

Effects of Swimming-Based High-Intensity Interval Exercise versus Moderate-Intensity Continuous Exercise on Diastolic Function in Women with Early-Stage Left Ventricular Diastolic Dysfunction: Randomized Controlled Trial

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Research Article

Keywords: Diastolic dysfunction, High-intensity interval training, Moderate-intensity continuous training, Swimming exercise, Echocardiography, Cardiac rehabilitation

Posted Date: April 26th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9027863/v1>

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Additional Declarations: No competing interests reported.

Abstract

Left ventricular diastolic dysfunction (LVDD) is a clinical condition representing the early stage of heart failure with preserved ejection fraction (HFpEF) and is frequently observed in middle-aged women with cardiometabolic risk factors. Although exercise therapy is recommended as a fundamental approach, data on the optimal exercise model are limited. This study aimed to comparatively evaluate the effects of swimming-based high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) on anthropometric measurements, lipid profiles, inflammatory markers, and echocardiographic diastolic function parameters in women diagnosed with stage 1 LVDD.

This randomized controlled study included 60 women aged 40–60 years with an ejection fraction $\geq 50\%$ and an isolated stage 1 LVDD diagnosis. Participants were randomized in a 1:1:1 ratio into HIIT ($n = 20$), MICT ($n = 20$), and control ($n = 20$) groups. Following a 2-week adaptation period, the intervention groups performed swimming-based HIIT and MICT exercises three days per week for 12 weeks. Exercise intensity was determined using the heart rate reserve and the Karvonen formula. The primary outcome measure was the change in the E/A ratio. Secondary outcome measures included lipid profile, C-reactive protein (CRP) level, B-type natriuretic peptide (BNP) level, blood pressure, and structural echocardiographic parameters. Analyses were performed on participants who completed the study ($n = 53$).

Both exercise groups showed significant improvements in anthropometric parameters, lipid profiles, blood pressure, and diastolic function compared to the control group ($p < 0.05$). The E/A ratio increased from 0.81 ± 0.11 to 1.27 ± 0.22 in the HIIT group ($p < 0.001$) and from 0.75 ± 0.10 to 1.01 ± 0.16 in the MICT group ($p < 0.001$). In intergroup comparisons, the improvement in the HIIT group was more pronounced ($p < 0.001$). Significant reductions in CRP levels were observed in both exercise groups, with a greater decrease in the HIIT group. The decrease in systolic blood pressure was more notable in the HIIT group. Structural adaptations consistent with physiological cardiac remodeling were observed in both exercise groups.

HIIT and MICT swimming exercises significantly improved cardiometabolic parameters and left ventricular diastolic function in women with early stage LVDD. The HIIT protocol resulted in more pronounced improvements in diastolic function and blood pressure. These findings suggest that time-efficient high-intensity aquatic exercise may be an effective therapeutic approach for this population.

ClinicalTrials.gov ID: NCT06945913 (10.03.2025)

INTRODUCTION

Sedentary lifestyle habits have become one of the most significant public health problems on a global scale. Sedentary behavior, characterized by minimal energy expenditure (≤ 1.5 MET), has been increasing in parallel with technological advancements [1]. Research shows that Sedentary lifestyle habits are an important risk factor for the development of cardiovascular diseases, type 2 diabetes, certain types of cancer, and obesity [2]. It has been reported that spending more than 8 hours a day being inactive and sitting increases the risk of all-cause mortality by 4%, independent of physical activity level [3]. Furthermore, sedentary behavior increases the risk of developing metabolic syndrome by 1.73 times and increases cardiovascular disease mortality by 18–34%. When examining sex-based differences, women have been found to have higher sedentary behavior habits than men [4, 5]. According to global data, 35% of women in high-income countries and 24% in low-income countries have insufficient levels of physical activity, whereas these rates are 26% and 12% for men, respectively [6]. Studies have shown that independent risk factors for the development of diastolic dysfunction (DD) include chronic hypertension, type 2 diabetes, obesity, advanced age, and female sex. Studies indicate that obesity due to physical inactivity can cause hemodynamic differences that predispose individuals to changes in cardiac morphology and in ventricular function. Potential changes include increased cardiac output, left ventricular (LV) hypertrophy, and diastolic and systolic dysfunction of both ventricles [7]. In particular, the presence of left ventricular

diastolic dysfunction (LVDD) is thought to be an early preclinical finding of heart failure. Considering that heart failure significantly impairs health and leads to death, it is important to identify the risk factors that could indicate LVDD to delay or prevent the development of heart failure [8]. LVDD is a condition resulting from impaired relaxation capacity of the left ventricle and/or insufficient diastolic filling, and is generally characterized by increased left atrial pressure. Current diagnostic approaches are based on multiparametric assessments of structural and functional indicators, such as mitral annular tissue Doppler velocities, left atrial volume index, and left ventricular filling pressures [9]. Epidemiological studies have shown that the prevalence of DD increases significantly with age, and that the overall prevalence reaches 27% in community-based samples. As age advances, this rate rises further, and hospital admission rates for advanced DD (stage II/III) can reach up to 19%. Longitudinal cohort studies have reported that even in healthy individuals, diastolic function increased from 11.3% to 29.8% over a 4-year follow-up period and progressively deteriorated with aging [10, 11]. In the combined presence of hypertension and DD, conducting basic laboratory tests for a comprehensive evaluation of the cardiometabolic risk profile is critically important [12, 13]. It has been indicated that regular exercise increases stroke volume and cardiac output in individuals due to functional adaptation of the circulatory system [14]. Studies have also suggested that physical activities of varying intensities improve adult well-being and reduce the risk of cardiovascular diseases and cancer [15]. With regular aerobic exercise, important risk factors for cardiovascular diseases, such as triglyceride, total cholesterol, and LDL cholesterol levels, decrease, while HDL cholesterol, which is beneficial for heart health, increases [16].

Individuals are drawn to various sports activities to maintain their overall health and prevent heart diseases. Walking, dancing, swimming, and strength training are the most preferred sports activities [16]. Swimming exercises enable the active use of large muscle groups. Regular training of large muscle groups provides cardiovascular adaptations that increase exercise capacity, endurance, and skeletal muscle strength, and at the same time, prevents the development of coronary artery disease and reduces symptoms in patients with established cardiovascular disease [17]. Blood pressure increases less during swimming exercises than during running or resistance exercises [18]. In exercise models where the upper extremity muscles are used actively, higher pressures are known to occur compared to those in exercises using the lower extremity muscles. Although the upper body muscles are used more actively in swimming exercises, the lower pressure is explained by the horizontal position of the body in the water, particularly in freestyle and backstroke, which require less cardiac effort [19]. Studies have indicated that traditional water-based exercises and swimming are recommended for patients with low-risk cardiac conditions [20]. Considering the relaxing effect of water, swimming exercises, which are easy to perform and minimize injury risks, can encourage the transition to an active lifestyle, especially in individuals with low-risk cardiac diseases [21]. Studies have shown that the trunk, head, back, and abdominal muscles work together during swimming exercises; accordingly, swimming exercises have beneficial effects on the cardiovascular and skeletal systems [22].

Traditionally, moderate-intensity continuous training (MICT) models are frequently recommended by physicians. MICT is an exercise modality performed at a steady intensity of 50–70% of the maximal heart rate over a long duration (30–60 min). Although MICT is a high-quality and successful exercise model for improving overall health, it can result in loss of motivation and low adherence in individuals owing to its time-consuming and monotonous nature. Research on this topic indicates that approximately 50% of individuals who join exercise programs drop out within the first 6 months, with lack of time cited as the most important reason [23, 24]. Therefore, recent studies have focused on high-intensity interval training (HIIT) applications, which can achieve similar or even superior effects in a shorter time. In recent years, HIIT has emerged as a time-efficient alternative. HIIT is an exercise modality in which short high-intensity activity periods (30 s–4 min) at 85–95% of maximal heart rate are alternated with active or passive rest intervals [25]. Simultaneously, HIIT's adaptable nature and safe applicability of HIIT in various populations enhance its clinical value [26, 27]. Current studies show that HIIT is effective and safe in different clinical populations, such as those with obesity, type 2 diabetes, cardiovascular diseases, and even cancer [25]. Meta-analysis studies have proven that HIIT improves cardiometabolic

health and increases the quality of life, even in elderly individuals [28]. These findings support the notion that HIIT is an effective exercise strategy across a wide range of populations, from sedentary individuals to elite athletes.

The incidence of heart failure with preserved ejection fraction (HFpEF) is increasing; however, there is still no effective treatment method that improves the course of the disease. Current guidelines emphasize that exercise is the most important method of treatment. However, data on the application, duration, and frequency of exercise therapy are insufficient. This study aimed to comparatively evaluate the effects of 12-week HIIT and MICT swimming exercises on anthropometric measurements, lipid profiles, inflammatory markers, and left ventricular diastolic function in women aged 40–60 who have been diagnosed with diastolic dysfunction.

METHODS

This was a single-center, parallel-group, three-arm, randomized controlled intervention trial. This study was conducted in accordance with the CONSORT 2010 guidelines (Fig. 1). The study protocol was approved by the Non-Interventional Clinical Research Ethics Committee of Uşak University (Decision No: 21, 07/11/2024). The study was pre-registered in the ClinicalTrials.gov database (NCT06945913, 10/03/2025). Written informed consent was obtained from all the participants.

Participants were selected from patients who visited the Cardiology Outpatient Clinic of Uşak University Training and Research Hospital (15/03/2025-15/06/2025). Participants were selected according to the following criteria:

Inclusion criteria were as follows

women aged 40–60 years, preserved ejection fraction ($EF \geq 50\%$), diagnosed with isolated stage 1 diastolic dysfunction consistent with HFpEF according to the stage B ASE/EACVI 2016 criteria, under stable antihypertensive treatment, and able to swim.

Exclusion criteria were as follows

known coronary artery disease, moderate-to-severe valvular heart disease, arrhythmia, chronic lung diseases, or orthopedic or neurological conditions that prevented exercise.

Sixty eligible participants were randomly assigned to three groups (HIIT, $n = 20$; MICT, $n = 20$; Control, $n = 20$) in a 1:1:1 ratio using a simple randomization method. The randomization sequence was generated using a computer-based program for random number generation. Group assignments were made using opaque, sealed, and sequentially numbered envelopes. Allocation concealment was ensured by a researcher independent of the intervention providers and the cardiologist. Echocardiographic assessments were performed by an experienced cardiologist blinded to the group assignments. Laboratory analyses were conducted in a routine hospital laboratory without sharing group information. Due to the nature of the exercise interventions, blinding of participants was not possible. The study was conducted in three groups: the first group consisted of 17 women who performed HIIT swimming exercises, and the second group consisted of 18 women who performed MICT swimming exercises. The control group included 18 women who, despite being advised to exercise, could not participate in any exercise. The participants in this group were asked to maintain their daily routines.

The sample size was calculated using G* Power (v3.1) software. With three groups in the study, an effect size of 0.25 was accepted for a medium effect, and the power was calculated as 0.90. As a result of these calculations, the total sample size required for an effective outcome was determined to be 54. Participants who lost eligibility by failing to meet at least one inclusion criterion during the study were excluded, and the study was completed by 53 participants.

The primary endpoint of the study was the change in the E/A ratio. The secondary endpoints included E velocity, A velocity, DT, LVEF, LAVI, LVMI, anthropometric measurements, blood pressure, lipid profile, CRP, and BNP.

EXERCISE PROTOCOL

The swimming exercise programs for the two groups participating in the exercises were carried out over a total period of 14 weeks, with an initial 2-week adaptation phase followed by 12 weeks of training, three days a week. The duration of each training session was individually determined based on the type and intensity of the exercises.

When determining the intensity of the exercise, individual differences were considered. Therefore, in this study, the training intensities and target heart rates were calculated individually for each participant according to the heart rate reserve (%HRR) using the Karvonen formula, which is one of the most reliable methods. The formula was applied based on each participant's age, resting heart rate, and maximal heart rate. The formula used was as follows: Target Heart Rate = [(Maximum Heart Rate – Resting Heart Rate) x (% Training Intensity)] + Resting Heart Rate [29]. In the HIIT group, short-duration, high-intensity intervals and active recovery periods were implemented at 85–95% HRR. In the MICT group, continuous moderate-intensity swimming exercises at 50–70% HRR were performed.

To determine the perceived difficulty of exercise, the Rate of Perceived Exertion (RPE) scale designed by Borg was used. This scale consists of numbers between 6 and 20, each associated with descriptors of exertion (e.g., 6-very, very light; 19-very, very hard) [30]. In this study, this scale was used during all exercise sessions to assess exertion levels. Additionally, throughout the study, each participant's heart rate was monitored and controlled using a portable Polar brand (S810i) heart rate monitor.

Participants were provided with relevant information about the types of exercises and application methods they would perform, and the exercise programs designed for each group were implemented accordingly. The study programs (HIIT-MICT) are presented in Table 1.

Table 1
Weekly Aquatic Exercise Training Protocol for the HIIT and MICT Groups

Week	Phase	Duration (min)	HIIT			MICT		
			Exercise Content	Intensity (%HRR)	Recovery	Exercise Content	Intensity (%HRR)	Recovery
1–4	Warm-up (10 min)	5	Low-intensity jogging, multi-directional upper and lower extremity movements, and ballistic stretching exercises (land-based)	40	—	Low-intensity jogging, multi-directional upper and lower extremity movements, and ballistic stretching exercises (land-based)	40	—
		5	In-water familiarisation: freestyle kick and sculling drills	50	1 min passive recovery	In-water familiarisation: freestyle kick and sculling drills	50	1 min passive recovery
	Main Phase (15 min)	15	3 sets × 4 repetitions × 30 s freestyle swimming	80	15 s active recovery between repetitions; between sets: in-water freestyle drills until HR ≤ 100 bpm†	23 min continuous freestyle swimming	65	2 min active recovery (in-water freestyle drills until HR ≤ 100 bpm)
		Variable [†]	In-water relaxation exercises for alactic and O ₂ debt recovery	50	Active (HR-guided)	—	—	—
	Cool-down (5 min)	5	Passive stretching of exercised muscle groups — upper and lower extremities (land-based)	40	Passive stretching	Passive stretching of exercised muscle groups — upper and lower extremities (land-based)	40	Passive stretching

HIIT, High-Intensity Interval Training; MICT, Moderate-Intensity Continuous Training; %HRR, percentage of Heart Rate Reserve; HR, Heart Rate; bpm, beats per minute.

[†]Inter-set recovery duration was individualized; participants performed in-water relaxation and freestyle drills until HR decreased to ≤ 100 bpm, thereby ensuring recovery was tailored to each participant's cardiac response.

Exercise frequency: 3 sessions/week for 12 weeks. A progressive overload principle was applied every four weeks by simultaneously increasing exercise intensity (%HRR) and volume (duration/repetitions). Individual target heart rates were calculated using the Karvonen formula (Heart Rate Reserve method) [29] and were continuously monitored using Polar heart rate monitors during all exercise sessions. The aquatic HIIT protocol was adapted from the protocols described by Tang et al. [54] and Angadi et al. [55]. The warm-up and cool-down content were identical across both groups. In-water freestyle drills: Sport-specific low-intensity exercises (e.g., freestyle kick, sculling) used to facilitate active recovery.

Week	Phase	Duration (min)	HIIT			MICT		
			Exercise Content	Intensity (%HRR)	Recovery	Exercise Content	Intensity (%HRR)	Recovery
5–8	Warm-up (10 min)	5	Low-intensity jogging, multi-directional upper and lower extremity movements, and ballistic stretching exercises (land-based)	40	—	Low-intensity jogging, multi-directional upper and lower extremity movements, and ballistic stretching exercises (land-based)	40	—
		5	In-water familiarisation: freestyle kick and sculling drills	50	1 min passive recovery	In-water familiarisation: freestyle kick and sculling drills	50	1 min passive recovery
	Main Phase (20 min)	20	3 sets × 6 repetitions × 30 s freestyle swimming	85	15 s active recovery between repetitions; between sets: in-water freestyle drills until HR ≤ 100 bpm†	33 min continuous freestyle swimming	70	2 min active recovery (in-water freestyle drills until HR ≤ 100 bpm)
		Variable [†]	In-water relaxation exercises for alactic and O ₂ debt recovery	50	Active (HR-guided)	—	—	—
	Cool-down (5 min)	5	Passive stretching of exercised muscle groups – upper and lower extremities (land-based)	40	Passive stretching	Passive stretching of exercised muscle groups – upper and lower extremities (land-based)	40	Passive stretching
9–12	Warm-up (10 min)	5	Low-intensity jogging, multi-directional upper and	40	—	Low-intensity jogging, multi-directional upper and	40	—

HIIT, High-Intensity Interval Training; MICT, Moderate-Intensity Continuous Training; %HRR, percentage of Heart Rate Reserve; HR, Heart Rate; bpm, beats per minute.

[†]Inter-set recovery duration was individualized; participants performed in-water relaxation and freestyle drills until HR decreased to ≤ 100 bpm, thereby ensuring recovery was tailored to each participant's cardiac response.

Exercise frequency: 3 sessions/week for 12 weeks. A progressive overload principle was applied every four weeks by simultaneously increasing exercise intensity (%HRR) and volume (duration/repetitions). Individual target heart rates were calculated using the Karvonen formula (Heart Rate Reserve method) [29] and were continuously monitored using Polar heart rate monitors during all exercise sessions. The aquatic HIIT protocol was adapted from the protocols described by Tang et al. [54] and Angadi et al. [55]. The warm-up and cool-down content were identical across both groups. In-water freestyle drills: Sport-specific low-intensity exercises (e.g., freestyle kick, sculling) used to facilitate active recovery.

Week	Phase	Duration (min)	HIIT			MICT		
			Exercise Content	Intensity (%HRR)	Recovery	Exercise Content	Intensity (%HRR)	Recovery
			lower extremity movements, and ballistic stretching exercises (land-based)			lower extremity movements, and ballistic stretching exercises (land-based)		
		5	In-water familiarisation: freestyle kick and sculling drills	50	1 min passive recovery	In-water familiarisation: freestyle kick and sculling drills	50	1 min passive recovery
	Main Phase (25 min)	25	3 sets × 7 repetitions × 30 s freestyle swimming	90	15 s active recovery between repetitions; between sets: in-water freestyle drills until HR ≤ 100 bpm†	43 min continuous freestyle swimming	75	2 min active recovery (in-water freestyle drills until HR ≤ 100 bpm)
		Variable [†]	In-water relaxation exercises for alactic and O ₂ debt recovery	50	Active (HR-guided)	—	—	—
	Cool-down (5 min)	5	Passive stretching of exercised muscle groups — upper and lower extremities (land-based)	40	Passive stretching	In-water relaxation exercises performed until HR ≤ 90 bpm, followed by passive stretching (land-based)	40	Passive stretching
Total Session Duration			Wk 1–4: ~35 min Wk 5–8: ~40 min Wk 9–12: ~45 min			Wk 1–4: ~40 min Wk 5–8: ~50 min Wk 9–12: ~60 min		
HIIT, High-Intensity Interval Training; MICT, Moderate-Intensity Continuous Training; %HRR, percentage of Heart Rate Reserve; HR, Heart Rate; bpm, beats per minute.								
†Inter-set recovery duration was individualized; participants performed in-water relaxation and freestyle drills until HR decreased to ≤ 100 bpm, thereby ensuring recovery was tailored to each participant's cardiac response.								
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DATA COLLECTION METHODS

Measurement of Physical Parameters

In this study, height was measured using an Onbody brand stadiometer. Height was recorded with a precision of ± 0.1 cm. Body weight and body composition measurements were performed using bioelectrical impedance analysis (Tanita Bc 601 Innerscan), with measurements taken barefoot and with the participants wearing shorts and a t-shirt. The precision of weight measurement ranged between ± 0.1 and ± 0.5 kg. The BMI values were automatically calculated by the device. Body Mass Index (BMI) was calculated by dividing weight (kg) by the square of height (m^2) and was assessed with a precision of ± 0.1 kg/ m^2 . Waist and hip circumferences were measured using Gullick tape. During the measurements, the tape was placed so that it closely contacted the participant's skin without being too tight, and the data were recorded in centimeters.

Heart Rate and Blood Pressure Measurement

Participants exercise heart rates were monitored using a Polar brand portable heart rate monitor, and they exercised within personalized heart rate zones determined using the Karvonen formula. Blood pressure measurements were performed using the oscillometric method via automated upper-arm devices. The measurement range was between 0 and 299 mmHg, encompassing both systolic and diastolic values, with a precision of ± 3 mmHg. Participants' blood pressure was measured after 10 minutes of rest, in a seated position, with the arm at heart level, using an Omron M3 Comfort HEM-7155 upper-arm blood pressure monitor on both arms, and the higher value was recorded.

Measurement of Echocardiographic Parameters

Echocardiographic assessments of all participants were performed using a Philips-brand transthoracic echocardiography device by an experienced cardiologist who was blinded to the study groups. Measurements were taken in the left lateral decubitus position using two-dimensional (2D), M-mode, and Doppler (Pulse-wave, Tissue Doppler) techniques. Data analysis and diastolic function classification were conducted in accordance with the latest ASE/EACVI guidelines (2016). From the parasternal long-axis view, the dimensions of the left ventricle (LV) and right ventricle (RV), interventricular septum (IVS), posterior wall (PW) thickness, and left atrium (LA) diameter were measured. Left ventricular ejection fraction (LVEF) was calculated in the apical four-chamber view using the Modified Simpson method. The left atrial volume index (LAVI) was determined by dividing the LA volume obtained from the apical four-chamber view by the body surface area (BSA). To assess the transmitral filling pattern, in the apical four-chamber view, a pulse-wave (PW) Doppler sample was placed at the level of the mitral valve leaflets; early diastolic filling velocity (E), atrial contraction velocity (A), E/A ratio, and E wave deceleration time (DT) were measured. The isovolumetric relaxation time (IVRT) was recorded as the time between aortic valve closure and mitral valve opening. Using the Tissue Doppler Imaging (TDI) method, early diastolic myocardial velocities (e') and atrial contraction velocities (a') were measured from the septal and lateral regions of the mitral annulus. As an indirect indicator of left ventricular filling pressure, the average E/ e' ratio was calculated by averaging the septal and lateral e' values.

Measurement of Elektrocardiographic Parameters

Electrocardiographic recordings were planned to be obtained after a 10-minute resting period using a GE Healthcare MAC 2000 ECG System by the same experienced nurse. All recordings were to be performed at a standard paper speed of 25 mm/s and an amplitude of 10 mm/mV.

Measurement of Blood Parameters

Blood samples were collected from the participants' antecubital veins in the morning after 12 h of fasting and analyzed at the central laboratory of Uşak University Education and Research Hospital. The samples were analyzed for biochemical blood tests, hemogram, WBC, PLT, NEU, LYM, creatinine, glucose, HbA1c, CRP, total cholesterol, HDL, LDL, triglyceride, TSH, urea, uric acid, and BNP. Biochemical parameters (glucose, lipid profile, uric acid, and liver enzymes) were measured using spectrophotometric and enzymatic methods, hemogram parameters using an automated hematology analyzer, CRP using the immunoturbidimetric method, and BNP using the immunochemiluminescence method. All analyses were calibrated regularly in accordance with laboratory quality control.

Statistical Analysis of Data

Normality of the data was tested using the Shapiro-Wilk test. Homogeneity of variances was determined using Levene's test. For normally distributed data, within-group comparisons were performed using the paired t-test, and between-group comparisons were performed using the One-way ANOVA test. When ANOVA was found to be significant, specific group differences were determined using Tukey's HSD post-hoc correction. For non-normally distributed data, within-group comparisons were performed using the Wilcoxon signed-rank test, and between-group comparisons were performed using the Kruskal-Wallis H test.

FINDINGS

A total of 200 individuals were assessed for eligibility. Sixty participants who met the inclusion criteria were randomized (HIIT: n = 20; MICT: n = 20; control: n = 20).

During the intervention, seven participants did not complete the study (HIIT: 3; MICT: 2; control: 2). The study was completed with 53 participants, and analyses were conducted using a per-protocol approach. At baseline, there were no statistically significant differences between the groups in terms of age, BMI, blood pressure, lipid profile, or echocardiographic parameters ($p > 0.05$).

Anthropometric Parameters

In our study, the HIIT group showed an average reduction of 2.43 kg in body weight (from 82.61 ± 18.43 to 80.18 ± 17.64 kg), 0.95 kg/m^2 in BMI (from 32.06 ± 6.55 to 31.11 ± 6.19), and 0.05 in waist-hip ratio (from 0.97 ± 0.10 to 0.92 ± 0.07) ($p < 0.05$), whereas the MICT group had reductions of 1.35 kg in body weight (from 84.34 ± 10.59 to 82.99 ± 9.97 kg) and 0.56 kg/m^2 in BMI (from 33.92 ± 4.73 to 33.36 ± 4.37) ($p < 0.05$). The HIIT group showed a 2.7% decrease in body fat percentage (from 34.56 ± 9.36 to 33.63 ± 9.53) ($p = 0.002$) (Table 2).

Table 2
Physical parameter findings for all groups

Variables	HIIT (n = 17)			MICT (n = 18)			Control (n = 18)		
	Pre-test	Post-test	p	Pre-test	Post-test	p	Pre-test	Post-test	p
Age(year)	50,59 ± 6,93	50,59 ± 6,93		51,67 ± 6,84	51,67 ± 6,84		51,94 ± 4,94	51,94 ± 4,94	
Height(cm)	160,24 ± 6,75	160,24 ± 6,75		157,94 ± 6,12	157,94 ± 6,12		158,28 ± 6,11	158,28 ± 6,11	
Weight (kg)	82,61 ± 18,43	80,18 ± 17,64	0,000	84,34 ± 10,59	82,99 ± 9,97	0,011	83,89 ± 9,70	83,93 ± 9,23	,899
BMI (kg/m²)	32,06 ± 6,55	31,11 ± 6,19	0,000	33,92 ± 4,73	33,36 ± 4,37	0,010	33,62 ± 4,64	33,63 ± 4,42	,942
Fat Rate %	34,56 ± 9,36	33,63 ± 9,53	0,002	36,06 ± 5,03	35,86 ± 5,00	0,742	36,29 ± 5,48	36,33 ± 5,53	,961
Waist/Hip (cm)	0,97 ± 0,10	0,92 ± 0,07	0,004	0,95 ± 0,06	0,96 ± 0,06	0,279	0,96 ± 0,08	0,97 ± 0,07	,807
Data are presented as the mean ± standard deviation. Statistical significance was set at p < 0.05. Body Mass Index (BMI).									

Lipid Profile

Both exercise groups exhibited significant improvements in their lipid profiles. In the HIIT group, total cholesterol decreased from 198.24 ± 34.27 mg/dL to 184.88 ± 31.13 mg/dL (a 6.7% reduction), LDL cholesterol declined from 116.65 ± 27.45 mg/dL to 106.64 ± 20.29 mg/dL (an 8.6% reduction), and triglycerides dropped from 148.53 ± 74.21 mg/dL to 136.24 ± 62.35 mg/dL (an 8.3% reduction) (p < 0.001). In the MICT group, total cholesterol decreased from 213.72 ± 46.97 mg/dL to 201.61 ± 40.64 mg/dL (5.7%), LDL cholesterol from 143.64 ± 75.68 mg/dL to 138.42 ± 71.60 mg/dL (3.6%), and triglycerides from 158.11 ± 84.92 mg/dL to 145.67 ± 74.92 mg/dL (7.9%) (p < 0.01) (Table 4).

Table 4
Blood parameter findings for all groups

Variables	HIIT (n = 17)			MICT (n = 18)			Control (n = 18)		
	Pre-test	Post-test	p	Pre-test	Post-test	p	Pre-test	Post-test	p
HGB (g/dL)	12,90 ± 1,29	13,49 ± 1,06	0,002	13,24 ± 1,41	13,56 ± 1,35	0,008	13,18 ± 1,03	13,23 ± 0,97	,778
WBC(10 ³ /μL)	6,42 ± 1,62	6,39 ± 1,56	0,938	7,58 ± 1,46	8,11 ± 2,03	0,128	7,63 ± 2,06	7,09 ± 1,52	,096
PLT (10 ³ /μL)	279,35 ± 50,45	268,24 ± 61,32	0,254	283,72 ± 58,96	275,00 ± 54,87	0,202	307,33 ± 60,37	298,06 ± 76,87	,512
NEU(10 ³ /μL)	3,57 ± 1,41	3,58 ± 1,14	0,985	7,85 ± 14,20	7,86 ± 12,46	0,993	4,80 ± 1,72	8,18 ± 16,99	,391
LYM(10 ³ /μL)	2,26 ± 0,45	2,22 ± 0,55	0,520	2,46 ± 0,58	2,60 ± 0,83	0,294	2,26 ± 0,74	2,26 ± 0,48	,983
Creatinine (mg/dL)	0,76 ± 0,14	0,77 ± 0,13	0,665	0,73 ± 0,12	0,76 ± 0,12	0,050	0,71 ± 0,09	0,72 ± 0,08	,777
Urea (mg/dL)	35,41 ± 16,57	35,78 ± 13,87	0,926	31,21 ± 10,07	32,27 ± 7,35	0,593	28,28 ± 7,74	29,02 ± 7,04	,758
Uric Asid (mg/dL)	5,75 ± 1,22	5,79 ± 1,16	0,894	5,57 ± 1,31	5,54 ± 1,20	0,912	5,17 ± 1,16	5,29 ± 1,24	,603
Glucose (mg/dL)	104,12 ± 20,25	101,18 ± 10,01	0,363	99,44 ± 17,06	98,06 ± 13,35	,630	112,33 ± 44,18	110,83 ± 35,26	,590
HbA1C (%)	4,17 ± 0,69	4,06 ± 0,64	0,468	4,21 ± 0,85	4,24 ± 0,95	,692	4,69 ± 1,65	5,31 ± 2,77	,251
T.Colesterol(mg/dL)	198,24 ± 34,27	184,88 ± 31,13	0,000	213,72 ± 46,97	201,61 ± 40,64	0,004	219,61 ± 33,49	220,89 ± 30,89	,745
TGL(mg/dL)	148,53 ± 74,21	136,24 ± 62,35	0,001	158,11 ± 84,92	145,67 ± 74,92	0,001	162,17 ± 87,75	159,06 ± 81,26	,188
LDL(mg/dL)	116,65 ± 27,45	106,64 ± 20,29	0,000	143,64 ± 75,68	138,42 ± 71,60	0,001	128,67 ± 26,86	127,08 ± 23,54	,489
HDL(mg/dL)	49,59 ± 10,80	51,18 ± 10,32	,435	51,56 ± 9,61	53,83 ± 10,87	,106	60,83 ± 10,79	59,22 ± 8,43	,344
TSH (μIU/mL)	2,14 ± 1,35	1,98 ± 1,19	0,626	2,62 ± 0,96	2,58 ± 1,84	0,282	2,55 ± 0,80	2,02 ± 1,01	,204
CRP (mg/dL)	7,35 ± 4,08	5,21 ± 2,95	0,036	6,22 ± 3,30	5,56 ± 3,10	0,000	6,95 ± 4,79	6,92 ± 3,25	,978
BNP (pg/mL)	43,24 ± 17,22	45,53 ± 16,71	0,000	38,94 ± 13,56	40,61 ± 13,92	0,000	42,06 ± 16,86	41,94 ± 16,63	,805
Data are presented as the mean ± standard deviation. A p-value of < 0.05 was considered statistically significant. (HGB) Hemoglobin, (WBC) White Blood Cell, (PLT) Platelet, (NEU) Neutrophil, (LYM) Lymphocyte, (HbA1c) Glycated Hemoglobin, (T. Cholesterol) Total Cholesterol, (TGL) Triglyceride, (LDL) Low-Density Lipoprotein, (HDL) High-Density Lipoprotein, (TSH) Thyroid Stimulating Hormone, (CRP) C-Reactive Protein, (BNP) B-Type Natriuretic Peptide									

Inflammatory Markers

In our study, the HIIT group showed a 2.14 mg/L (29.1%) reduction in CRP levels, with values decreasing from 7.35 ± 4.08 mg/L to 5.21 ± 2.95 mg/L ($p = 0.036$). In the MICT group, CRP levels decreased by 0.66 mg/L (10.6%), from 6.22 ± 3.30 mg/L to 5.56 ± 3.10 mg/L ($p < 0.001$). In the control group, there was no significant change in CRP levels (from 6.95 ± 4.79 to 6.92 ± 3.25 mg/L, $p = 0.978$) (Table 4).

Cardiac Biomarkers and Blood Pressure

For BNP values, the HIIT group showed a significant decrease from 43.24 ± 17.22 pg/mL to 45.53 ± 16.71 pg/mL ($p < 0.001$), and the MICT group showed a decrease from 38.94 ± 13.56 pg/mL to 40.61 ± 13.92 pg/mL ($p < 0.001$).

For hemoglobin values, the HIIT group saw a significant decrease from 12.90 ± 1.29 g/dL to 13.49 ± 1.06 g/dL ($p = 0.002$), and the MICT group decreased from 13.24 ± 1.41 g/dL to 13.56 ± 1.35 g/dL ($p = 0.008$) (Table 4).

In blood pressure parameters, the HIIT group showed a reduction in systolic blood pressure from 130.06 ± 13.65 to 124.18 ± 12.63 mmHg ($p < 0.001$) and diastolic blood pressure from 83.82 ± 8.07 to 80.59 ± 9.23 mmHg ($p < 0.001$). In the MICT group, systolic blood pressure decreased from 132.33 ± 6.29 to 129.50 ± 5.88 mmHg ($p < 0.001$) and diastolic blood pressure from 83.00 ± 10.40 to 81.78 ± 8.93 mmHg ($p = 0.013$) (Table 3).

Table 3
Blood Pressure parameter findings for all groups

Variables	HIIT (n = 17)			MICT (n = 18)			Control (n = 18)		
	Pre-test	Post-test	p	Pre-test	Post-test	p	Pre-test	Post-test	p
DKAH(beat/mn.)	$82,35 \pm 6,17$	$77,47 \pm 6,54$	0,000	$80,06 \pm 7,09$	$76,89 \pm 6,96$	0,000	$82,28 \pm 7,38$	$82,56 \pm 5,80$	,639
SKB (mmHg)	$130,06 \pm 13,65$	$124,18 \pm 12,63$	0,000	$132,33 \pm 6,29$	$129,50 \pm 5,88$	0,000	$131,11 \pm 6,04$	$131,89 \pm 5,30$	,413
DKB(mmHg)	$83,82 \pm 8,07$	$80,59 \pm 9,23$	0,000	$83,00 \pm 10,40$	$81,78 \pm 8,93$	,013	$84,06 \pm 5,51$	$84,61 \pm 5,02$	,555
Data are presented as the mean $\pm$ standard deviation. Statistical significance was set at $p < 0.05$. (DKAH) Resting Heart Rate, (SKB) Systolic Blood Pressure, (DKB) Diastolic Blood Pressure									

Glycemic Control and Metabolic Parameters

A significant decrease in glucose levels was observed in the MICT group, from 99.44 ± 17.06 to 98.06 ± 13.35 mg/dL ($p = 0.003$), but the change in the HIIT group was not significant (from 104.12 ± 20.25 to 101.18 ± 10.01 mg/dL, $p = 0.363$) (Table 4).

Left Ventricular Diastolic Function

The E/A ratio, one of the key findings of the study, increased from 0.81 ± 0.11 to 1.27 ± 0.22 in the HIIT group ($p < 0.001$). In the MICT group, the E/A ratio increased from 0.75 ± 0.10 to 1.01 ± 0.16 ($p < 0.001$). Again, in both exercise groups, a significant change was observed in E wave velocity. In the HIIT group, the E wave velocity increased from 0.70 ± 0.08 to 0.91 ± 0.11 m/s, and in the MICT group, it increased from 0.67 ± 0.10 to 0.82 ± 0.15 m/s ($p < 0.001$). In contrast, the A wave velocity decreased from 0.87 ± 0.12 to 0.73 ± 0.12 m/s in the HIIT group and from 0.90 ± 0.09 to 0.81 ± 0.08 m/s in the MICT group ($p < 0.001$) (Table 5).

Table 5
Echocardiography Parameter findings for all groups

Variables	HIIT (n = 17)			MICT (n = 18)			Control (n = 18)		
	Pre-test	Post-test	p	Pre-test	Post-test	p	Pre-test	Post-test	p
LVDCAP(mm)	4,60 ± 0,28	4,80 ± 0,26	0,000	4,73 ± 0,32	5,05 ± 0,33	0,000	4,76 ± 0,26	4,73 ± 0,27	,217
LVSCAP(mm)	3,00 ± 0,26	3,07 ± 0,25	0,006	3,15 ± 0,29	3,07 ± 0,31	0,004	3,23 ± 0,27	3,21 ± 0,27	,362
LVEF (%)	65,12 ± 1,90	68,35 ± 2,80	0,000	63,44 ± 2,57	64,89 ± 3,03	0,070	62,28 ± 2,08	62,39 ± 2,45	,782
IVS(mm)	1,04 ± 0,09	1,15 ± 0,06	0,001	1,06 ± 0,09	1,11 ± 0,08	0,002	1,09 ± 0,08	1,07 ± 0,08	,118
PW(mm)	1,01 ± 0,11	1,10 ± 0,29	0,193	1,02 ± 0,06	1,12 ± 0,07	0,000	1,06 ± 0,07	1,05 ± 0,10	,558
SOLCAP(mm)	3,70 ± 0,21	3,61 ± 0,20	0,000	3,78 ± 0,25	3,70 ± 0,21	0,007	3,84 ± 0,15	3,85 ± 0,15	,574
EHIZ (m/s)	0,70 ± 0,08	0,91 ± 0,11	0,000	0,67 ± 0,10	0,82 ± 0,15	0,000	0,68 ± 0,10	0,69 ± 0,10	,031
AHIZ(m/s)	0,87 ± 0,12	0,73 ± 0,12	0,000	0,90 ± 0,09	0,81 ± 0,08	0,000	0,88 ± 0,08	0,87 ± 0,10	,720
E/A	0,81 ± 0,11	1,27 ± 0,22	0,000	0,75 ± 0,10	1,01 ± 0,16	0,000	0,77 ± 0,07	0,79 ± 0,10	,140
E' (cm/s)	0,69 ± 0,15	0,82 ± 0,24	0,006	0,62 ± 0,20	0,76 ± 0,29	0,000	0,60 ± 0,10	0,62 ± 0,11	,085
E/E'	1,05 ± 0,23	1,19 ± 0,34	0,016	1,14 ± 0,22	1,18 ± 0,37	0,608	1,13 ± 0,15	1,13 ± 0,17	1,000
DT (ms)	275,94 ± 31,42	236,12 ± 33,27	0,000	286,00 ± 27,87	260,33 ± 28,50	0,000	275,56 ± 34,25	271,17 ± 34,25	,527
LVMI (g/m ²)	82,76 ± 3,48	87,06 ± 4,80	0,000	86,36 ± 6,68	88,92 ± 6,18	0,015	86,12 ± 5,70	85,06 ± 5,77	,060
LAVI (g/m ²)	26,78 ± 2,08	26,20 ± 2,13	0,179	27,81 ± 2,19	26,88 ± 2,27	0,000	28,40 ± 1,80	27,92 ± 1,76	,026
Data are presented as the mean ± standard deviation. Statistical significance was set at p < 0.05. (LVDCAP) Left Ventricular End-Diastolic Diameter, (LVSCAP) Left Ventricular End-Systolic Diameter, (LVEF) Left Ventricular Ejection Fraction, (IVS) Interventricular Septum, (PW) Posterior Wall, (SOLCAP) Left Atrium Diameter, (EHIZ) E Velocity, (E') E Prime, (DT) Deceleration Time, (LVMI) Left Ventricular Mass Index, (LAVI) Left Atrium Volume Index									

Deceleration time showed a significant decrease in both groups, falling from 275.94 ± 31.42 ms to 236.12 ± 33.27 ms in the HIIT group and from 286.00 ± 27.87 ms to 260.33 ± 28.50 ms in the MICT group (p < 0.001).

A significant increase was observed in left ventricular ejection fraction (LVEF) in the HIIT group, rising from 65.12 ± 1.90 to 68.35 ± 2.80 (p < 0.001). Although there was also a trend toward an increase in the MICT group, from 63.44 ± 2.57 to 64.89 ± 3.03, this change did not reach statistical significance (p = 0.070). In between-group comparisons, the HIIT group demonstrated significantly higher LVEF in the final test than the MICT and control groups (p < 0.001) (Table 5).

Significant increases in the intraventricular septum (IVS) and posterior wall (PW) thicknesses were observed in both the exercise groups. In the HIIT group, IVS increased from 1.04 ± 0.09 cm to 1.15 ± 0.06 cm ($p < 0.001$), and PW increased from 1.01 ± 0.11 cm to 1.10 ± 0.29 cm. In the MICT group, IVS increased from 1.06 ± 0.09 cm to 1.11 ± 0.08 cm ($p < 0.001$), and PW from 1.02 ± 0.06 cm to 1.12 ± 0.07 cm ($p < 0.001$) (Table 5).

Left ventricular diastolic diameter (LVDD) increased in both groups (HIIT: from 4.60 ± 0.28 to 4.80 ± 0.26 cm, 4.3%, $p < 0.001$; MICT: from 4.73 ± 0.32 to 5.05 ± 0.33 cm, 6.8%, $p < 0.001$) (Table 5).

The changes in LAVI varied among the exercise groups. In the HIIT group, there was no significant change ($p = 0.179$), whereas in the MICT group, it decreased from 27.81 ± 2.19 to 26.88 ± 2.27 mL/m² ($p < 0.001$). In the control group, the left atrial volume index (LAVI) changed significantly from 28.40 ± 1.80 to 27.92 ± 1.76 mL/m² ($p = 0.026$).

Significant increases in left ventricular mass index (LVMI) were observed in both groups (HIIT: from 82.76 ± 3.48 to 87.06 ± 4.80 g/m², $p < 0.001$; MICT: from 86.36 ± 6.68 to 88.92 ± 6.18 g/m², $p = 0.015$) (Table 5).

DISCUSSION

In our study, we comprehensively evaluated the effects of 12-week HIIT and MICT swimming exercises on anthropometric measurements, lipid profiles, inflammatory markers, and left ventricular diastolic function in women aged 40–60 years who had been diagnosed with diastolic dysfunction. The findings revealed that both types of exercise significantly improved cardiovascular health parameters; however, the HIIT protocol led to more pronounced adaptations in most parameters. Diastolic dysfunction is characterized by impaired myocardial relaxation and increased ventricular stiffness. An increase in the E/A ratio indicates an improvement in the early filling phase. The more prominent increase observed in the HIIT group may be related to mechanisms such as high-intensity exercise enhancing endothelial function, improving nitric oxide bioavailability, and reducing the arterial stiffness.

The absolute body weight loss observed in the HIIT group (2.43 kg) was approximately 80% higher than that in the MICT group. This finding is consistent with previous studies reporting that HIIT can produce more pronounced effects on body weight and fat loss through higher energy expenditure, increased excess post-exercise oxygen consumption (EPOC), and the triggering of metabolic adaptations. Studies have emphasized that HIIT protocols lead to significant improvements in body composition and cardiometabolic risk factors and can produce comparable levels of fat loss in a shorter time frame compared to moderate-intensity continuous exercises. The 2.7% decrease in body fat percentage observed in the HIIT group indicates a reduction in visceral adiposity and an improvement in the cardiometabolic risk profile. Considering that adipose tissue is a significant source of chronic low-grade inflammation, this change is paralleled by the observed decrease in CRP levels (Table 6) [31, 32, 33].

Table 6
ANOVA and Post-hoc findings of physical parameters between groups

Variables	Pre-test			Post-test		
	F	p	PostHoq	F	p	PostHoq
Age(year)	,225	,799		,225	,799	
Height(cm)	,663	,520		,663	,520	
Weight (kg)	,262	,770		,407	,668	
BMI (kg/m ²)	,902	,412		1,301	,281	
Fat Rate %	,325	,724		,750	,477	
Waist/Hip (cm)	,197	,822		2,471	,095	
The F value indicates the differences between the groups. Statistical significance was set at p < 0.05. (BMI) Body Mass Index						

Significant changes in total cholesterol, LDL, and triglyceride levels were observed in both the HIIT and MICT groups. These results highlight the regulatory effects of regular aerobic exercise on the lipoprotein metabolism. Previous studies have reported that high-intensity interval training can reduce triglyceride and LDL cholesterol levels through increased energy turnover and fatty acid oxidation [34]. Similarly, moderate-intensity continuous exercise has been reported to improve total cholesterol and triglyceride levels by suppressing hepatic lipid synthesis and increasing peripheral lipid utilization. Current approaches demonstrate that both HIIT and MICT protocols provide clinically significant and comparable positive effects on the lipid profile (Table 8) [35, 36, 37].

Table 8
ANOVA and Post-hoc findings of blood parameters between groups

Variables	Pre-test			Post-test		
	F	p	PostHoc	F	p	PostHoc
HGB (g/dL)	,365	,696		,419	,660	
WBC(10 ³ /μL)	2,698	,077		4,427	,017	2 ≥ 1>2
PLT (10 ³ /μL)	1,242	,297		1,021	,368	
NEU(10 ³ /μL)	1,223	,303		,755	,475	
LYM(10 ³ /μL)	,655	,524		1,861	,166	
Creatinine (mg/dL)	,661	,521		1,218	,304	
Urea (mg/dL)	1,572	,218		2,069	,137	
Uric Acid (mg/dL)	1,005	,373		,741	,482	
Glucose (mg/dL)	,397	,674		,493	,614	
HBA1C (%)	,265	,769		2,670	,079	
T.Colesterol(mg/dL)	1,405	,255		4,755	,013	1 ≥ 2>3
TGL(mg/dL)	,125	,883		,428	,654	
LDL(mg/dL)	1,318	,277		2,188	,123	
HDL(mg/dL)	,207	,814		,888	,418	
TSH (μIU/mL)	,609	,548		1,754	,184	
CRP (mg/dL)	,340	,713		1,491	,235	
BNP (pg/mL)	,341	,712		,451	,640	
The F value indicates post-hoc differences between the groups. When a significant effect was detected, pairwise comparisons were performed using the Bonferroni-corrected post-hoc test. The level of statistical significance was accepted as $p < 0.05$. (HGB) Hemoglobin, (WBC) White Blood Cell, (PLT) Platelet, (NEU) Neutrophil, (LYM) Lymphocyte, (HbA1c) Glycated Hemoglobin, (T. Cholesterol) Total Cholesterol, (TGL) Triglyceride, (LDL) Low-Density Lipoprotein, (HDL) High-Density Lipoprotein, (TSH) Thyroid Stimulating Hormone, (CRP) C-Reactive Protein, (BNP) B-Type Natriuretic Peptide						

The lack of significant changes in lipid parameters in the control group shows that the observed improvements were specific to the exercise intervention and not due to spontaneous regression. This finding emphasizes the necessity of structured exercise programs for reducing cardiovascular risk factors in individuals (Table 8).

C-reactive protein (CRP) is an important biomarker widely used in the assessment of cardiovascular risk and reflects chronic inflammation. On examination of the results obtained, although the final measurement values in both the HIIT and MICT groups remained within the high cardiovascular risk range (> 3 mg/L), significant decreases were observed in these values. These decreases suggest that the exercise intervention provided clinically significant improvements in systemic inflammation. The literature indicates that regular aerobic exercise contributes to the reduction of cardiovascular risk by lowering CRP levels, and that high-intensity interval training, in particular, can elicit more prominent anti-inflammatory responses [38, 39]. The lack of change in CRP levels in the control group confirms that the observed anti-inflammatory effects were directly attributable to the exercise intervention (Table 8).

B-type natriuretic peptide (BNP) is an indicator of cardiac wall tension and left ventricular filling pressure. In our study, a statistically significant increase in BNP levels was observed in both the exercise groups. Temporarily increased cardiac wall tension during exercise training may have stimulated BNP secretion. The transient myocardial wall tension developing due to increased left ventricular end-diastolic pressure during physical exercise may stimulate the secretion of B-type natriuretic peptide (BNP); however, as demonstrated in studies, this increase remains below the clinical threshold values (< 100 pg/mL) and does not reflect any cardiac pathology [40] (Table 8).

A significant decrease in glucose levels was observed in the MICT group; however, the change was not significant in the HIIT group. However, no significant changes were observed in HbA1c levels in either group. These findings indicate that the participants were not diabetic at the outset and had normal glycemic control.

A borderline significant increase in creatinine levels was observed in the MICT group. This increase may reflect exercise-induced muscle mass gain or temporary renal hemodynamic changes. All values remained within normal limits, and no impairment of renal function was observed.

A significant increase in hemoglobin levels was observed in both the exercise groups. This increase reflects the stimulatory effect of exercise training on erythropoiesis and improvement in oxygen-carrying capacity. This change, one of the necessary adaptations for increasing aerobic capacity, supports the improvement of cardiorespiratory fitness [41] (Table 8).

Significant reductions in blood pressure were observed in both exercise groups. In between-group comparisons, the HIIT group showed a more pronounced decrease in systolic blood pressure than the CON group. This can be explained by the stronger stimulatory effect of high-intensity exercise on endothelial function and nitric oxide bioavailability [42] (Table 7).

Table 7
ANOVA and Post-hoc findings of intergroup blood pressure parameters

Variables	Pre-test			Post-test		
	F	p	PostHoq	F	p	PostHoq
DKAH(beat/mn.)	,635	,534		4,176	,021	1 ≥ 2>3
SKB (mmHg)	,266	,768		3,744	,031	1 ≥ 2>3
DKB(mmHg)	,681	,511		1,618	,208	
The F value indicates the differences between the groups. When a significant effect was detected, pairwise comparisons were performed using the Bonferroni-corrected post-hoc test. The level of statPost-hocsignificance was set at p < 0.05. (RHR) Resting heart rate; (SBP) Systolic blood pressure; (DBP) Diastolic blood pressure.						

One of the most striking findings of our study was the marked improvement in the E/A ratio, which is an important indicator of left ventricular diastolic function. The E/A ratio increased by 57% in the HIIT group and 35% in the MICT group. While increases in the E/A ratio in both groups indicate significant improvement in diastolic filling patterns, the more pronounced increase observed in the HIIT group suggests that high-intensity exercise may have stronger effects on myocardial relaxation and early diastolic filling mechanisms. Current echocardiography guidelines define normal diastolic function as an E/A ratio between 0.8 and 2.0. In this context, the HIIT group achieving a value of 1.27 not only reflects a return to normal range but also the attainment of an optimal diastolic filling pattern. In light of the data obtained, the significant increase in E velocity in both exercise groups confirmed the improvement in the active relaxation capacity of the left ventricle. The significant decrease in A velocity in both groups indicates that diastolic filling became less dependent on atrial contraction and that the passive filling phase was strengthened [43, 44, 45]. The absence of a significant change in the E/A ratio in the control group (p = 0.140) suggests that diastolic function does not improve spontaneously and highlights the importance of structured exercise programs (Table 9).

Table 9
ANOVA and Post-hoc findings of echocardiographic parameters between groups

Variables	Pre-test			Post-test		
	F	p	PostHoc	F	p	PostHoc
LVDCAP(mm)	1,479	,238		6,222	,004	1 > 3>2
LVSCAP(mm)	3,040	,050	3 ≥ 2>1	1,470	,240	
LVEF (%)	7,285	,002	1 ≥ 2>3	20,371	,000	1 > 2>3
IVS(mm)	1,672	,198		17,770	,000	1 > 2>3
PW(mm)	3,505	,038		6,887	,002	
SOLCAP(mm)	2,028	,142		7,053	,002	1 > 2>3
EHIZ (m/s)	,404	,670		13,907	,000	1 ≥ 2>3
AHIZ(m/s)	,306	,738		7,949	,001	1 > 2>3
E/A	1,880	,163		35,160	,000	1 > 2>3
EUS (cm/s)	1,770	,181		3,615	,034	1 ≥ 2>3
E/EUS	1,204	,308		,187	,830	
DT (ms)	,640	,532		5,439	,007	1 ≥ 2>3
LVMI (g/m ²)	2,335	,107		2,112	,132	
LAVI (g/m ²)	2,852	,050		3,087	,050	1 ≥ 2>3
The F value indicates the difference between groups. When a significant effect was detected, pairwise comparisons were performed using the Bonferpost-hocrected post hoc test. The level of statistical significance was accepted as p < 0.05. (LVDCAP) Left Ventricular End-Diastolic Diameter (LVEDD), Left Ventricular End-Systolic Diameter, (LVEF) Left Ventricular Ejection Fraction, (IVS) Interventricular Septum, (PW) Posterior Wall, (LAD) Left Atrium Diameter, (E-wave) E Velocity, (A-wave) A Velocity, (E') E Prime, (DT) Deceleration Time, (LVMI) Left Ventricular Mass Index, (LAVI) Left Atrium Volume Index						

Deceleration time (DT) is an important echocardiographic parameter used to assess left ventricular diastolic compliance, and values between 160 and 240 ms are considered normal. In our study, baseline DT values were pathologically prolonged in both groups. After the exercise intervention, statistically significant reductions in DT values were observed in both groups. The 14.4% decrease in the HIIT group suggests that the ventricular diastolic function was approaching the normal physiological limits. In the MICT group, although a 9% reduction was observed, this value remained near the upper normal limit. These findings suggest that high-intensity interval training, in particular, may have more pronounced beneficial effects on left ventricular relaxation characteristics and diastolic compliance (Table 9) [46, 43, 47].

The shortening observed in the DT indicates improved ventricular relaxation time and increased myocardial compliance. In a comprehensive review by Dalen et al. (2024), including elite endurance athletes, it was emphasized that long-term endurance training increases left ventricular diastolic filling, particularly strengthening the early diastolic filling phase. The findings of our study suggest that these diastolic adaptations, which are mainly described in elite athletes in the literature, can also occur in middle-aged women through regular exercise, supporting the generalizability of these physiological responses to broader populations [48].

Our findings revealed that the HIIT protocol provided a more pronounced improvement in left ventricular ejection fraction (LVEF) than MICT. This is in line with studies suggesting that HIIT is more effective than MICT in increasing cardiac

contractility and stroke volume [49]. This significant increase in LVEF can be attributed to the strong stimulatory effect of high-intensity exercise on the systolic function (Table 9).

On the other hand, increases in interventricular septal (IVS) and posterior wall (PW) thickness observed in both exercise groups are typical indicators of the physiological cardiac adaptation known as "athlete's heart." Unlike pathological hypertrophy, these morphological changes are not associated with a loss of myocardial function but rather with increased performance capacity [50]. This concentric adaptation, which develops in response to exercise load, is a process of structural remodeling that the heart undertakes to meet increased hemodynamic demands (Table 9).

The significant increases in left ventricular diastolic diameter (LVDD) in both groups indicate that eccentric remodeling occurred due to the chronic volume load developed during the training process. This finding is consistent with studies in the literature reporting that endurance training creates volumetric enlargement of the ventricular chambers [51]. The simultaneous observation of both concentric (wall thickening) and eccentric (diameter increase) components may be interpreted as evidence that the exercise protocols included in the study initiated a balanced cardiac adaptation process in the myocardium (Table 9).

The significant increase in the left ventricular mass index (LVMI) in both groups reflected functional improvement rather than pathological hypertrophy. Indeed, improvement in diastolic function, decreased wall stress, and increased ejection fraction (LVEF) accompanying the increase in LVMI prove that this process is a typical manifestation of "physiological cardiac hypertrophy" [52]. Unlike pathological hypertrophy, exercise-induced structural changes maximize cardiovascular efficiency by increasing the contractile reserve of the myocardium (Table 9).

LAVI changes differed among the exercise groups: no change was detected in the HIIT group ($p = 0.179$), whereas a decrease was observed in the MICT group (from 27.81 ± 2.19 to 26.88 ± 2.27 mL/m², $p < 0.001$). Left atrial volume reflects the chronic effects of left ventricular filling pressure and is an important indicator of diastolic dysfunction. The decrease in the MICT group may indicate an improvement in the left ventricular filling pressure. The decrease in LAVI in the control group was an unexpected finding and was likely a reflection of measurement variation (Table 9).

In post-exercise between-group comparisons, the HIIT group was found to be significantly different from the control group in terms of resting heart rate (RHR), systolic blood pressure, total cholesterol, leukocyte count, LVDD, LVEF, IVS, left diameter, E velocity, A velocity, E/A ratio, E', deceleration time, and LAVI parameters. The MICT group also differed from the control group in many parameters, although the HIIT group generally achieved better results than either group (Table 9).

The difference between the groups was particularly pronounced in the E/A ratio (HIIT: 1.27 ± 0.22 , MICT: 1.01 ± 0.16 , Control: 0.79 ± 0.10 , $p < 0.001$). This finding indicates that both exercise modalities are effective, but HIIT provides superior results in the restoration of diastolic function (Table 9).

Clinical Implications and Practical Applications

Our findings indicate that both HIIT and MICT swimming exercises are effective strategies for improving cardiovascular health and preventing or treating diastolic dysfunction in women aged 40–60 years. However, HIIT may be an advantageous option for individuals with time constraints because it provides more pronounced cardiac adaptations in a shorter period. Our results show that significant improvements in diastolic dysfunction can be achieved through regular exercise. The fact that the E/A ratio in both groups increased from pathological levels (< 0.8) to within normal limits (> 1.0) demonstrates that structured exercise programmes can correct early stage diastolic dysfunction.

Improvements in lipid profiles are also clinically significant. The 10.01 mg/dL reduction in LDL cholesterol in the HIIT group may be associated with an approximately 5% reduction in cardiovascular event risk. Studies have emphasized that

each 38.7 mg/dL decrease in LDL results in a 22% reduction in major cardiovascular events [53]. In this context, the LDL reduction we observed is clinically notable and is expected to contribute to a decreased cardiovascular risk.

The decrease in CRP levels was another important finding. Reduced systemic inflammation can provide protective effects not only against cardiovascular risk but also against metabolic syndrome, type 2 diabetes, and other chronic diseases. The 29.1% decrease in CRP levels in the HIIT group demonstrates the strong anti-inflammatory effects of high-intensity exercise.

Limitations

This study had some limitations. First, the study duration was limited to 12 weeks, and it did not provide information about long-term adaptations and sustainability. In future studies, follow-up periods of six months or longer should be planned, and it is recommended to evaluate the detraining effects after discontinuation of the exercise program.

In our study, only echocardiography was used, and more advanced imaging techniques that provide higher reproducibility and tissue characterization were not employed. Echocardiography is operator-dependent, and measurement variability may occur.

Although electrocardiographic measurements were initially planned as part of the study protocol, reliable ECG data could not be obtained due to a technical malfunction of the ECG device during the data collection period. Therefore, ECG parameters were not included in the final analysis.

The study sample comprised only women; therefore, the findings cannot be generalized to men. Sex differences may affect cardiac adaptations, and future studies are recommended to compare both sexes.

CONCLUSION

Our study investigated the effects of twelve-week HIIT and MICT swimming exercise interventions in women aged 40–60 years diagnosed with diastolic dysfunction. According to the results obtained, both types of exercise significantly improved anthropometric parameters, lipid profiles, inflammatory markers, and left ventricular diastolic function. HIIT produced more pronounced changes than MICT in the E/A ratio, deceleration time, LVEF, lipid parameters and CRP levels. These findings support the notion that HIIT swimming elicits a stronger physiological stimulus for cardiometabolic adaptations.

Both exercise modalities are effective and safe strategies for improving cardiovascular health. Exercise prescriptions should be individualized, considering personal fitness level, cardiovascular risk profile, and long-term sustainability. Swimming is an ideal exercise modality for this population because it minimizes joint load and can be applied safely.

The results of our study indicate that early-stage diastolic dysfunction in individuals can be reversed by exercise training. These findings emphasize the importance of structured exercise programs in the prevention and treatment of cardiovascular diseases and provide evidence-based exercise recommendations for clinicians. Regular swimming exercise is recommended as a valuable tool for reducing the risk of developing heart failure with a preserved ejection fraction and optimizing cardiovascular health.

Abbreviations

(LVDCAP) Left Ventricular End-Diastolic Diameter

(LVSCAP) Left Ventricular End-Systolic Diameter

(SOLCAP) Left Atrium Diameter

(EHIZ) E Velocity

(AHIZ) A Velocity

(DT) Deceleration Time

(LVMI) Left Ventricular Mass Index

(LAVI) Left Atrium Volume Index

(DD) Diastolic Dysfunction

(LV) Left Ventricle

(RV) Right Ventricle

(IVS) Interventricular Septum

(PW) Posterior Wall

(LA) Left Atrium

(LVDD) Left Ventricular Diastolic Dysfunction

(LVEF) Left Ventricular Ejection Fraction

(HFpEF) Heart Failure with Preserved Ejection Fraction

(EF) Ejection Fraction

(IVRT) Isovolumic Relaxation Time

(TDI) Tissue Doppler Imaging

(DKAH) Resting Heart Rate

(SKB) Systolic Blood Pressure

(DKB) Diastolic Blood Pressure

(HGB) Hemoglobin

WBC (White Blood Cell)

(PLT) Platelet

(NEU) Neutrophil

(LYM) Lymphocyte

(HbA1c) Glycated Hemoglobin

(T. Cholesterol) Total Cholesterol

(TGL) Triglyceride

(LDL) Low-Density Lipoprotein

(HDL) High-Density Lipoprotein

(TSH) Thyroid Stimulating Hormone

(CRP) C-Reactive Protein

(BNP) B-Type Natriuretic Peptide

(CTID) Clinical Trials ID

Declarations

Ethical Approval and Consent Forms

The study design and methodology were reviewed and approved by the Uşak University Non-Interventional Clinical Research Ethics Committee (Decision No: 21, Date: 07/11/2024). The study protocol was registered and certified through the International Clinical Research Database ClinicalTrials.gov (CTID: NCT06945913 Date: 10/03/2025). All participants were thoroughly informed about the scope of the research, and written consent was obtained through the "Informed Volunteer Consent Form." The study was conducted in accordance with the ethical standards concerning human experiments and the revised 2013 version of the 1975 Declaration of Helsinki.

Consent for Publication

Not applicable.

Protocol and Statistical Analysis Plan

The study protocol and statistical analysis plan are not publicly available; however, all relevant methodological details are provided in this article.

Authors Contributions

Conceptualization: Merve BOZ CİNCİ, Esin GÜLLÜ

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Competing Interests

The authors declare no conflict of interest.

Acknowledgments

This study was based on the first author's doctoral dissertation. We thank all the participants and staff involved in this study.

Funding

All resources used in this study were provided by the authors.

Data Availability

The datasets used and analyzed in this study are available from the corresponding author upon reasonable request.

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Figures

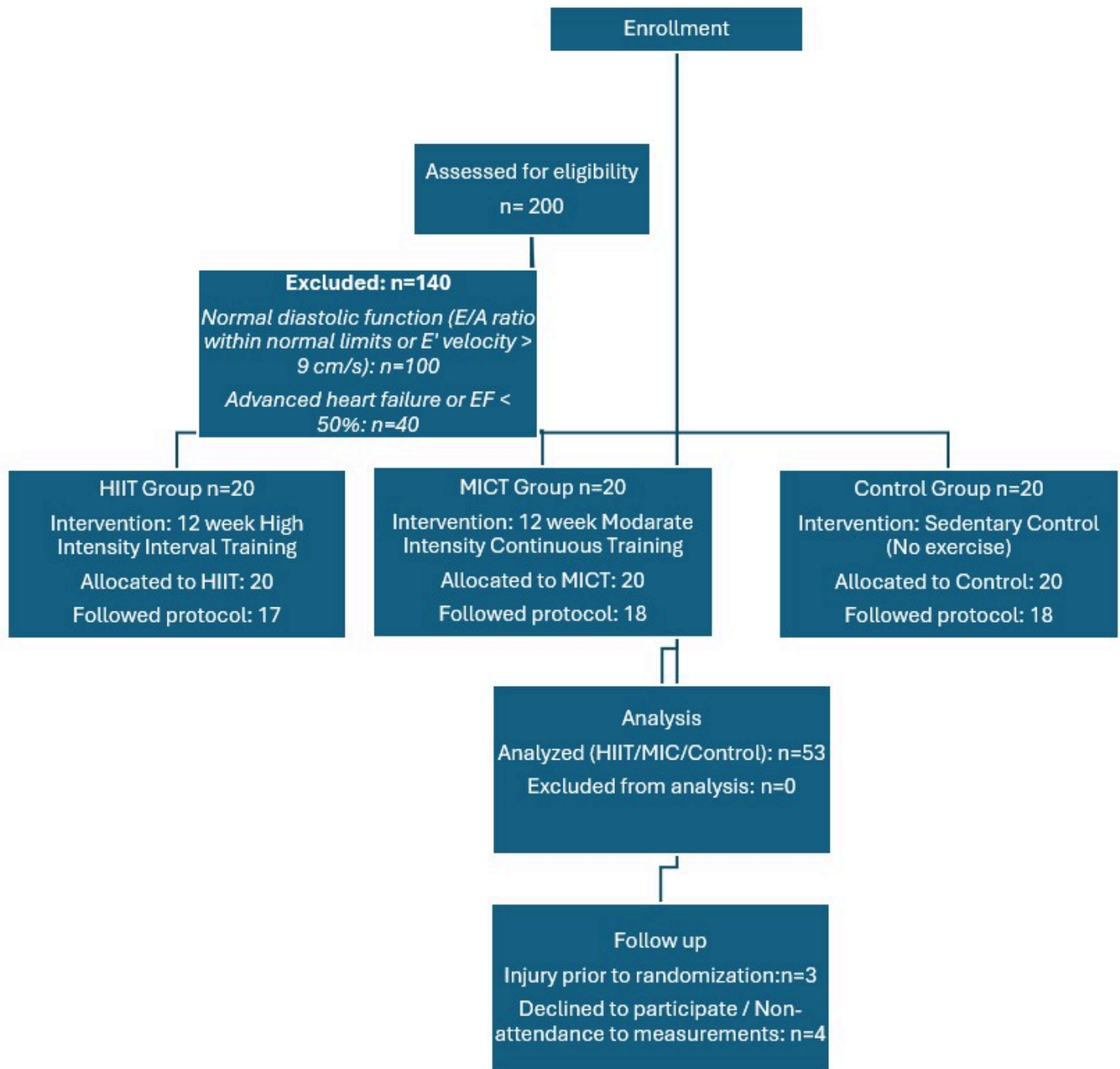


Figure 1

CONSORT 2010 Flow Diagram