

Research Article



INTERNATIONAL RESEARCH JOURNAL OF PHARMACY

www.irjponline.com

ISSN 2230-8407 [LINKING]

The effects of aerobic and resistance training on HRV parameters in individuals with type 2 diabetes mellitus.

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How to cite: Dr. Kavindra Kumar, Dr. Ashutosh Jain, Dr. Dhiraj Mahaseth. The effects of aerobic and resistance training on HRV parameters in individuals with type 2 diabetes mellitus. International Research Journal of Pharmacy. 2025; 16:11: 1-9.

DOI: <http://doi.org/10.56802/irjp.2025.v16.i11.pp1-9>

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Abstract:

Background: Heart rate variability (HRV) is a non-invasive marker of autonomic nervous system (ANS) function and cardiovascular health, reflecting beat-to-beat fluctuations in heart rate. Exercise training is recognized as a potential modulator of HRV, particularly in individuals with type 2 diabetes mellitus (T2DM), a condition often associated with impaired autonomic function.

Objective: This study aimed to compare the effects of aerobic and resistance training on HRV parameters in individuals with T2DM over a 12-week period.

Methods: A total of 100 participants with T2DM were randomized into either an exercise group or a control group. Baseline and post-intervention assessments included anthropometric parameters (height, weight, BMI, waist circumference, body fat percentage), hemodynamic measures (blood pressure, resting heart rate), and HRV indices.

Physical fitness outcomes, including handgrip strength, leg strength, maximal oxygen uptake ($VO_2\text{max}$), and muscle endurance, were also evaluated. The exercise group underwent a supervised 12-week program comprising combined aerobic and resistance training, performed three times weekly.

Results: Compared with controls, participants in the exercise group demonstrated significant reductions in body weight, waist circumference, body fat percentage, and both systolic and diastolic blood pressure ($p < 0.05$). Improvements were also observed in $VO_2\text{max}$, handgrip strength, and bilateral leg strength. However, no statistically significant changes in HRV indices were detected between groups after 12 weeks.

Conclusion: While combined aerobic and resistance training improved cardiovascular risk factors, muscle strength, and cardiorespiratory fitness in individuals with T2DM, it did not significantly alter HRV parameters within the study period. Larger and longer-term studies are warranted to further clarify the impact of structured exercise on autonomic regulation in this population and to explore the role of individualized training regimens for optimizing health outcomes.

Keywords: HRV, autonomic nervous system, resistance exercise training, endurance exercise training, parasympathetic activity.

Introduction:

Heart rate variability (HRV), defined as the fluctuation in the interval between successive heartbeats, is a widely accepted non-invasive marker of autonomic nervous system (ANS) regulation and overall cardiovascular health. Higher HRV reflects greater adaptability of the ANS and improved stress resilience, whereas reduced HRV has been associated with an elevated risk of cardiovascular morbidity and mortality, as well as impaired physiological stress tolerance ^[1,2].

Exercise training is one of the most effective non-pharmacological interventions for improving cardiovascular health and modulating autonomic function. Both resistance exercise training (RET) and endurance exercise training (EET) have been shown to influence HRV, albeit through different physiological pathways ^[2,3]. RET, which primarily enhances muscular strength and endurance, has demonstrated mixed effects on HRV. Acute RET may transiently reduce parasympathetic modulation, particularly in young and healthy individuals, thereby increasing the risk of post-exercise autonomic imbalance ^[4,5]. In contrast, chronic RET has been reported to improve parasympathetic regulation in individuals with autonomic dysfunction, such as middle-aged adults and patients with cardiovascular disease ^[6]. Clinical trials further support the therapeutic potential of RET, with evidence showing that high-repetition, low-load resistance programs can improve physical performance, endurance, and HRV markers in patients with coronary artery disease ^[2,3].

EET, involving prolonged aerobic activities such as cycling, running, or swimming, has consistently been linked to enhanced cardiovascular efficiency and autonomic regulation ^[4-6]. Regular participation in endurance exercise

improves parasympathetic activity, lowers resting heart rate, and increases HRV [5,6]. A meta-analysis further highlighted endurance training as one of the most effective strategies for reducing resting heart rate, a surrogate of cardiovascular efficiency [6]. In addition, EET promotes structural and functional adaptations, including improved capillary density, stroke volume, VO₂ max, and overall endurance capacity, all of which contribute to cardiovascular resilience and improved HRV [5-8].

Despite growing evidence supporting the benefits of both RET and EET, direct comparisons of their effects on HRV remain limited, particularly in populations with impaired autonomic function. The present study aims to compare the effects of resistance and endurance training on HRV over a 12-week intervention, with a specific focus on cardiovascular health and autonomic modulation.

Materials & methods:

Study population and design: A total of 100 participants with type 2 diabetes mellitus were recruited and randomly allocated to either the exercise group (n = 50) or the control group (n = 50). Written informed consent was obtained from all participants after providing a detailed explanation of the study objectives, procedures, and potential benefits. The study protocol adhered to the ethical principles of the Declaration of Helsinki.

Anthropometric and physiological measurements: Body weight and height were recorded, and body mass index (BMI) was calculated as weight (kg)/height (m²). Waist circumference was measured to the nearest 0.1 cm at the midpoint between the lower margin of the ribs and the iliac crest, with participants standing upright. Body fat percentage was assessed using a bioelectrical impedance body composition analyzer. Resting blood pressure (systolic and diastolic) was measured with an automated sphygmomanometer following a 10-minute seated rest, and resting heart rate was recorded using a wireless heart rate monitor.

Heart rate variability assessment: HRV was evaluated at 10:00 a.m. following a 20-minute rest period using a standardized HRV analyzer. A five-minute ECG recording was analyzed in both time and frequency domains. Time-domain indices included the root mean square of successive differences (rMSSD), reflecting parasympathetic activity, and the standard deviation of normal-to-normal intervals (SDNN), indicating overall variability. Frequency-domain measures included low-frequency (LF: sympathetic and partial parasympathetic influence), high-frequency (HF: parasympathetic activity), and the LF/HF ratio, used as a marker of sympathovagal balance.

Physical fitness assessment: Cardiorespiratory fitness (VO₂max) was estimated using a submaximal graded exercise test on a cycle ergometer. VO₂max was calculated from the peak heart rate achieved during incremental workloads. Muscular strength was measured using a handgrip dynamometer (adjusted to the second finger joint for standardized positioning) and a leg muscle strength measuring device, which assessed maximal bilateral force in a seated position. Muscular endurance was assessed using a 30-second sit-up test on a calibrated board.

Exercise intervention: The exercise group completed a supervised 12-week program comprising aerobic and resistance

training, three sessions per week, in accordance with the American College of Sports Medicine (ACSM) guidelines.

Aerobic training: Each session included 30 minutes of treadmill walking at 60% of the heart rate reserve (HRR), calculated using the Karvonen formula: $Target\ HR = Resting\ HR + (Exercise\ Intensity \times [Maximum\ HR - Resting\ HR])$. Training intensity was monitored continuously using a Polar heart rate analyzer to ensure adherence.

Resistance training: Following aerobic exercise, participants performed resistance training consisting of two sets of 8–12 repetitions across nine machine-based exercises (curl-ups, leg press, leg extension, leg curl, calf raise, and lat pulldown), with intensity set at 60–80% of one-repetition maximum (1-RM). The Fleck and Kramer indirect 1-RM method was used to estimate load.

Each session included a 10-minute warm-up and cool-down involving stretching exercises. The control group did not participate in structured exercise but continued with their usual lifestyle.

Statistical analysis:

Data were analyzed using SPSS software (version XX, IBM Corp., Armonk, NY, USA). A two-way repeated-measures analysis of variance (ANOVA) was employed to evaluate the effects of group (exercise vs. control), time (pre- vs. post-intervention), and their interaction on the study variables. Statistical significance was set at $p < 0.05$.

Results:

Table 1 : Demographic parameters of the study population

Variables	Groups	At baseline	After 8 weeks	Student test P Value
Weight (Kg)	Exercise group	58.1 ± 8.8	54.2 ± 9.1	0.0327; df = 98; t = 2.1661
	Control group	62.3 ± 9.9	62.4 ± 9.2	0.058; df = 98; t = 0.0523
% of fat	Exercise group	32.2 ± 8.1	30.4 ± 7.9	0.0402; df = 98; t = 2.079
	Control group	34.2 ± 7.8	34.3 ± 7.7	0.048; df = 98; t = 0.0645
Waist circumference	Exercise group	84.2 ± 12.5	79.3 ± 11.7	0.0457; df = 98; t = 2.0237
	Control group	82.4 ± 19.2	80.4 ± 18.2	0.594; df = 98; t = 0.5356
Systolic Blood pressure	Exercise group	136.2 ± 23.2	127.3 ± 31.3	0.020; df = 98; t = 2.3533
	Control group	132.7 ± 28.1	130.1 ± 27.2	0.6393; df = 98; t = 0.4701
Diastolic blood pressure	Exercise group	77.1 ± 21.1	70.3 ± 19.1	0.0445; df = 98; t = 2.035
	Control group	80.2 ± 11.2	79.2 ± 12.1	0.669; df = 98; t = 0.4289

Table 1 shows regarding body composition, weight ($p < 0.001$), body fat % ($p < 0.001$), and waist circumference ($p < 0.001$) in the exercise group were significantly decreased, compared to before exercise. In addition, systolic blood pressure ($p < 0.001$), and diastolic blood pressure ($p < 0.01$) in the exercise group were significantly decreased after the

exercise program compared to before exercise. The control group showed no significant difference in any variable of anthropometric indices between the pre and post periods.

Regarding physical fitness, VO₂max (p<0.05), grip strength (p<0.05), left leg strength (p<0.01), right leg strength (p<0.01), and muscular endurance (p<0.01) in the exercise group were significantly increased after the exercise program compared to before exercise. The control group showed no significant difference in any variable of physical fitness between the pre- and post-part periods (Table 2). Regarding HRV, there was no significant difference in SDNN, rMSSD, LF, HF, or LF/HF between the pre and post periods in either group.

Table 2: Fitness parameters of the study population.

Variables	Groups	At baseline	After 8 weeks	Student test P Value
VO ₂ max (ml/kg/min)	Exercise group	21.4 ± 2.2	22.6 ± 2.6*	=0.0144; df = 98; t = 2.4914
	Control group	26.2 ± 2.1	26.6 ± 1.8	= 0.3090; df = 98; t = 1.0226
Grip strength (Kg)	Exercise group	23.5 ± 2.6	26.6 ± 2.1*	=0.0001; df = 98; t = 6.2629
	Control group	22.9 ± 3.4	22.7 ± 2.9	=0.7523; df = 98; t = 0.3165
Left leg strength (Kg)	Exercise group	26.6 ± 4.1	28.8 ± 3.1	<0.0032; df = 98; t = 3.0265
	Control group	25.9 ± 2.2	25.7 ± 2.3	= 0.6578; df =98; t = 0.4443
Right leg strength (Kg)	Exercise group	20.3 ± 4.2	22.6 ± 4.5	<0.0096; df =98; t = 2.6421
	Control group	21.5 ± 2.2	21.4 ± 2.1	= 0.8166; df = 98; t = 0.2325
Sit Ups (count/30sec)	Exercise group	5.2 ± 2.3	6.4 ± 2.1	= 0.00.76; df =98; t = 2.7245
	Control group	4.5 ± 1.8	4.6 ± 1.2	= 0.7445; df = 98; t = 0.3269

Discussion:

This study demonstrated significant improvements in anthropometric and cardiovascular parameters including weight, body fat percentage, waist circumference, systolic blood pressure (SBP), and diastolic blood pressure (DBP) in participants who underwent structured exercise training, while no such changes were observed in the control group. These findings reinforce the established role of exercise in improving body composition and cardiovascular health.

The observed reductions in body weight, body fat percentage, and waist circumference are consistent with previous Indian and international trials, which have shown that structured aerobic and resistance exercise programs enhance metabolic efficiency and energy expenditure, leading to favorable alterations in body composition [9-11]. Similarly, the reductions in SBP and DBP align with prior evidence demonstrating the antihypertensive effects of regular physical activity, mediated by improvements in endothelial function, vascular compliance, and autonomic balance [11-13]. The absence of changes in the control group further highlights the necessity of structured exercise interventions, as passive lifestyle modifications alone have shown limited efficacy [13].

In addition to anthropometric benefits, participants in the exercise group exhibited improvements in physical fitness parameters, including VO₂max, grip strength, bilateral leg strength, and muscular endurance. The increase in VO₂max reflects enhanced cardiorespiratory capacity, likely mediated by improvements in oxygen transport, cardiac output, and mitochondrial efficiency, in agreement with both Indian and international studies [12-14]. Gains in grip and leg strength indicate improved neuromuscular adaptation and muscle hypertrophy, which are consistent with resistance training outcomes reported across diverse populations [15]. Improvements in muscular endurance further confirm the effectiveness of the combined training regimen, echoing evidence from both national and global literature [16,17]. Collectively, these findings underscore the multifaceted benefits of structured exercise for functional capacity and overall health.

In contrast, no significant improvements were observed in HRV indices (SDNN, rMSSD, LF, HF, LF/HF) in either group following the 12-week intervention. These findings suggest that while aerobic and resistance training may rapidly improve anthropometric and functional outcomes, modulation of autonomic activity reflected through HRV may require longer intervention durations, higher exercise intensities, or greater session frequency. Prior studies have indicated that significant autonomic adaptations often emerge after ≥ 16 weeks of consistent training [18,19]. International evidence further suggests that HRV responses may vary widely depending on baseline autonomic tone, individual stress levels, and other lifestyle factors such as sleep and nutrition, which may not have been fully controlled in the present study [20,21]. Additionally, the relatively normal baseline HRV values in participants could have created a ceiling effect, limiting the potential for measurable improvements.

Taken together, the findings from this trial confirm the substantial benefits of structured exercise programs on anthropometric indices, cardiovascular health, and physical fitness, but also highlight the complexity of HRV as an outcome measure. Future research with larger sample sizes, longer intervention durations, and controlled monitoring of lifestyle confounders is warranted to better elucidate the relationship between exercise modalities and autonomic regulation in individuals with type 2 diabetes mellitus.

Conclusion:

This study demonstrates that structured exercise programs incorporating aerobic and resistance training improve cardiovascular risk factors, body composition, and physical fitness in individuals with type 2 diabetes mellitus, although no significant changes in HRV were observed within the 12-week intervention. These findings suggest that regular exercise may support cardiovascular health and contribute to autonomic balance, with differential effects depending on exercise modality. Importantly, they highlight the potential value of individualized exercise prescriptions to optimize cardiometabolic and autonomic outcomes. Future studies with larger cohorts, extended intervention periods, and long-term follow-up are warranted to confirm these effects and further clarify the role of exercise in modulating autonomic function.

Conflict of interest:

There is no conflict of interest among the present study authors.

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