equipment provided by local councils. The resistance component targeted both upper and lower body muscle groups and included exercises such as bench press, seated row, shoulder press, pull-down, leg press, extensions, curls, abdominal crunches, and back extensions. All exercise protocols were standardized by a certified PA specialist, who also trained the primary care nurses responsible for supervising the sessions. To maintain intervention fidelity across the different outdoor settings and groups, a uniform exercise program was utilized, and supervisors followed a standardized protocol for all participants to ensure that the resistance component was executed with correct technique and consistent intensity. Healthcare professionals closely monitored participant attendance and engagement to ensure adherence.

Participants in the control group received standard care without any PA advice or intervention from the research team.

2.4 | PA Assessment

PA was assessed at baseline and 9 months during face-to-face visits conducted by trained nurses. Each assessment consisted of administering the short version of the International Physical Activity Questionnaire (IPAQ-S), a validated questionnaire for the Catalan population [28]. The face-to-face administration by trained clinical staff provided an opportunity to standardize the interpretation of exercise intensities across all participants. This methodological approach helps mitigate the typical recall bias associated with independent self-administration and ensures that exercise intensity was differentiated according to the validated IPAQ-S protocol. This questionnaire collects data on the frequency, duration, and intensity (walking, moderate, or high)

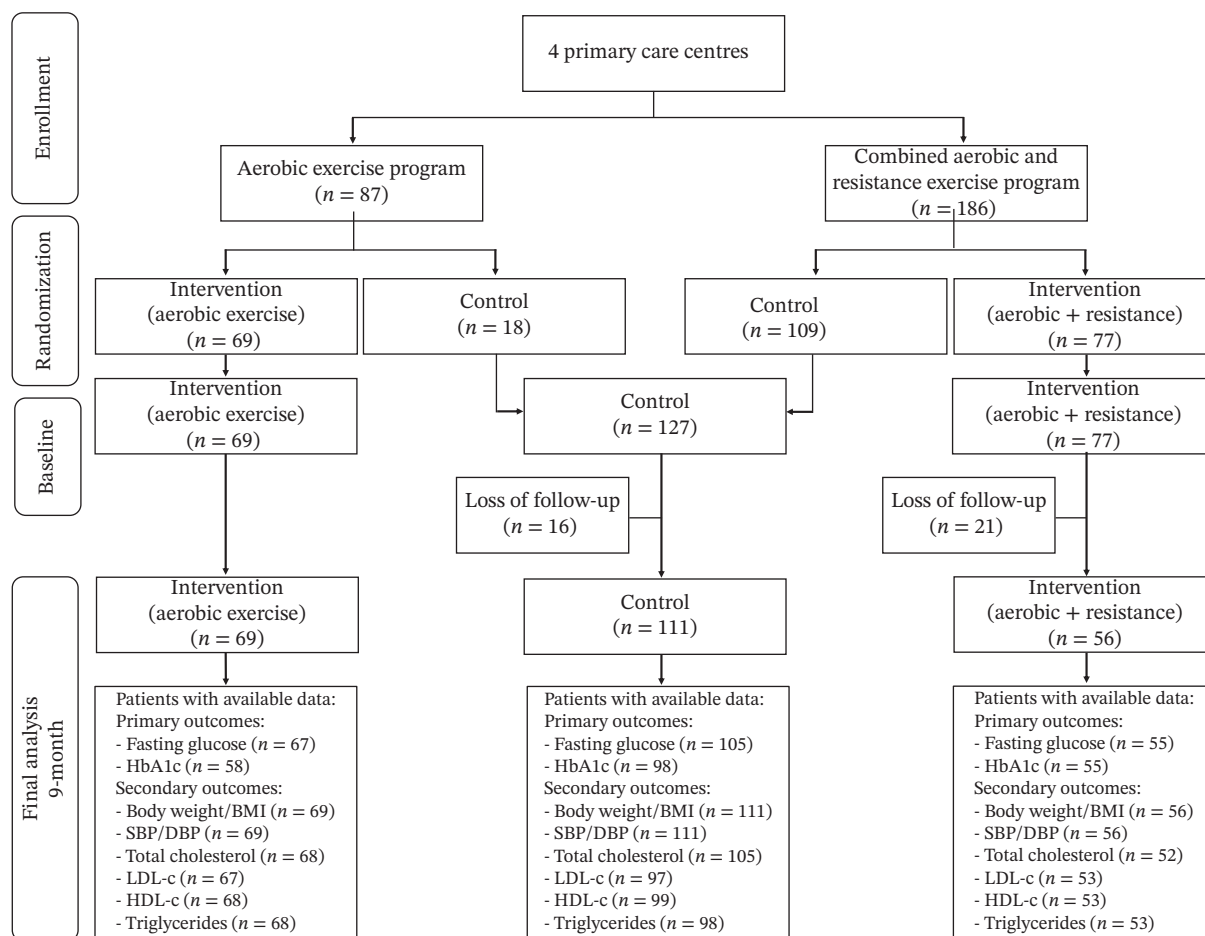


FIGURE 1 | Flow diagram of study participants.

of PA. For each intensity category, energy expenditure was calculated in MET-minutes per week by multiplying the assigned MET value (3.3 MET for walking, 4.0 MET for moderate intensity, and 8.0 MET for high intensity) by the total minutes of activity per week. The sum across all intensities provided the total PA levels expressed in MET-minutes/week, and additionally, they were categorized into low, moderate, and high.

2.5 | Outcomes Assessment

The primary outcomes were the absolute changes in fasting glucose and HbA1c levels within and between the study groups at 9 months. Secondary outcomes included changes in adiposity parameters (body weight and BMI), lipid profile (total cholesterol, HDL-c, LDL-c, and triglycerides), and blood pressure (SBP and DBP) from baseline to 9 months.

At both time points, blood samples were collected after an overnight fast of at least 8 h. Serum concentrations of glucose, HbA1c, total cholesterol, HDL-c, LDL-c, and triglycerides were determined using standard biochemical procedures. Blood pressure (SBP and DBP) was measured using a calibrated manual sphygmomanometer after the participants had rested for at least 5 min in a seated position. Three readings were taken, and the average of the second and third was used in the analysis. Anthropometric measurements included body weight (kg) and height (cm), recorded using a calibrated scale and stadiometer.

Body mass index (BMI, kg/m²) was calculated and used in this study as a proxy for adiposity.

2.6 | Covariate Assessment

At baseline, a general questionnaire was used to gather information on sociodemographic factors (age, sex, employment status, and social class), medical history (hypertension, dyslipidemia, controlled diabetes [defined as HbA1c < 7.0%], and cardiovascular risk), and smoking status. Social class was determined using an adaptation of the British Registrar General's Classification System, which categorizes individuals into three groups: high (Class I–II), middle (Class IIIN–IIIM), and low (Class IV–V) [29]. Cardiovascular risk was assessed using the REGICOR (Registre Gironí del Cor) risk score, extracted from computerized clinical records. This score is an adaptation of the Framingham risk function calibrated for the Spanish population and estimates the 10-year risk of coronary heart disease. The REGICOR algorithm incorporates the following variables: age, sex, presence of diabetes, smoking status, SBP and DBP, and total serum cholesterol [30].

Food consumption was assessed using a self-administered food frequency questionnaire (FFQ) covering 45 food groups, previously validated in our population [31]. Overall diet quality was evaluated using a relative Mediterranean diet score, adapted from the original Mediterranean Diet Score [32], which is based on the intake of nine key components of this dietary pattern:

TABLE 1 | Baseline characteristics of the study participants.

	Overall (<i>n</i> = 273)	Control (<i>n</i> = 127)	Aerobic (<i>n</i> = 69)	Aerobic + resistance (<i>n</i> = 77)	<i>p</i>
Age (years), mean ± SD	68.43 ± 8.58	68.22 ± 9.92	71.25 ± 6.08	66.26 ± 7.44	0.002
Age categories (years), <i>n</i> (%)					< 0.001
< 65	87 (31.9)	43 (33.9)	10 (14.5)	34 (44.2)	
≥ 65	186 (68.1)	84 (66.1)	59 (85.5)	43 (55.8)	
Women, <i>n</i> (%)	157 (57.5)	63 (49.6)	49 (71.0)	45 (58.4)	0.015
Body weight (kg), mean ± SD	80.67 ± 15.00	80.65 ± 14.98	78.40 ± 15.30	82.88 ± 14.62	0.208
Waist circumference, mean ± SD	105.86 ± 14.34	105.49 ± 17.13	104.83 ± 12.10	107.50 ± 10.59	0.504
BMI (kg/m ²), mean ± SD	30.98 ± 4.94	30.73 ± 5.22	30.61 ± 4.43	31.74 ± 4.90	0.301
Missing, <i>n</i> (%)	9 (3.3)	3 (2.3)	0 (0.0)	6 (7.8)	
BMI categories, <i>n</i> (%)					0.434
Normal weight	26 (9.9)	14 (11.3)	9 (13.0)	3 (4.2)	
Overweight	89 (33.7)	42 (33.9)	23 (33.3)	24 (33.8)	
Obesity	149 (56.4)	68 (54.8)	37 (53.6)	44 (62.0)	
Employment status, <i>n</i> (%)					0.024
Employed	37 (13.6)	25 (19.7)	6 (8.7)	6 (7.8)	
Unemployed/retired	192 (70.3)	88 (69.3)	47 (68.1)	57 (74.0)	
Incapacitated/disabled/other	44 (16.1)	14 (11.0)	16 (23.2)	14 (18.2)	
Social class, <i>n</i> (%)					0.165
High Class I–II	21 (7.6)	7 (5.5)	12 (17.4)	2 (2.6)	
Middle Class IIIN–IIIM	101 (37.0)	53 (41.7)	34 (49.3)	14 (18.2)	
Low Class IV–V	78 (28.6)	42 (33.1)	22 (31.9)	14 (18.2)	
Missing, <i>n</i> (%)	73 (26.7)	25 (19.7)	1 (1.4)	47 (61.0)	
Hypertension, <i>n</i> (%)					0.150
No	84 (30.8)	33 (26.0)	21 (30.4)	30 (39.0)	
Yes	189 (69.2)	94 (74.0)	48 (69.6)	47 (61.0)	
Dyslipidemia, <i>n</i> (%)					0.699
No	106 (38.8)	52 (40.9)	24 (34.8)	30 (39.0)	
Yes	167 (61.2)	75 (59.1)	45 (65.2)	47 (61.0)	
Smoking, <i>n</i> (%)					0.550
No	250 (91.6)	114 (89.8)	65 (94.2)	71 (92.2)	
Yes	23 (8.4)	13 (10.2)	4 (5.8)	6 (7.8)	
Controlled diabetes, <i>n</i> (%)					0.942

(Continues)

TABLE 1 | (Continued)

	Overall (<i>n</i> = 273)	Control (<i>n</i> = 127)	Aerobic (<i>n</i> = 69)	Aerobic + resistance (<i>n</i> = 77)	<i>p</i>
No	162 (59.3)	75 (59.1)	42 (60.9)	45 (58.4)	
Yes	104 (38.1)	50 (39.4)	27 (39.1)	27 (35.1)	
Missing, <i>n</i> (%)	7 (2.6)	2 (1.6)	0 (0.0)	5 (6.5)	
REGICOR cardiovascular risk score (point), mean ± SD	7.25 ± 4.04	7.20 ± 3.51	7.66 ± 5.20	6.92 ± 3.47	0.585
Missing, <i>n</i> (%)	55 (20.2)	35 (27.6)	7 (10.1)	13 (16.9)	
Mediterranean diet score (point), mean ± SD	8.93 ± 2.48	8.94 ± 2.60	9.16 ± 2.32	8.68 ± 2.43	0.518
Missing, <i>n</i> (%)	8 (2.9)	3 (2.4)	0 (0.0)	5 (6.5)	

Note: Values are expressed in means ± SD (standard deviation) or number (%; percentage). *p* values for between-group differences from univariate ANOVA with Bonferroni correction to adjust for multiple comparisons or chi-square test, as appropriate. Numbers in bold as *p* value < 0.05. REGICOR, cardiovascular risk calculator. Abbreviation: BMI, body mass index.

fruits (including nuts and seeds but excluding fruit juices), vegetables, legumes, cereals (including whole-grain and refined flour, pasta, rice, and other grains), fresh fish (including prawns and shellfish), meat (including processed meat), dairy products (including milk, yogurt, cheese, and cream desserts), olive oil, and alcohol. The score ranges from 0 to 18 points, with higher scores indicating greater adherence to the Mediterranean dietary pattern and, consequently, higher overall diet quality.

2.7 | Statistical Analysis

A preliminary (a priori) power analysis was conducted in accordance with standard methodological approaches for clinical trials, using a two-sided significance level of 5% and a target statistical power of 80% [33], and informed by previous intervention studies [34, 35], to determine the sample size needed to detect clinically meaningful between-group differences in cardiometabolic risk factors. From this analysis, a total sample of 273 participants (aerobic: *n* = 69, aerobic and resistance: *n* = 77, control: *n* = 127) was determined. All analyses were conducted using a per-protocol approach, including only participants with available outcome data at the 9-month follow-up. Participants lost to follow-up (control: *n* = 16; combined aerobic and resistance: *n* = 21) were excluded from the final models due to a lack of postintervention data.

Descriptive data are presented as mean ± standard deviation (SD) for quantitative variables and as frequency (percentages) for categorical variables. The normality of continuous variables was evaluated using the Shapiro–Wilk test and visually assessed through histograms and quantile–quantile (Q–Q) plots.

Baseline differences between groups were tested using one-way ANOVA with Bonferroni correction for multiple comparisons, or χ^2 tests, as appropriate. Changes in the cardiometabolic risk factors from baseline to 9 months were analyzed using both unadjusted and multivariable-adjusted linear regression models. Estimates are presented as β coefficients with 95% confidence intervals (CIs). Adjusted models included the following covariates: age (years), sex, smoking status (no [ref.], yes), and employment status (employed, unemployed/retired, or incapacitated/disabled/other). To account for baseline clinical and lifestyle profiles, models were further adjusted for hypertension (no [ref.], yes), obesity (no [ref.], yes), and Mediterranean diet score. Additionally, changes in diabetes control (maintained uncontrolled, improved to controlled, or worsened to uncontrolled), which were based on HbA1c status, were included to account for variations in clinical management over the 9-month period.

Multivariable-adjusted logistic regression models were performed to estimate the likelihood of reducing or maintaining—versus increasing (reference)—each cardiometabolic risk marker separately after 9 months. Results are expressed as odds ratios (OR) with 95% CIs. All models were adjusted for the same covariates as described above. Additionally, sensitivity analyses compared reductions versus increases in cardiometabolic risk factors, and stratified models were conducted according to diabetes control status. Statistical significance was set at *p* < 0.05. All analyses were performed using RStudio (Version 2024.12.1–563) and Stata SE (Version 15.1).

TABLE 2 | Physical activity at baseline and changes at 9 months of the intervention.

	Baseline				9 months			
	Control (<i>n</i> = 127)	Aerobic (<i>n</i> = 69)	Aerobic + resistance (<i>n</i> = 77)	<i>p</i>	Control (<i>n</i> = 111)	Aerobic (<i>n</i> = 69)	Aerobic + resistance (<i>n</i> = 56)	<i>p</i>
Total physical activity (METs/min/ week), mean ± SD	3731.19 ± 3805.20	2654.59 ± 3202.36	3319.73 ± 2895.35	0.121	3576.99 ± 2911.22	3348.52 ± 3672.91	5235.25 ± 3996.81 ^{a,b,c}	0.007
Level of physical activity (%)								
Low	13.1	19.4	5.9		9.4	7.7	0.0	
Moderate	47.5	52.2	45.6	0.071	38.6	52.3	20.8	0.001
High	39.3	28.4	48.5		51.9	40.0	79.2	

Note: Values are expressed in means ± SD (standard deviation) or number (%; percentage). p values for between-group differences from univariate ANOVA with Bonferroni correction (for multiple comparisons) or chi-square test, as appropriate. Numbers in bold as p value < 0.05. METs, metabolic equivalents.

^ap value < 0.05 versus control group.

^bp value < 0.05 versus aerobic group.

^cp value < 0.05 for within-group changes at 9 months.

3 | Results

Baseline characteristics of the study participants are presented in Table 1. The mean age of the total cohort was 68.4 ± 8.6 years, with 68.1% aged ≥ 65 years. Women accounted for 57.5% of the sample. The average BMI was 30.98 ± 4.94 kg/m², with more than half of the participants classified as obese (56.4%). Most individuals were unemployed or retired (70.3%), and clinically, 69.2% had hypertension, 61.2% had dyslipidemia, and 59.3% had uncontrolled diabetes. The mean REGICOR cardiovascular risk score was 7.25 ± 4.04 points, and the average Mediterranean diet score was 8.93 ± 2.48. Regarding the safety of the intervention, no exercise-related adverse events were reported by participants in either the aerobic or combined exercise groups throughout the 9-month period.

Baseline characteristics were generally comparable across study groups (control, aerobic exercise, and aerobic and resistance exercise). However, statistically significant differences were observed for age, age categories (< 65 years, ≥ 65 years), sex, and employment status (all p < 0.05).

Table 2 summarizes PA levels at baseline and at 9 months of intervention. At baseline, there were no significant differences between groups in total PA (measured in METs/min/week) or in the distribution across low, moderate, and high intensity categories. However, significant differences were observed at 9 months, with the combined aerobic and resistance group showing the greatest total PA (+5235.25 METs/min/week; p < 0.05 vs. aerobic and control groups). Additionally, this group had the highest proportion of participants maintaining or shifting to high PA levels (79.2%), with significant between-group differences (p = 0.001).

Table 3 shows the within-group effects of aerobic and combined aerobic and resistance exercise on cardiovascular risk outcomes after 9 months. In the aerobic exercise group, significant reductions were observed in body weight, BMI, and total cholesterol, with the greatest decrease seen in total cholesterol (−8.72 mg/dL) (all p < 0.05). The combined aerobic and resistance exercise group exhibited broader improvements, including significant reductions not only in body weight and BMI but also in fasting glucose (−10.34 mg/dL) and HbA1c (−0.34%), LDL-c (−9.44 mg/dL), and blood pressure (SBP: −4.85 mmHg; DBP: −3.96 mmHg) (all p < 0.05).

Figure 2 compares changes in cardiovascular risk outcomes across study groups at 9 months. The combined aerobic and resistance exercise group showed significantly greater reductions in body weight (−1.51 kg; p = 0.006) and BMI (−0.47 kg/m²; p = 0.026) compared to the control. Regarding glucose metabolism, the combined training group also showed a significantly larger decrease in fasting glucose compared to the aerobic exercise group (−13.40 mg/dL, p = 0.038). Conversely, the aerobic exercise group had a significant increase in fasting glucose versus the control (+12.89 mg/dL, p = 0.019). No significant between-group differences were observed for HbA1c, lipids, or blood pressure.

Figure 3 shows the multivariable-adjusted ORs for achieving a reduction or maintenance (vs. an increase) in adiposity and glucose-related outcomes after 9 months across study groups (see also Supporting Table S1 for unadjusted analyses). Participants in the combined aerobic and resistance group had significantly

TABLE 3 | Effect of aerobic and combined aerobic + resistance exercise on cardiovascular risk outcomes at 9 months of the intervention.

Outcome	Control	Aerobic	Aerobic + resistance
Body weight (kg)	(n = 111)	(n = 69)	(n = 56)
Baseline (mean ± SD)	80.79 ± 15.08	78.40 ± 15.30	82.48 ± 14.68
9-month (mean ± SD)	80.54 ± 15.74	77.49 ± 15.18	80.80 ± 13.89
Change at 9-month year (95% CI)*	−0.22 (−0.82 to 0.38)	−0.93 (−1.70 to −0.17)	−1.73 (−2.59 to −0.86)
BMI (kg/m ²)	(n = 111)	(n = 69)	(n = 56)
Baseline (mean ± SD)	30.91 ± 5.26	30.61 ± 4.43	31.76 ± 4.90
9-month (mean ± SD)	30.79 ± 5.44	30.24 ± 4.35	31.23 ± 4.55
Change at 9-month year (95% CI)*	−0.11 (−0.34 to 0.12)	−0.36 (−0.65 to −0.07)	−0.57 (−0.90 to −0.24)
Fasting glucose (mg/dL)	(n = 105)	(n = 67)	(n = 55)
Baseline (mean ± SD)	142.43 ± 45.50	137.71 ± 37.61	151.27 ± 38.73
9-month (mean ± SD)	134.27 ± 46.24	141.29 ± 30.73	137.13 ± 34.87
Change at 9-month year (95% CI)*	−9.83 (−16.42 to −3.23)	3.06 (−5.26–11.39)	−10.34 (−19.60 to −1.08)
HbA1c (%)	(n = 98)	(n = 58)	(n = 55)
Baseline (mean ± SD)	7.64 ± 1.46	7.51 ± 1.17	7.70 ± 1.35
9-month (mean ± SD)	7.45 ± 1.36	7.46 ± 1.25	7.23 ± 1.13
Change at 9-month year (95% CI)*	−0.23 (−0.42 to −0.05)	−0.06 (−0.31 to 0.18)	−0.34 (−0.60 to −0.09)
Total cholesterol (mg/dL)	(n = 105)	(n = 68)	(n = 52)
Baseline (mean ± SD)	179.91 ± 34.55	188.67 ± 39.38	181.63 ± 25.71
9-month (mean ± SD)	178.94 ± 28.56	179.27 ± 41.43	176.01 ± 28.53
Change at 9-month year (95% CI)*	−1.56 (−7.20 to 4.09)	−8.72 (−15.78 to −1.67)	−5.33 (−13.51 to 2.86)
LDL-c (mg/dL)	(n = 97)	(n = 67)	(n = 53)
Baseline (mean ± SD)	101.09 ± 28.84	106.98 ± 35.66	105.03 ± 25.12
9-month (mean ± SD)	98.00 ± 24.13	100.74 ± 33.95	96.22 ± 22.68
Change at 9-month year (95% CI)*	−3.14 (−8.19 to 1.92)	−5.67 (−11.81 to 0.46)	−9.44 (−16.47 to −2.42)
HDL-c (mg/dL)	(n = 99)	(n = 68)	(n = 53)
Baseline (mean ± SD)	48.81 ± 11.75	50.13 ± 13.12	48.77 ± 9.86
9-month (mean ± SD)	48.40 ± 11.98	51.58 ± 15.07	49.28 ± 10.77
Change at 9-month year (95% CI)*	−0.22 (−1.95 to 1.50)	1.78 (−0.32–3.88)	−0.27 (−2.68 to 2.15)
Triglycerides (mg/dL)	(n = 98)	(n = 68)	(n = 53)
Baseline (mean ± SD)	152.38 ± 80.16	161.72 ± 88.70	171.99 ± 58.02
9-month (mean ± SD)	145.93 ± 81.33	150.40 ± 85.17	164.80 ± 61.98
Change at 9-month year (95% CI)*	−6.45 (−18.50 to 5.61)	−12.04 (−26.61 to 2.52)	−6.27 (−23.04 to 10.50)
SBP (mm Hg)	(n = 111)	(n = 69)	(n = 56)
Baseline (mean ± SD)	136.28 ± 15.19	134.99 ± 18.08	136.25 ± 18.04
9-month (mean ± SD)	131.76 ± 15.36	132.80 ± 12.96	130.57 ± 14.03
Change at 9-month year (95% CI)*	−4.66 (−7.79 to −1.54)	−2.64 (−6.63 to 1.36)	−4.85 (−9.35 to −0.34)
DBP (mm Hg)	(n = 111)	(n = 69)	(n = 56)
Baseline (mean ± SD)	76.58 ± 9.75	76.99 ± 9.88	74.77 ± 8.95
9-month (mean ± SD)	72.21 ± 10.44	74.52 ± 8.22	71.36 ± 8.95
Change at 9-month year (95% CI)*	−4.38 (−6.57 to −2.20)	−2.00 (−4.78 to 0.79)	−3.96 (−7.11 to −0.82)

Note: Values are expressed in means ± SD (standard deviation) and adjusted mean changes from baseline to 9 months with 95% CIs (confidence intervals). Numbers in bold as p value < 0.05 for within-group 9-month changes.

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol; SBP, systolic blood pressure.

*Estimates represent least squares means obtained using the *margins* command after linear regression, adjusted for age (years), sex, hypertension (no [ref.], yes), overweight (no [ref.], yes), obesity (no [ref.], yes), smoking status (no [ref.], yes), Mediterranean diet score, employment status (employed, unemployed/retired, incapacitated/disabled/other), and changes in the control of diabetes (maintained uncontrolled, improved to controlled, worsened to uncontrolled).

higher odds of reducing or maintaining body weight compared to the control group (OR = 3.25; 95% CI: 1.45, 7.32; *p* = 0.004). Similar results were observed for BMI, with the combined

training group showing significantly greater odds of improvement compared to the control (OR = 2.62; 95% CI: 1.19–5.76; *p* = 0.016). For fasting glucose, no significant differences were

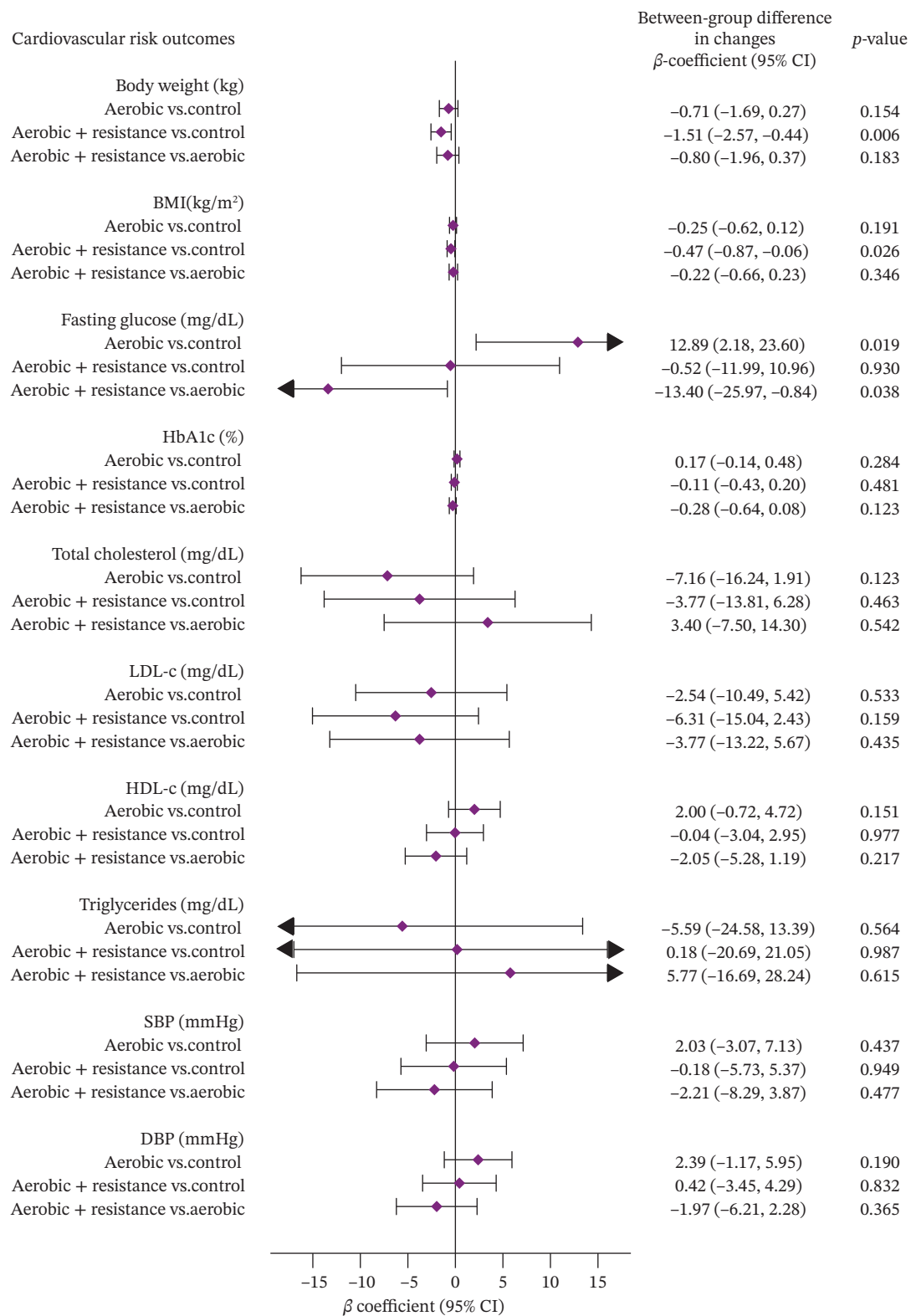


FIGURE 2 | Comparisons of control, aerobic, and combined aerobic + resistance exercise on changes in cardiovascular risk outcomes at 9 months of the intervention. Multivariable linear regression models were used to calculate the β coefficient (β) and 95% CI (in parentheses), representing between-group differences in changes from baseline to 9 months. Models were adjusted for age (years), sex, hypertension (no [ref.], yes), obesity (no [ref.], yes), smoking status (no [ref.], yes), Mediterranean diet score, employment status (worker, unemployed/retired, incapacitated/disabled/other), and changes in diabetes control (maintained uncontrolled, improved to controlled, worsened to uncontrolled). The diamonds represent the β coefficient (β), and the whisker plots represent 95% CIs. Numbers in bold as p value < 0.05 for between-group 9-month changes. Abbreviations: BMI, body mass index; HDL-c, high-density lipoprotein cholesterol; LDL-c, low-density lipoprotein cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure.

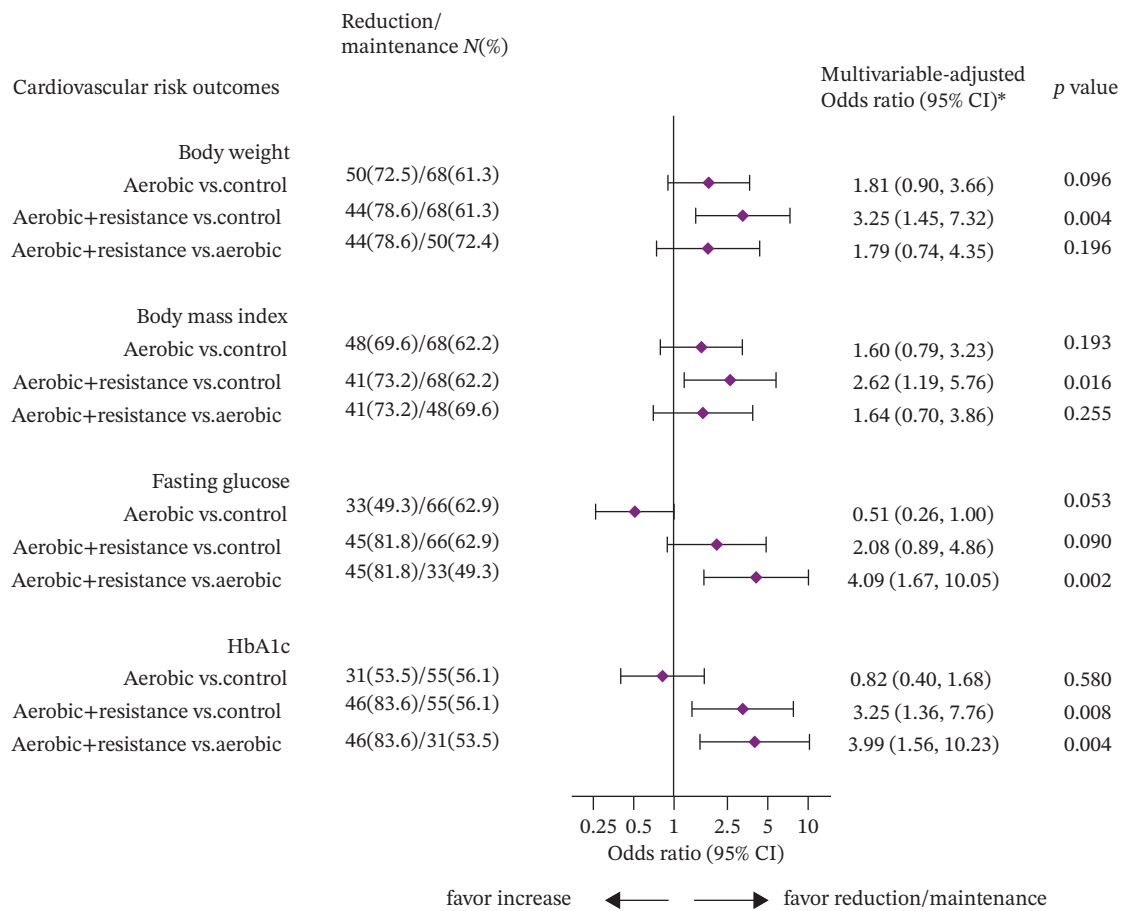


FIGURE 3 | Multivariable-adjusted odds ratio for the reduction/maintenance of cardiometabolic risk outcomes at 9 months of the intervention. Models were adjusted for age (years), sex, hypertension (no [ref.], yes), obesity (no [ref.], yes), smoking status (no [ref.], yes), Mediterranean diet score, employment status (worker, unemployed/retired, incapacitated/disabled/other), and changes in the control of diabetes (maintained uncontrolled, improved to controlled, worsened to uncontrolled). For all factors, T1 and T2 represent reduced or maintained values, while T3 is the reference group representing increased values. The diamonds represent the odds ratios, and the whisker plots represent 95% CIs. Numbers in bold as *p* value < 0.05.

observed between either intervention group or the controls. However, the combined aerobic and resistance group showed significantly higher odds of reduction or maintenance compared to the aerobic-only group (OR = 4.09; 95% CI: 1.67, 10.05; *p* = 0.002). Regarding HbA1c, while aerobic and control groups showed no significant difference, the combined aerobic and resistance group had significantly higher odds of reduction or maintenance compared to both the control (OR = 3.25; 95% CI: 1.36–7.76; *p* = 0.008) and aerobic group (OR = 3.99; 95% CI: 1.56–10.23; *p* = 0.004) (Figure 3). Supporting Figure S1 presents similar trends when the outcome was restricted to reduction only (instead of reduction/maintenance), reinforcing the additional benefit of combined aerobic + resistance training for improving glucose control.

To further explore the effects of diabetes control status, we conducted a stratified analysis, as shown in Supporting Table S2. Among participants with controlled diabetes, those in the combined aerobic and resistance group had significantly higher odds of reducing or maintaining HbA1c levels compared to both the control (OR = 13.24; *p* = 0.025) and the aerobic exercise group (OR = 18.00; *p* = 0.013). Additionally, this group had significantly greater odds of reducing or maintaining fasting glucose levels compared to the aerobic group (OR = 8.78;

p = 0.016), though not compared to control. Among participants with uncontrolled diabetes, both the aerobic and combined aerobic and resistance groups showed significantly higher odds of reducing or maintaining body weight compared to controls (OR = 0.12 and 4.62, respectively; both *p* < 0.05). Furthermore, combined training showed significantly greater odds of improving fasting glucose (OR = 4.45; *p* = 0.020) and HbA1c (OR = 3.41; *p* = 0.041) compared to the aerobic exercise group. No significant differences were found with the control group.

4 | Discussion

This trial evaluated the 9-month effects of two PA interventions— aerobic exercise alone and a combination of aerobic and resistance training—on cardiometabolic markers in Mediterranean adults with T2D. Our findings indicate that participants in the combined, also known as concurrent, training group achieved significantly greater improvements in PA levels, glycemic control, body weight, and BMI compared to those in the aerobic-only or control groups. These benefits were consistent across adjusted and stratified analyses, underscoring the robustness of our results. By evaluating a community-based intervention in Mediterranean primary care settings, this study

contributes valuable context-specific evidence to an area with unique population characteristics. Overall, the observed improvements highlight the clinical value of a combined, non-pharmacological intervention for managing T2D and its cardiometabolic complications, supporting its continued inclusion in clinical guidelines and implementation into primary care.

Individuals that participated in the aerobic and resistance intervention program observed significant within-group and between-group differences, when compared with controls, in total PA after 9 months. In addition, their level of PA shifted significantly toward a higher intensity, with no participants remaining in the low-intensity level after 9 months. This increase in overall activity, particularly through combined training, has been consistently linked to improvements in glycemic control, with prior evidence showing reductions in glucose and HbA1c among individuals with T2D, in line with our study findings [16, 17, 22, 23]. While aerobic exercise alone is well known for improving cardiovascular fitness and metabolic outcomes, the addition of resistance training may amplify these effects by increasing muscle mass and enhancing insulin sensitivity [34, 35]. After 9 months, combined training showed a significant reduction in fasting glucose, exceeding 10 mg/dL—a clinically meaningful change linked to lower diabetes complications risk [36]—and had a higher likelihood of reducing or maintaining fasting glucose compared to both the aerobic-only and control groups [36].

A similar trend was observed for HbA1c, with significant within-group reductions of -0.34% found only in the combined training group. Although these changes may appear modest, they are highly clinically relevant; prior estimates suggest that even a reduction of this level could translate into a 5%–7% reduction in cardiovascular risk and a 12% decrease in microvascular complications [37, 38]. While between-group differences in absolute changes were not statistically significant, participants in this group had higher odds of reducing or maintaining HbA1c compared to both the aerobic-only and control groups. This distinction highlights that while absolute statistical significance between groups may vary, the magnitude of the reduction achieved in the combined group reaches a recognized threshold for potential clinical impact in T2D management. These findings were further supported by sensitivity analyses restricted to reductions only, as well as subgroup analyses by diabetes control.

Notably, the combined training group showed consistent benefits across glycemic profiles—particularly among individuals with controlled diabetes and among those with uncontrolled diabetes when compared to aerobic training alone—underscoring its effectiveness in diverse clinical scenarios. Our results align with previous meta-analyses of RCTs demonstrating that combined training leads to greater HbA1c improvements than aerobic exercise alone or standard care, reinforcing the added value of resistance training alongside aerobic exercise for better glycemic control [10, 22].

Further supporting this, two RCTs conducted in primary care settings also reported improvements in HbA1c following structured exercise interventions [24, 25]. One study found significant within-group HbA1c reductions after 10 weeks of either sprint interval-based aerobic exercise or combined training, suggesting both modalities can be effective. This reinforces the vital role of

various exercise approaches, including aerobic, resistance, interval, and concurrent training, in managing populations with metabolic dysregulation [20, 39, 40]. The use of high-intensity sprint intervals—which are known to enhance insulin sensitivity and glucose uptake—may explain the improvements in their aerobic group, contrasting with the moderate-intensity aerobic exercise in our trial, which may have had a lower metabolic impact [20, 24].

Mechanistically, the observed benefits likely result from the complementary effects of both exercise modalities: resistance training provides a unique anabolic stimulus to preserve skeletal muscle mass—the primary site for insulin-mediated glucose disposal [41]—an adaptation not robustly elicited by aerobic exercise alone. Conversely, aerobic exercise increases GLUT4 expression and mitochondrial density, thereby enhancing glucose uptake and oxidative metabolism [42]. Although the combined group accumulated a greater overall exercise volume, increased volume alone would be expected to amplify adaptations within a single physiological pathway. Instead, the superior outcomes in the combined group are consistent with the integration of modality-specific mechanisms targeting both peripheral glucose disposal capacity and mitochondrial efficiency [41, 42], supporting the viewpoint that training diversity, rather than volume, drove the observed improvements. Our previous observations regarding the limited effectiveness of the aerobic exercise-based “Pas a Pas” program in patients with T2D support the added benefit of incorporating resistance training beyond the improvements achieved with aerobic exercise alone. These metabolic improvements may also be partly explained by greater reductions in body weight and BMI observed after 9 months in the combined training group compared to the non-exercise controls. Prior studies have emphasized the role of resistance training in preserving lean mass, which complements the fat-reducing effects of aerobic exercise, resulting in favorable changes in body composition [23, 43]. Although our study did not directly assess fat and lean mass, it is plausible that improvements in lean-to-fat mass ratio contributed to the superior glycemic outcomes observed in the combined group, as shown in previous trials involving normal-weight individuals with T2D [44]. It is worth noting that the aerobic-only group also exhibited reductions in weight and BMI; however, these changes were not statistically significant compared to controls, highlighting the added value of resistance training in enhancing body composition and amplifying the cardiovascular benefits of aerobic exercise [6].

The beneficial effects of combined training extended to blood pressure. Only the aerobic and resistance training group achieved significant reductions in both SBP and DBP. While aerobic exercise improves vascular function and reduces arterial stiffness [45], resistance training has been shown to decrease sympathetic nervous system activity and peripheral resistance [46]. By combining these mechanisms, integrated training programs can yield synergistic improvements in blood pressure regulation. These findings align with meta-analyses [10, 23] and RCTs conducted in primary care [25].

Regarding lipid profiles, total cholesterol and LDL-c levels showed modest improvements, particularly in the combined aerobic and resistance training, which supports prior trials in the T2D population [22, 47]. The LDL-c reductions observed may be

due to enhanced insulin sensitivity and increased expression of LDL receptors via SREBP-2 (sterol regulatory element-binding protein-2) activation from resistance training [48]. No significant changes were seen for HDL-c or triglycerides in either intervention group, which is consistent with previous studies showing that these parameters are less responsive to exercise alone and may require concurrent dietary interventions for substantial change [49, 50]. One study further supports this, showing that combined nutrition and exercise interventions yield stronger effects on HDL-c and triglycerides than exercise alone [49].

An unexpected observation in our study was the improvements in fasting glucose, HbA1c, and blood pressure after 9 months in the control group. We hypothesize that these changes may partly be explained by unrecorded modifications to pharmacological treatment during the study period or behavioral changes triggered by participants' awareness of being monitored (i.e., the Hawthorne effect) [51]. The absence of data on pharmacological treatments is a notable limitation that warrants caution in interpreting these findings. Nevertheless, the significantly greater magnitude of improvement observed in the combined training group relative to the control group supports a robust additive effect of the intervention. Moreover, the RCT design of this study likely distributed potential confounding factors evenly across groups, thereby strengthening the inference that the structured exercise program was the primary contributor to the superior clinical outcomes observed in the intervention groups.

Our findings offer several practical insights for healthcare practitioners and exercise specialists, with the aim of supporting them in working with this population in this field [52]. First, the supervised combination of aerobic and resistance training offers a safe and highly effective “non-pharmacological prescription” for older adults with T2D, even those with uncontrolled baseline glucose. Second, the success of this intervention using outdoor public park equipment demonstrates that clinical-grade improvements can be achieved without the need for expensive gym facilities, making it a more scalable model for primary care and more inclusive for individuals from diverse socioeconomic backgrounds. This high safety profile and lack of adverse events should encourage practitioners to refer high-risk patients to community-based concurrent training programs, as these provide more comprehensive cardiometabolic benefits than walking programs alone.

The study's strengths include its randomized controlled design, long intervention period (9 months), real-world implementation in primary care, and focus on a high-risk, often underrepresented population. The stratified analyses by diabetes control status added depth and revealed that individuals with both controlled and uncontrolled diabetes may benefit from combined training, though responses may differ. Limitations include the reliance on self-reported PA data and the lack of continuous assessment of habitual PA throughout the intervention, reducing the ability to account for spontaneous changes in daily routines outside the supervised sessions. Additionally, there was a lack of information on changes in medication use during the intervention period and an absence of direct measures of body composition (e.g., fat and lean mass). Furthermore, the three study groups did not recruit the same sample size, which may have impacted statistical power for some between-group comparisons, although we did aim to

address this by utilizing multivariable-adjusted models. Finally, although our study addresses an important evidence gap by focusing on Mediterranean adults with T2D in primary care, this regional context may limit the generalizability of the findings to populations with different cultural, dietary, or healthcare characteristics.

In conclusion, a 9-month program combining aerobic and resistance training produced superior improvements in PA, adiposity, and glycemic control compared to aerobic training alone or standard care in primary care adult users with T2D. These findings reinforce current recommendations to include resistance training in diabetes care and support the implementation of such programs in primary care and community-based settings.

Nomenclature

ANOVA	Analysis of variance
BMI	Body mass index
DBP	Diastolic blood pressure
HbA1c	Hemoglobin A1c
HDL	High-density lipoprotein
IPAQ-S	Short version of the International Physical Activity Questionnaire
LDL	Low-density lipoprotein
MET	Metabolic equivalent of task
PCC	Primary care center
REGICOR	Registre Gironí del Cor (Gironese Heart Registry)
SBP	Systolic blood pressure
T2D	Type 2 diabetes

Author Contributions

Conceptualization, Felipe Villalobos and Victoria Arija; data curation, Victoria Arija; investigation and project management, Felipe Villalobos and Victoria Arija, formal analysis, Olivia Burton and Andrés Díaz-López; writing–original draft preparation, Olivia Burton and Andrés Díaz-López; writing–review and editing, Olivia Burton, Andrés Díaz-López, Cristina Jardí, Cristina Rey-Reñones, and Victoria Arija; supervision, Felipe Villalobos; funding acquisition, Victoria Arija.

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Disclosure

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Supporting Information.** Supporting Figure S1. Multivariable-adjusted odds ratio for the reduction of cardiometabolic risk outcomes at 9 months of intervention. Supporting Table S1. Multivariable-adjusted odds ratio of reduction/maintenance of cardiometabolic risk outcomes at 9 months of the intervention. Supporting Table S2. Multivariable-adjusted odds ratio of reduction/maintenance of cardiometabolic risk outcomes at 9 months of the intervention, according to controlled diabetes Status.