Kim et al. BMC Sports Science, Medicine and Rehabilitation (2025) 17:93
https://doi.org/10.1186/s13102-025-01156-9

BMC Sports Science, Medicine and Rehabilitation

RESEARCH

Open Access

Effect of treadmill walking on cardiometabolic risk factors and liver function markers in older adults with MASLD: a randomized controlled trial

Jiyoun Kim[1], Sungju Lee[2] and Yong-Seok Jee[2,3*]

Abstract

Background Regular walking has been reported to improve metabolically-associated steatotic liver disease (MASLD) by altering the metabolic environment. However, no studies to date have focused on older individuals in both conditions. Therefore, this study aimed to investigate the effects of a 12-week walking intervention on metabolic syndrome risk factors, liver function indicators, and liver ultrasound findings in older adults with both metabolic syndrome and MASLD.

Methods A total of 66 participants aged 65–85 years had average ages, heights, and weights of 75.3 ± 5.8 years, 159.3 ± 9.3 cm, and 68.6 ± 6.8 kg, respectively. The participants resided in four senior living communities, and their diets were uniform. The participants from two facilities were assigned to the control group (CON, *n* = 33), whereas those from the other two facilities were allocated to the treadmill walking program group (WPG, *n* = 33). Each group comprised 13 males and 20 females. The intervention consisted of a low- to moderate-intensity walking program, conducted for 30 min per day, 6 days per week, totaling 180 min per week. The total daily calorie expenditure was recorded based on the values calculated from the treadmill. The walking intensity was adjusted by modifying the treadmill incline according to each participant's heart rate corresponding to their maximal oxygen consumption (VO_2max). The exercise intensity was set at 50% on Mondays and Fridays, 60% on Tuesdays and Thursdays, and 70% on Wednesdays and Saturdays. Sundays were designated as rest days.

Results Although there were no significant differences in caloric intake between the groups, the WPG exhibited a 52.5% increase in physical activity levels ($p < 0.001$), resulting in significant reductions in body weight (-10.2%), fat mass (-17.2%), and abdominal fat (-4.8%). The WPG showed a 16.1% increase in VO_2max, along with significant reductions in systolic blood pressure (-9.6%) and blood glucose (-16.9%), as well as notable improvements in lipid profiles ($p < 0.001$). The WPG also demonstrated significant reductions in aspartate aminotransferase (-40%), alanine aminotransferase (-23.5%), total protein (-14.4%), albumin (-8.1%), bilirubin (-17.6%), and liver ultrasound scores (-31.8%), with all changes showing significant intergroup differences ($p < 0.001$).

*Correspondence:
Yong-Seok Jee
jeeys@hanseo.ac.kr

Full list of author information is available at the end of the article

Conclusions Along with a consistent diet, a 12-week walk has been shown to induce significant changes in the body composition and cardiometabolic factors of older adults, as well as notable improvements in liver function markers and imaging findings.

Trial registration This study was registered with the Clinical Research Information Service of the Korea Centers for Disease Control and Prevention under Clinical Trials KCT0010079 on 26/12/2024.

Keywords Older adults, Walking, Metabolically-Associated steatotic liver disease (MASLD), Cardiometabolic factors

Background

Metabolic syndrome is not a single disease but rather a condition resulting from the complex interaction of genetic predisposition and environmental factors [1]. Irregular lifestyle habits, excessive eating, and predominantly sedentary behavior can lead to abdominal obesity, which increases the risk of developing cardiometabolic diseases such as hypertension, diabetes, and hyperlipidemia [2]. While metabolic syndrome often presents no symptoms in its early stages, its progression is associated with kidney disease, cardiovascular and cerebrovascular diseases, various cancers, and increased mortality rates [3, 4]. In addition, metabolic syndrome has been reported to be closely associated with nonalcoholic fatty liver disease (NAFLD), indicating that approximately 90% of patients present at least two features of metabolic syndrome and that approximately 33% meet three or more criteria. It develops due to the accumulation of triglycerides in the liver, caused by an imbalance in the uptake, synthesis, export, and oxidation of fatty acids [5]. NAFLD is characterized by abnormal lipid accumulation in the liver in the absence of other liver diseases and is known to be a major cause of chronic conditions such as type 2 diabetes and cardiovascular diseases such as metabolic syndrome, as well as liver-related disorders such as hepatitis, liver cirrhosis, and hepatocellular carcinoma [6]. The global prevalence of metabolic dysfunction-associated steatotic liver disease (MASLD) [7], resulting from the coexistence of metabolic syndrome and/or NAFLD, continues to show an increasing trend [8].

Metabolic syndrome has been shown to be particularly detrimental to older adults with chronic diseases, as it is directly associated with MASLD, a decline in various visceral organs, and a reduction in overall lifespan [9–11]. In light of the rapidly growing older population, these findings are not merely individual concerns but are also intrinsically linked to the economic and policy challenges faced by nations worldwide. Consequently, the prevention and treatment of metabolic syndrome, including NAFLD, are critical, making early intervention a priority in public health strategies. According to the National Cholesterol Education Program (NCEP) Adult Treatment Panel (ATP) III criteria [12, 13], when the prevalence of metabolic syndrome is assessed in older adults, considering the types and levels of conditions applied to adults, obese older individuals with a high body mass index have a metabolic syndrome prevalence of 32.1%, indicating a serious health problem. In particular, obese older individuals are found to have not only reduced liver function but also decreased aerobic capacity compared with older individuals without metabolic syndrome, highlighting the importance of physical activity (PA) [14]. In the prevention and management of MASLD, regular PA is one of the most important factors, along with dietary control [15]. It has been reported that it helps reduce and maintain body fat mass in the long term and effectively reduces the risk of cardiometabolic diseases [16].

Walking, a widely accessible form of PA, has been extensively documented to offer diverse health benefits [17]. These include reductions in body weight and blood pressure, improvements in lipid profiles and MASLD, and a decreased risk of developing heart disease [18, 19]. Additionally, it has been reported to increase insulin sensitivity in the liver, skeletal muscle, and adipose tissue, improving the insulin response to blood glucose levels and thus increasing the body's ability to utilize blood glucose [20, 21]. Proper walking is defined as a movement characterized by a relaxed posture, maintaining a forward gaze, and swinging the arms naturally without applying excessive force [22]. This activity can be performed at varying speeds, ranging from slow to fast, depending on situational requirements. The pace and distance of walking significantly influence the metabolic rate, thereby contributing to caloric expenditure and to intestinal fatness. These physiological effects make walking an effective strategy for body weight management and offer a range of health benefits [21]. However, while the health benefits of walking program are widely recognized, its specific effects on older adults with MASLD remain underexplored. Notably, among the older population, impaired liver functions such as MASLD are commonly observed, yet there is a significant lack of research investigating whether walking program can positively impact compromised liver function. Therefore, this study was initiated to examine the effects of a regular walking program on the markers of metabolic syndrome, as well as the liver function indicators in older adults with risk factors for MASLD.

Materials and methods

Study design

The study was designed as a prospective, double-blind, randomized controlled trial, targeting residents of senior living communities who had been diagnosed with MASLD. The study period was twelve weeks, and changes in metabolic syndrome variables and liver function markers and images were examined before and after the walking program. This study was approved by the Hanseo University Institutional Review Board (HS23-06-01) and registered on ClinicalTrials.gov with the identifier KCT0010079 on 26/12/2024. The study followed CONSORT guidelines, with a completed checklist included in the supplementary information (Supplementary Table 1).

Participants

Older adults living in four Seoul Seniors Towers in Korea were recruited for this study. The participants ranged in age from 65 to 85 years and provided written informed consent in accordance with the Declaration of Helsinki (2013). They were selected on the basis of individuals who had not regularly participated in an exercise program for more than six months and were diagnosed with MASLD. The criteria for diagnosing metabolic syndrome followed three or more of the five risk factors specified in the NCEP ATP III for adult metabolic syndrome [12]. Upper abdominal ultrasound imaging was performed, and the patients were diagnosed by a radiologist. Based on the modified NCEP criteria, a diagnosis of metabolic syndrome is made when any three of the following five conditions are present: abdominal obesity; high triglyceride levels (≥ 1.7 mmol/L); low levels of high density lipoprotein (HDL) cholesterol (≤ 1.03 mmol/L for men and ≤ 1.29 mmol/L for women); elevated blood pressure (systolic ≥ 130 mmHg and/or diastolic ≥ 85 mmHg, or current use of antihypertensive medication); and elevated fasting glucose (fasting plasma glucose ≥ 5.6 mmol/L). The modified NCEP ATP III guidelines also recommend that waist circumference thresholds be tailored to specific ethnic groups, with a cut-off of 90 cm for men and 80 cm for women of Asian descent. Metabolic syndrome is diagnosed when three or more of these criteria are met [23, 24]. In addition, NAFLD was diagnosed using abdominal ultrasound examination. The diagnosis was based on typical sonographic findings such as increased hepatic echogenicity compared to the renal cortex, blurring of the portal vein walls, and posterior beam attenuation. The severity of fatty liver was classified as follows: mild (slight increase in liver echogenicity with clear visualization of diaphragm and intrahepatic vessels), moderate (moderate increase in echogenicity with slightly impaired visualization of intrahepatic vessels and diaphragm), and severe (marked increase in echogenicity with poor or no visualization of intrahepatic vessels, diaphragm, and posterior segment of the liver) [25, 26]. Those who had received weight loss treatments, took medication affecting body composition, or had undergone surgery for more than one year before the study began were excluded from the study. Individuals with a history of cardiovascular or cerebrovascular disease, cancer, or psychiatric disorders were also excluded from the study.

The sample size was determined via G*Power (ver.3.1.9.7; Heinrich-Heine-Universität, Düsseldorf, Germany), with assumptions including an effect size of $f^2(V) = 0.25$, an α error probability of 0.05, a power of 0.95, two groups, and two measurements [27, 28]. The minimum required sample size was 54 participants. As shown in Fig. 1, a total of 107 participants were recruited from four separate facilities to prevent communication between the groups; however, 31 were excluded because they failed to meet the inclusion criteria or for personal reasons. Among the remaining 76 participants who completed the demographic survey and baseline assessment, random tags selected by 4 representatives were used to assign one facility to the control group (CON) and another facility to the walking program group (WPG). The principal investigator carried out all of these procedures. A total of 38 participants were allocated to the CON across two facilities, whereas 38 participants were assigned to the WPG across two facilities. During the 12-week program, five participants from each group dropped out, leaving 33 participants in each group for the final analysis. During the walking exercises performed by the WPG, participants in the CON convened at the exercise centers within their respective facilities to engage in meditation sessions. Standard guidelines were provided for pre- and postassessments to maintain strict blinding throughout the study.

Walking program

The intervention comprised a walking program designed to achieve 180 min of mild- to moderate-intensity aerobic exercise per week, distributed as 30-minute sessions conducted six days a week [29, 30]. Prior to the commencement of the walking program, participants in the WPG performed floor-based stretching exercises for 10 min while seated. After completing the walking session, they engaged in floor-based stretching exercises for 10 min in the supine position. The walking program was conducted on a treadmill, and the exercise intensity was adjusted by modifying the treadmill incline according to each participant's maximal oxygen consumption (VO_2max) determined through the modified Bruce protocol. The participants were encouraged to reach the target intensity, which was determined via the rate of perceived exertion (RPE) scale and heart rate (HR). This study employed the RPE 10-point scale for this purpose [31]. Exercise

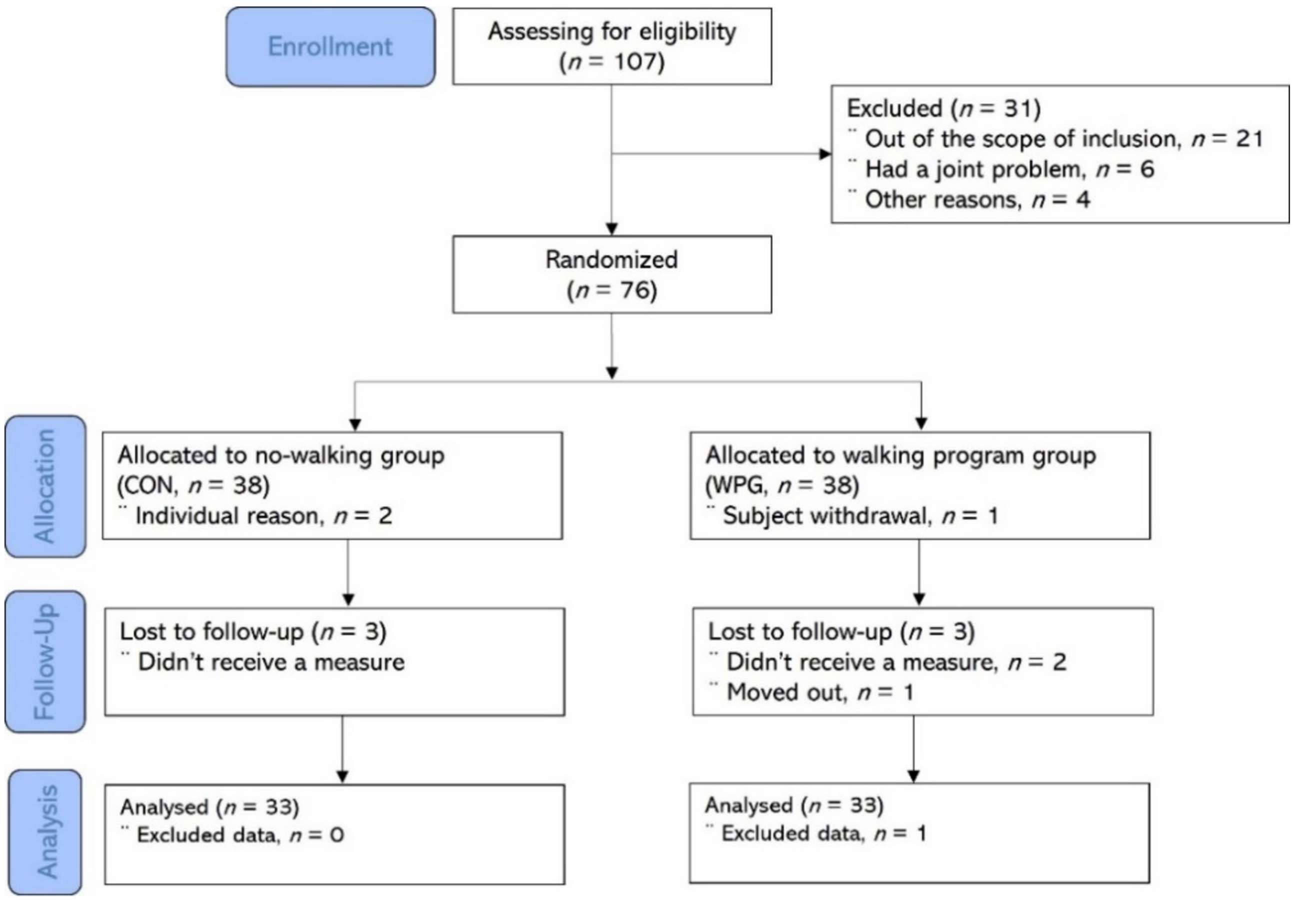

Fig. 1 CONSORT diagram

intensity was prescribed based on target heart rates corresponding to specific percentages of each participant's VO_2max. On Monday, Tuesday, and Wednesday, intensities were set at 50%, 60%, and 70% of VO_2max, respectively. The treadmill incline was subsequently readjusted to match the same target intensities on Thursday (50%), Friday (60%), and Saturday (70%) [32–34]. Sunday was designated as a rest day.

Outcome measures

Caloric intake and physical activity volume

Throughout the three-month experimental period, participants in both groups consumed three meals per day, which were prepared under the supervision of a certified nutritionist. The daily caloric intake was set at 1,500–1,800 kcal, and the dietary regimen was designed to be predominantly plant-based. The dietary plan included macronutrients—carbohydrates, proteins, and fats—along with micronutrients such as vitamin A and vitamin C. To ensure accuracy and compliance, a researcher recorded participants' daily dietary intake via CAN-Pro 5.0 (http://canpro5.kns.or.kr; The Korean Nutrition Soc iety). Moreover, PA levels were estimated via the International PA Questionnaire (IPAQ)-Short Form [35, 36]. Both caloric intake and PA levels were recorded daily from the start to the end of the experiment and analysed on a weekly and monthly basis.

Anthropometric and clinical data

Demographic characteristics and body composition parameters were assessed via an InBody 720 device (Biospace, Seoul, Korea), with the waist-to-hip ratio (WHR) manually remeasured by a single expert; waist circumference was measured at the midpoint between the iliac crest and the lower rib, whereas hip circumference was measured at the widest point above the hips and below the iliac crest. Body mass index (BMI) was calculated via the formula weight (kg)/height (m^2). All participants were instructed to wake at 7 a.m. and gather at the meeting location, where their blood pressure and fasting blood glucose (FBG) levels were measured by an Accu-Chek Guide Glucometer (Roche Diabetes Care, Basel, Switzerland). Their physical condition for the day was also assessed through a brief questionnaire.

Blood sampling and variable measures

A clinical pathologist conducted blood sampling, and the collected samples were analysed. Blood was drawn from all participants both before and after the experiment, following a minimum fasting period of 10 h [37]. They arrived at the laboratory an hour before blood collection and were allowed to rest for at least 30 min. For routine blood tests (e.g., CBC, liver function, kidney function, lipid profile), approximately 5 to 20 mL of blood is typically drawn from a vein in the arm. However, for more comprehensive or specialized testing, more than 20 mL may be required [38]. Blood lipid and liver function markers were analysed via an enzymatic colorimetric method with an automated biochemical analyser (Cobas 8000, Roche Diagnostics, Mannheim, Germany). Total cholesterol (TC), triglycerides (TG), high-density lipoprotein (HDL) cholesterol, and low-density lipoprotein (LDL) cholesterol were quantified through enzymatic reactions that produce chromogenic compounds via a spectrophotometer. Aspartate aminotransferase (AST), alanine aminotransferase (ALT), bilirubin, and total protein were analysed via standardized enzymatic and colorimetric methods.

Abdominal ultrasound measures

An abdominal ultrasound examination was conducted to assess the structure and shape of the liver. The equipment used was a Panavista Model GM-2600 A (Matsushita Ltd., Japan) with a 3.5 MHz convex probe. The degree of fat deposition in the liver was classified on the basis of differences in echo reflections, as shown in Fig. 2, following the grading system.

On the basis of previous studies [25, 26], the classification criteria for this study were as follows: Grade 1 was defined as a slight increase in fine hepatic echoes with normal visualization of the diaphragm and vascular borders. Grade 2 was defined as a moderate increase in fine hepatic echoes, accompanied by blurred visualization of the diaphragm and blood vessels, as well as reduced clarity of the posterior portion of the right hepatic lobe. Grade 3 was defined as a marked increase in fine hepatic echoes, rendering the diaphragm and vascular structures indistinguishable and the posterior portion of the right hepatic lobe poorly visible [39, 40].

Cardiopulmonary fitness measures

VO_2max was measured by a gas analyser (Qurak CPET®, Cosmed, Rome, Italy), electrocardiogram analyser (Heartwave II®, Cambridge Heart Inc., Tewksbury, MA, USA), and treadmill ergometer (T150, HP/Cosmos®, Bavaria, Germany). All the participants were instructed to refrain from eating three hours prior and avoid intense PA. Electrodes for the ECG were attached to the chest, and a cuff for blood pressure and HR measurements was placed on the brachial artery of the right arm. A mask was adjusted to fit each participant's face to prevent air from escaping while breathing through the mouth and nose. The modified Bruce protocol was used to assess the work capacity of older adults [41, 42]. All the participants were encouraged to walk or run until they reached their maximum perceived level of exertion. The participants were monitored for chest pain, shortness of breath, dizziness, and leg pain during and after walking or running on the treadmill. The test was terminated if any of the following symptoms occurred: (a) a drop in systolic blood pressure (SBP) of 10 mmHg from baseline despite increased workload, accompanied by ischemia; (b) moderate to severe angina; (c) increasing neurological symptoms; (d) signs of cyanosis; (e) a request to stop; (f) sustained ventricular tachycardia; or (g) ST elevation (> 1 mm) in leads without Q waves [41]. This study analysed VO_2max, HR, resting SBP, resting diastolic blood pressure (DBP), and rate pressure product (RPP).

Statistical analysis

All the data are reported as the means ± standard deviations and were analysed via GraphPad Prism 10.4.1 (La Jolla, CA, USA). The Kolmogorov–Smirnov test was employed to check the normality of the demographic and anthropometric data. For normally distributed data, repeated-measures ANOVA was applied for variable comparisons. For nonnormally distributed data, the Mann−Whitney U test was used to analyse differences between groups. Intragroup changes were evaluated via the Wilcoxon signed-rank test. A detailed analysis involved calculating the Δ% for each period. Effect sizes (η^2) were interpreted as small, moderate, or large on the basis of thresholds of 0.2, 0.5, and 0.8 for parametric measures and 0.1, 0.3, and 0.5 for nonparametric

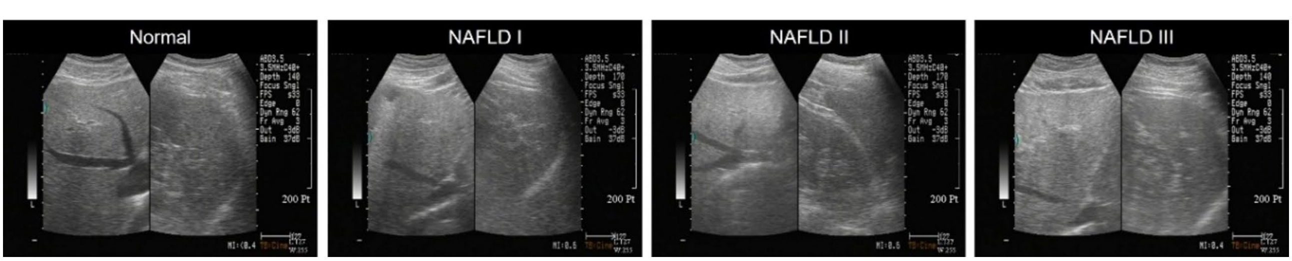

Fig. 2 Ultrasound imaging for diagnosing MASLD

measures, respectively [43]. Statistical significance was set at $p \leq 0.05$.

Results

Demographic characteristics

As detailed in Table 1, a total of 66 individuals participated in the study. The CON consisted of 13 males and 20 females, whereas the WPG was composed of an equal number. There were no significant differences in demographic or anthropometric variables between the two groups prior to the experiment. Among all the older adults, chronic conditions were observed, with no significant differences between the groups.

Changes in caloric intake, PA levels, and body composition

As shown in Table 2, there were no significant differences in daily caloric intake, including nutrient factors, between the groups. Prior to the experiment, no significant differences in PA levels were observed between the two groups. However, following the experiment, PA levels decreased in the CON group but increased in the WPG group, indicating significant differences in between-group, within-group, and interaction effects. Subfactors also showed significant interaction effects after the experiment.

The differences in caloric intake, PA levels, and body composition between the two groups, expressed as the Δ% between pre- and postintervention values, are illustrated in Fig. 3. There were no significant differences in the daily caloric nutrient components between the CON and WPG before and after the experiment (Fig. 3A). Regarding PA levels, participants in the WPG engaged solely in the treadmill exercise prescribed by the study. Prior to the intervention, there were no significant differences between the two groups. However, following the intervention, the CON group showed a 16.3% decrease in PA levels, while the WPG exhibited a 52.5% increase, resulting in a significant difference between the groups (Fig. 3B). The body weight increased by 4.2% in the CON group but decreased by 10.2% in the WPG, resulting in a significant difference between the groups (Fig. 3C). Lean body mass decreased by 6.4% in the CON but increased by 4.5% in the WPG (Fig. 3D). Fat mass increased by 14.6% (Fig. 3E), fat percentage by 10.2%, WHR by 2.9% (Fig. 3F), and BMI by 4.2% in the CON. In contrast, fat mass decreased by 17.2% (Fig. 3E), fat percentage by 6.5%, WHR by 4.8% (Fig. 3F), and BMI by 10.2% in the WPG.

Changes in cardiometabolic factors and liver function markers

As presented in Table 3, no significant differences in cardiometabolic factors were observed between the CON and WPG groups prior to the experiment. After the experiment, the VO_2max and HDL levels decreased in the CON group but increased in the WPG group, indicating significant interaction effects. Additionally, HR, SBP, DBP, RPP, FBG, TG, TC, and LDL levels increased in the CON group, whereas they decreased in the WPG group, which also demonstrated significant interaction effects. As also presented in Table 3, no significant differences in liver function markers were observed between the groups before the experiment. However, after the experiment, AST, ALT, total protein, albumin, bilirubin,

Table 1 Demographic and anthropometric characteristics at baseline

Items	Groups		Z	*p*	η^2
	CON, $n=33$	WPG, $n=33$			
Demographic feature					
Age (yr)	75.5 ± 5.3	75.2 ± 6.3	-0.039	0.969	0.00
Sex †	1.6 ± 0.5	1.6 ± 0.5	0.000	1.000	0.00
Body composition feature					
Stature (cm)	159.9 ± 8.3	158.7 ± 10.3	-0.847	0.397	0.01
Body weight (kg)	68.0 ± 6.9	69.2 ± 6.7	-0.770	0.442	0.01
Lean mass (kg)	39.3 ± 4.8	38.5 ± 6.3	-0.616	0.538	0.01
Fat mass (kg)	19.5 ± 4.1	22.2 ± 6.0	-1.610	0.107	0.07
Fat percentage (%)	29.0 ± 6.8	32.3 ± 9.5	-1.122	0.262	0.04
BMI (kg/m^2)	26.6 ± 2.6	27.6 ± 2.6	-1.694	0.090	0.03
Waist circumference (cm)	100.9 ± 5.0	101.3 ± 6.3	-0.507	0.612	0.01
Cardiometabolic feature					
SBP (mmHg)	140.4 ± 8.1	141.9 ± 8.3	-0.847	0.397	0.01
DBP (mmHg)	87.6 ± 4.8	86.3 ± 3.4	-0.947	0.344	0.03
TG (mmol/L)	2.5 ± 0.8	2.4 ± 0.6	-0.399	0.690	0.01
HDL (mmol/L)	1.1 ± 0.1	1.0 ± 0.2	-0.706	0.480	0.01
FBG (mmol/L)	7.3 ± 1.0	7.4 ± 0.7	-0.705	0.481	0.04

The symbol † represents sex, with '1' and '2' indicating male and female. CON, control group; WPG, walking program group; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglyceride; HDL, high density lipoprotein cholesterol; FBG, fasting blood glucose

Table 2 Comparative results of calorie intake, PA levels, and body composition

Items	Time	Groups		*p*		
		CON	WPG	G	T	G×T
Calorie intake (kcal)						
Daily calorie (kcal/day)	Pre	1609.0 ± 172.2	1610.6 ± 185.2	0.507	0.002	0.647
	Post	1717.4 ± 229.9	1754.4 ± 191.5			
Carbohydrates (g/day)	Pre	118.4 ± 14.4	119.5 ± 14.4	0.455	0.639	0.700
	Post	118.6 ± 13.3	121.3 ± 11.5			
Fibre (g/day)	Pre	19.6 ± 3.7	19.3 ± 3.8	0.599	0.089	0.482
	Post	20.4 ± 3.5	21.2 ± 3.5			
Protein (g/day)	Pre	50.8 ± 6.1	51.7 ± 6.5	0.829	0.742	0.338
	Post	51.6 ± 6.4	50.2 ± 6.3			
Fat (g/day)	Pre	50.6 ± 7.7	49.5 ± 7.5	0.729	0.374	0.334
	Post	50.5 ± 8.3	52.4 ± 7.9			
Vitamin A (ug RAE/day)	Pre	543.9 ± 62.9	546.0 ± 61.0	0.848	0.661	0.697
	Post	552.6 ± 57.6	546.5 ± 58.6			
Vitamin C (mg/day)	Pre	95.4 ± 13.4	94.3 ± 13.0	0.820	0.376	0.814
	Post	97.3 ± 15.2	97.7 ± 14.0			
Calcium (mg/day)	Pre	716.8 ± 99.5	698.0 ± 88.9	0.249	0.057	0.821
	Post	681.5 ± 131.9	653.4 ± 140.5			
Iron (mg/day)	Pre	12.2 ± 3.2	12.8 ± 3.6	0.554	0.937	0.617
	Post	12.5 ± 3.2	12.5 ± 3.3			
Physical activity levels (MET·min/week)						
	Pre	1567.0 ± 329.2	1565.7 ± 371.4	0.001	0.001	0.001
	Post	1276.6 ± 223.0	2239.7 ± 400.5			
Body composition						
Body weight (kg)	Pre	68.0 ± 6.9	69.2 ± 6.7	0.030	0.001	0.001
	Post	70.7 ± 6.7	62.1 ± 8.3			
Lean mass (kg)	Pre	39.3 ± 4.8	38.5 ± 6.3	0.340	0.391	0.001
	Post	36.7 ± 4.6	40.2 ± 8.2			
Fat mass (kg)	Pre	19.5 ± 4.1	22.2 ± 6.0	0.511	0.034	0.001
	Post	22.1 ± 4.2	18.0 ± 4.1			
Fat percentage (%)	Pre	29.0 ± 6.8	32.3 ± 9.5	0.734	0.667	0.001
	Post	31.5 ± 6.4	29.3 ± 7.2			
Waist-to-hip ratio	Pre	0.9 ± 0.0	1.0 ± 0.0	0.003	0.110	0.001
	Post	1.0 ± 0.1	0.9 ± 0.1			
Body mass index (kg/m^2)	Pre	26.6 ± 2.6	27.6 ± 2.6	0.111	0.001	0.001
	Post	27.8 ± 3.2	24.7 ± 3.0			

CON, control group; WPG, walking program group.

and ultrasound image scores increased in the CON group but decreased in the WPG group, indicating significant interaction effects.

The differences in cardiometabolic and liver function markers between the two groups are illustrated in Fig. 4. In terms of VO_2max, no significant differences were observed between the groups prior to the experiment; however, the CON group presented a decrease of 11.8%, whereas the WPG group presented a 16.1% increase, resulting in a significant difference between the groups ($p < 0.001$) after the 12-week period (Fig. 4A). Similarly, HDL levels decreased by 5.9% in the CON group but increased by 25.1% in the WPG group, indicating a significant difference ($p < 0.001$) (Fig. 4I).

Additionally, HR (9.0%), SBP (4.1%), DBP (1.5%), RPP (13.6%), FBG (10.5%), TG (4.9%), TC (8.9%), and LDL (16.2%) levels increased in the CON group. In contrast, HR (7.4%, Fig. 4B), SBP (9.6%, Fig. 4C), DBP (10.4%, Fig. 4D), RPP (16.3%, Fig. 4E), FBG (16.9%, Fig. 4F), TG (13.1%, Fig. 4G), TC (8.7%, Fig. 4H), and LDL (15.3%, Fig. 4J) levels decreased in the WPG, demonstrating significant differences between the groups ($p < 0.001$). With respect to AST and ALT, no significant differences were observed between the groups prior to the experiment. However, the CON group presented increases of 12.6% and 18.7%, whereas the WPG decreased by 40.0% and 23.5%, resulting in a significant difference between the groups ($p < 0.001$) after the 12-week period (Fig. 4K and L). Similarly, the total protein, albumin, and bilirubin

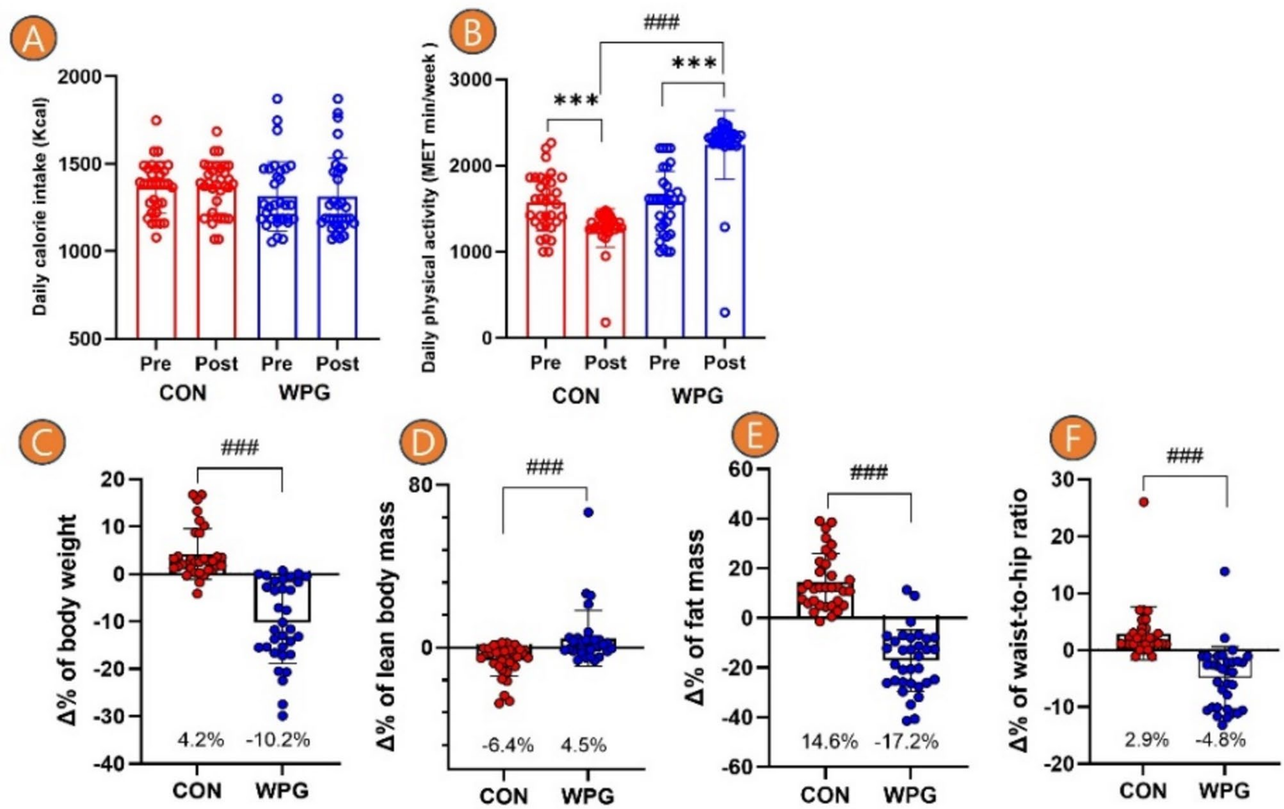

Fig. 3 Differences and changes in daily caloric intake, PA levels, and body composition. *** and ### indicate $p < 0.001$ between times and between groups, respectively

levels increased by 4.6%, 5.2%, and 3.3%, respectively, in the CON group but decreased by 14.4% (Fig. 4M), 8.1% (Fig. 4N), and 17.6% (Fig. 4O), respectively, in the WPG, indicating a significant difference ($p < 0.001$). Finally, the image scores confirmed by hepatic ultrasonography increased by 24.2% in the CON group, whereas they decreased by 31.8% in the WPG group, showing a significant difference between the two groups after the 12-week walking exercise program ($p < 0.001$) (Fig. 5).

Discussion

This study revealed that walking led to noticeable reductions in body weight, body fat mass, and abdominal fat. It was also observed that the cardiometabolic factors and liver function markers of the WPG significantly improved. Similarly, Prasertsri et al. [44] randomly assigned 43 hypertensive participants aged 60–80 years into either continuous walking (CON) or intermittent walking (INT) groups. The participants in the CON group walked for 30 min, 3 days per week, over 12 weeks, whereas those in the INT group walked for a total of 30 min per session, which was split into three equal intervals. Following walking, the CON group presented a significant reduction in hip circumference. In contrast, the INT group presented significant decreases in fat mass, hip circumference, and visceral fat levels. Additionally, the CON group experienced a significant increase in HDL, whereas TG and the TC/HDL ratio significantly decreased. Additionally, FBG and RPP were significantly lower in the INT group than in the CON group. These findings suggest that, whether walking is performed intermittently with an increasing number of sets or continuously, it can yield positive outcomes for BP and lipid components—key factors of metabolic syndrome—as well as myocardial oxygen consumption. Similarly, Kim et al. [45] reported that 14 obese middle-aged women who engaged in walking exercise at 50–60% of their VO_2max experienced significant reductions in obesity indices and metabolic risk factors. These included decreases in body weight, body fat, BMI, waist circumference, BP, and TG. They also reported significant improvements in cardiometabolic factors, such as HDL and VO_2max, which aligns with the findings of this study.

Pavlou et al. [46] studied changes in lean mass and body fat among obese men with an average body fat percentage of 38%, observing the effects of diet combined with exercise. They reported that participants who combined diet and exercise maintained their lean mass, whereas those who followed only a diet experienced a reduction in lean mass. Specifically, participants who focused only on

Table 3 Comparative results of cardiometabolic factors and liver function markers

Items	Time	Groups		p		
		CON	WPG	G	T	G×T
Cardiometabolic factors						
VO_2max (ml/kg/min)	Pre	24.4 ± 5.5	24.6 ± 3.2	0.001	0.399	0.001
	Post	21.4 ± 5.3	28.3 ± 3.7			
HR (beats/min)	Pre	72.6 ± 6.6	72.8 ± 6.9	0.001	0.732	0.001
	Post	78.7 ± 6.9	67.3 ± 6.8			
SBP (mmHg)	Pre	140.4 ± 8.1	141.9 ± 8.3	0.001	0.001	0.001
	Post	145.9 ± 8.2	127.9 ± 6.8			
DBP (mmHg)	Pre	87.6 ± 4.8	86.3 ± 3.4	0.001	0.001	0.001
	Post	88.8 ± 3.7	77.2 ± 6.1			
RPP (bpmmmHg×10^{-3})	Pre	10.2 ± 11.1	10.3 ± 11.6	0.001	0.143	0.001
	Post	11.4 ± 12.2	8.6 ± 0.9			
FBG (mmol/L)	Pre	7.3 ± 1.0	7.4 ± 0.7	0.001	0.005	0.001
	Post	8.0 ± 0.7	6.1 ± 0.5			
TG (mg/dl)	Pre	174.0 ± 21.6	175.5 ± 27.4	0.005	0.002	0.001
	Post	181.1 ± 16.9	151.0 ± 24.1			
TC (mg/dl)	Pre	224.2 ± 24.1	229.2 ± 32.4	0.025	0.707	0.001
	Post	242.8 ± 26.3	207.7 ± 38.8			
HDL (mg/dl)	Pre	44.2 ± 6.1	42.9 ± 7.3	0.001	0.006	0.001
	Post	40.9 ± 6.6	52.5 ± 8.2			
LDL (mg/dl)	Pre	145.2 ± 26.4	151.2 ± 33.4	0.009	0.481	0.001
	Post	165.7 ± 28.0	125.0 ± 35.4			
Liver function markers						
AST (IU/L)	Pre	51.6 ± 6.2	52.2 ± 8.4	0.001	0.001	0.001
	Post	57.5 ± 4.8	30.7 ± 7.9			
ALT (IU/L)	Pre	40.1 ± 5.5	40.2 ± 7.1	0.001	0.130	0.001
	Post	47.5 ± 8.1	30.2 ± 7.0			
Total protein (g/dL)	Pre	8.2 ± 0.9	8.3 ± 0.7	0.001	0.001	0.001
	Post	8.5 ± 0.9	7.0 ± 0.6			
Albumin (g/dL)	Pre	4.9 ± 0.7	5.0 ± 0.7	0.082	0.146	0.001
	Post	5.1 ± 0.8	4.5 ± 0.4			
Bilirubin (mg/dL)	Pre	1.6 ± 0.2	1.6 ± 0.2	0.001	0.001	0.001
	Post	1.7 ± 0.3	1.3 ± 0.3			
Ultrasound image (grade)	Pre	1.4 ± 0.6	1.5 ± 0.6	0.013	0.074	0.001
	Post	1.7 ± 0.7	0.9 ± 0.5			

CON, control group; WPG, walking program group; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; RPP, rate pressure product; FBG, fasting blood glucose; TG, triglyceride; TC, total cholesterol; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; AST, aspartate aminotransferase; ALT, alanine aminotransferase

dietary adjustments experienced a lean mass reduction of 24–28%, whereas those who included exercise experienced a smaller reduction of only 11–13%. This suggests that while exercise may not entirely prevent lean mass loss during dietary weight reduction, it significantly mitigates it, which in turn can help maintain the basal metabolic rate. By preserving the basal metabolic rate, exercise enhances fat oxidation during rest, potentially preventing age-related increases in body fat [47]. These results were similar to those observed in this study. Specifically, both the CON and WPG groups maintained a healthy diet. The outcomes of participants who combined this dietary regimen with walking exercise were consistent with those reported in previous studies. After the 12-week experiment of this study, changes in body composition revealed that body weight in the CON group increased by 4.2%, whereas it decreased by 10.2% in the WPG. The lean mass in the CON decreased by 6.4%, whereas it increased by 4.5% in the WPG. Furthermore, fat mass, fat percentage, WHR, and BMI in the CON group increased by 14.6%, 10.2%, 2.9%, and 4.2%, respectively. In contrast, these measures in the WPG decreased by 17.2%, 6.5%, 4.8%, and 10.2%, highlighting the effectiveness of walking exercise. In addition, VO_2max and HDL levels decreased by 11.8% and 5.9%, respectively. In contrast, the WPG increased the VO_2max and HDL levels by 16.1% and 25.1%, respectively. Notably, the walking intervention performed by the WPG resulted in significant reductions in HR, SBP, and RPP, as well as marked improvements in FBG, TG, TC, and LDL levels. Similar findings were

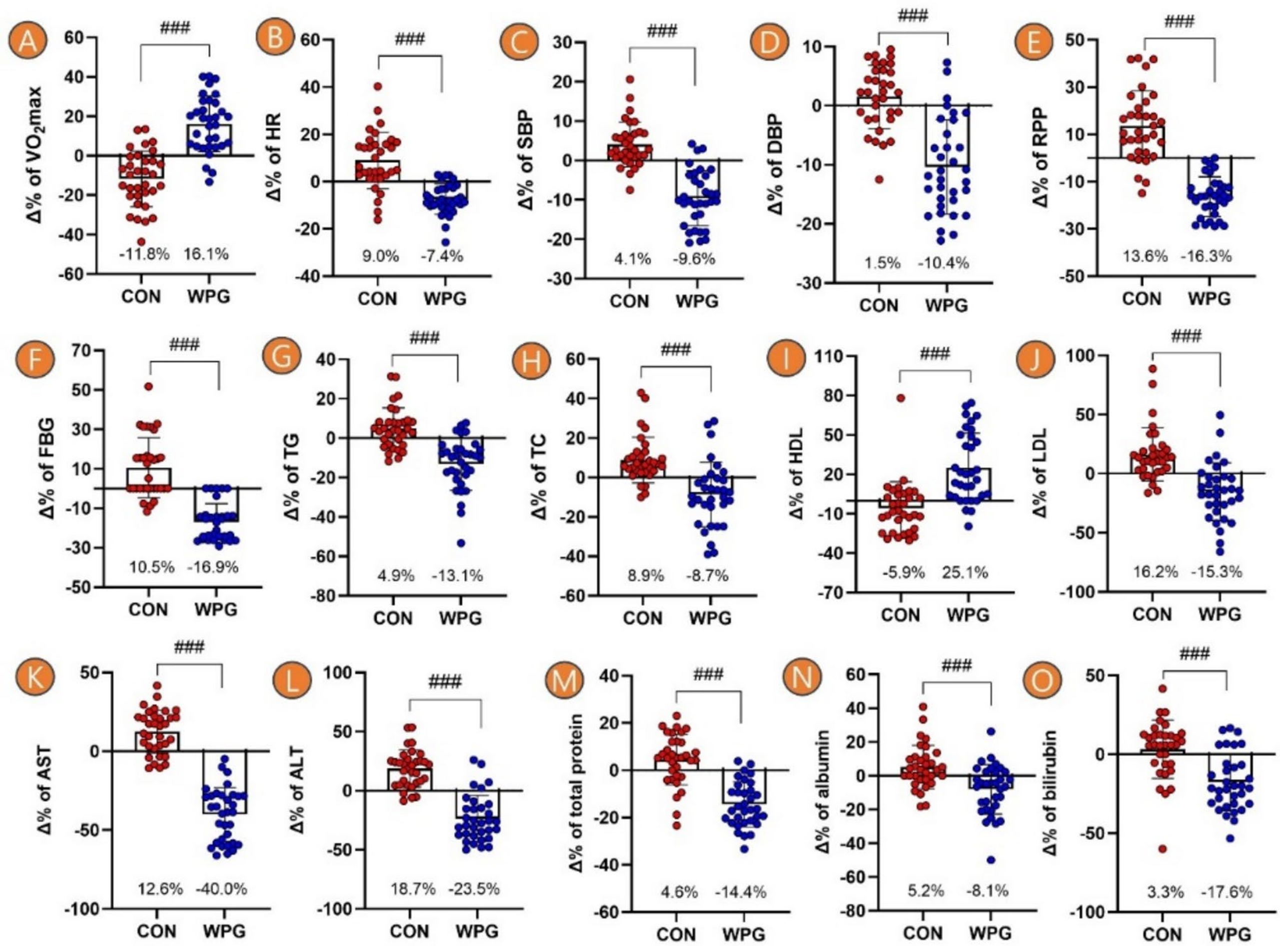

Fig. 4 Differences and changes in cardiometabolic factors and liver function markers. CON, control group; WPG, walking program group; VO_2max, maximal oxygen uptake; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; RPP, rate pressure product; FBG, fasting blood glucose; TG, triglyceride; TC, total cholesterol; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; AST, aspartate aminotransferase; ALT, alanine aminotransferase. ### indicates $p < 0.001$ between groups

reported in a study involving a 12-week walking exercise program for obese middle-aged women with a body fat percentage exceeding 30% [48]. A study reported that combining aerobic exercise, resistance training, and traditional Korean dance three times a week for 12 weeks resulted in improvements in body weight, blood pressure, and HDL and LDL levels [49]. Generally, long-term aerobic exercise increases HDL levels while reducing TG, TC, and LDL levels [29]. Similar results have been reported in numerous other studies involving various forms of aerobic exercise [37, 50–54], highlighting the positive effects of aerobic exercise on the human body.

According to Lee et al. [55], an analysis of a total of 571,872 Korean military personnel who participated in health examinations from January 2015 to July 2021 revealed that 77,020 individuals (13.47%) were classified as having NAFLD, indicating a continuous increase in the prevalence of MASLD. They also noted an increase in the prevalence of obesity, hypercholesterolemia, hyperglycemia, and hypertension during the same period. These findings indicate that the prevalence of fatty liver disease is positively correlated with advancing age [56]. Similarly, in this study, all participants were women aged 65 years and older with MASLD. When obesity and metabolic syndrome are present, fat can accumulate not only in other organs but also in the liver [57, 58]. In fact, the severity of fatty liver increases with the degree of obesity [59–61]. Conversely, while fat accumulation in the liver increases proportionally with weight gain, it decreases with weight loss. The current academic consensus suggests that an increase in body fat and a decrease in lean mass, which can negatively affect fatty liver, can lead to positive changes through long-term exercise programs [62]. Some previous studies have reported weight loss through endurance training in both obese and nonobese individuals. For example, a study involving nine participants aged 22–45 years who engaged in walking and jogging for four hours a week over ten weeks reported

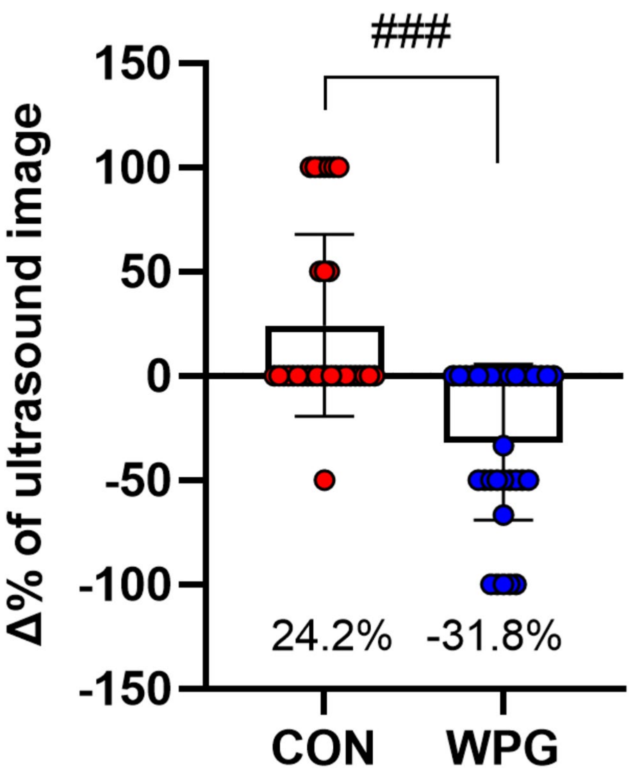

Fig. 5 Differences and changes in liver ultrasound image. CON, control group; WPG, walking program group
indicates $p < 0.001$ between groups

a reduction in body fat [63]. In this context, the study involved older adults with MASLD who participated in a 12-week mild- to moderate-intensity walking program. As shown in the results of this study, walking led to significant positive changes in cardiac metabolic factors. Additionally, the study revealed a tendency for decreases in liver function enzymes, as well as total protein, albumin, and bilirubin levels, suggesting that walking also contributes to positive changes in MASLD. These results demonstrate the positive effects of walking on liver function. Additionally, in terms of the echogenicity of the ultrasound images, while the CON group showed an increase, the WPG decreased 31.8%. These findings indicate that walking significantly contributes to improvements in liver function. In this context, Hickman et al. [64] reported that at the end of a weight loss intervention, 68% of 21 patients achieved and maintained weight loss, with an average reduction of 9.4% (4.0%). They also reported a correlation ($r = 0.35$, $p = 0.04$) between the improvement in ALT level and the amount of weight lost. Notably, for those who maintained weight loss, the average ALT levels at the 15-month follow-up were significantly lower than those at baseline, whereas for those who regained weight, the ALT levels at 15 months were similar to those at registration. These findings suggest that the normalization of liver function was sustained through the maintenance of weight loss.

The apparent independent benefit of PA on the liver suggests that changes in adipose function, beyond fat loss, such as improvements in adipose insulin sensitivity and alterations in adipokine secretion, may be crucial [65]. Although exercise-induced insulin sensitization is typically discussed in the context of improving skeletal muscle insulin resistance, in adipose tissue, insulin resistance is characterized by a reduced ability to suppress lipolysis with insulin, leading to increased free fatty acid release [66, 67]. The extent of adipose insulin resistance is associated with hepatic triglyceride levels in individuals with type 2 diabetes and NAFLD [68]. By improving insulin sensitivity, aerobic exercise reduces the free fatty acid concentration both at rest and under insulin-stimulated conditions [65, 69]. In fact, aerobic exercise increases energy expenditure, making it an effective method for weight loss [47, 52]. Moreover, regulating obesity through exercise not only reduces body fat but also increases lean mass, leading to significant health improvements. These findings reflect a trend similar to that observed in the walking program applied in this study. Ultimately, these research findings largely align with the results of previous studies. It can be concluded that the walking exercise implemented in this research led to positive changes in body composition, blood lipid profiles, and the ultrasound-detected prevalence among older adults with MASLD.

However, despite these findings, this study has several limitations. First, while the sample size was determined via scientific methods, the participants may not have fully represented the broader older population. Second, since all participants in this study were of East Asian descent, applying the interventions used here to older individuals of other ethnic backgrounds may present certain limitations. Third, while this study focused on representative factors related to MASLD, it is important to recognize that the scientific community has identified a more diverse range of factors beyond those explored in this research. Given these limitations, further studies examining the impact of PA on a larger and more diverse cohort, along with assessments of a broader range of MASLD-related biomarkers, are needed.

Conclusions

This study revealed that long-term walking, when coupled with a healthy diet, can positively impact MASLD markers in older adults, although some limitations should be taken into account.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01156-9.

Supplementary Material 1

Supplementary Material 2

Acknowledgements
We sincerely thank all the patients who permitted us to use their data for this study. We also extend our gratitude to the researchers at the Seoul Songdo Hospital Immunocyte Laboratory.

Author contributions
Y.-S.J. and J.K. conceived the idea. S.L. and Y.-S.J. developed the background and performed the calibration of different devices used in the tests. S.L. and Y.-S.J. verified the methods section. All authors discussed the results and contributed to the final manuscript. J.K., S.P. and S.L. performed the tests. Y.-S.J. wrote the manuscript with support from J.K. All authors contributed to the final version of the manuscript. All authors contributed to the interpretation of the results and data analysis, and they drafted the manuscript and designed the figures and tables. All authors provided critical feedback and helped shape the research, analysis, and manuscript. All authors have read and agreed to the published version of the manuscript.

Funding
This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2022S1A5C2A07090938).

Data availability
All data are available upon request, should the readers wish to access them.

Declarations

Ethics approval and consent to participate
This study adhered to ethical guidelines, with all participants providing informed consent after being fully informed of the study's purpose and procedures. Confidentiality was maintained, and participants could withdraw at any time. They were also offered access to the study's results if requested. The Ethics Committee of Hanseo University (HS23-06-01) approved this study, and the study was registered with the Clinical Research Information Service of the Korea Centers for Disease Control and Prevention (KCT0010079) on 26/12/2024. The researchers followed the principles outlined in the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Exercise Rehabilitation, Gachon University, Hombakmoero, Yeonsu-gu, Incheon 406-799, Korea
[2]Research Institute of Sports and Industry Science, Hanseo University, Seosan, Korea
[3]Department of Public Health Special Education, Graduate School of Health Promotion, Hanseo University, #1 Hanseo-ro, Haemi-myeon, Seosan 31962, Korea

Received: 28 January 2025 / Accepted: 15 April 2025
Published online: 25 April 2025

References

1. Neeland IJ, Lim S, Tchernof A, Gastaldelli A, Rangaswami J, Ndumele CE, Powell-Wiley TM, Després JP. Metabolic syndrome. Nat Rev Dis Primers. 2024;10(1):77.
2. Lee J, Lee H. Effects of risk factor numbers on the development of the metabolic syndrome. J Exerc Rehabil. 2020;16(2):183–8.
3. Park SK, Park S, Jee YS. Effects of physical inactivity behavior during COVID-19 pandemic on physical fitness, body composition, inflammatory cytokine, and immunocytes in older adults: A retrospective and prospective study. Physiol Behav. 2024;284:114640.
4. Williams EP, Mesidor M, Winters K, Dubbert PM, Wyatt SB. Overweight and obesity: prevalence, consequences, and causes of a growing public health problem. Curr Obes Rep. 2015;4(3):363–70.
5. Almeda-Valdés P, Cuevas-Ramos D, Aguilar-Salinas CA. Metabolic syndrome and non-alcoholic fatty liver disease. Ann Hepatol. 2009;8(Suppl 1):S18–24.
6. Abd El-Kader SM, El-Den Ashmawy EM. Non-alcoholic fatty liver disease: the diagnosis and management. World J Hepatol. 2015;7(6):846–58.
7. Czapla BC, Dalvi A, Hu J, Moran IJ, Wijarnpreecha K, Chen VL. Physical activity, diet, and social determinants of health associate with health related quality of life and fibrosis in MASLD. Sci Rep. 2025;15(1):7976.
8. Le MH, Yeo YH, Li X, Li J, Zou B, Wu Y, Ye Q, Huang DQ, Zhao C, Zhang J, Liu C, Chang N, Xing F, Yan S, Wan ZH, Tang NSY, Mayumi M, Liu X, Liu C, Rui F, Yang H, Yang Y, Jin R, Le RHX, Xu Y, Le DM, Barnett S, Stave CD, Cheung R, Zhu Q, Nguyen MH. 2019 Global NAFLD prevalence: A systematic review and meta-analysis. Clin Gastroenterol Hepatol. 2022;20(12):2809–17.
9. Han TS, Lean ME. A clinical perspective of obesity, metabolic syndrome and cardiovascular disease. JRSM Cardiovasc Dis. 2016;5:2048004016633371.
10. Marchesini G, Moscatiello S, Di Domizio S, Forlani G. Obesity-associated liver disease. J Clin Endocrinol Metab. 2008;93(11 Suppl 1):S74–80.
11. Tam BT, Morais JA, Santosa S. Obesity and ageing: two sides of the same coin. Obes Rev. 2020;21(4):e12991.
12. Cook S, Weitzman M, Auinger P, Nguyen M, Dietz WH. Prevalence of a metabolic syndrome phenotype in adolescents: findings from the third National health and nutrition examination survey, 1988–1994. Arch Pediatr Adolesc Med. 2003;157(8):821–7.
13. Lipsy RJ. The National cholesterol education program adult treatment panel III guidelines. J Manag Care Pharm. 2003;9(1 Suppl):2–5.
14. Török K, Szelényi Z, Pórszász J, Molnár D. Low physical performance in obese adolescent boys with metabolic syndrome. Int J Obes Relat Metab Disord. 2001;25(7):966–70.
15. Lakka TA, Laaksonen DE. Physical activity in prevention and treatment of the metabolic syndrome. Appl Physiol Nutr Metab. 2007;32(1):76–88.
16. James PT, Rigby N, Leach R, International Obesity Task Force. The obesity epidemic, metabolic syndrome and future prevention strategies. Eur J Cardiovasc Prev Rehabil. 2004;11(1):3–8.
17. Davison RC, Grant S. Is walking sufficient exercise for health? Sports Med. 1993;16(6):369–73.
18. Iwanaga S, Matsuse H, Hashida R, Bekki M, Kawaguchi T, Shiba N. The effect of walking combined with neuromuscular electrical stimulation on liver stiffness and insulin resistance in patients with non-alcoholic fatty liver disease: an exploratory randomized controlled trial. Kurume Med J. 2023;67(4):137–46.
19. Vázquez-Vandyck M, Roman S, Vázquez JL, Huacuja L, Khalsa G, Troyo-Sanromán R, Panduro A. Effect of breathwalk on body composition, metabolic and mood state in chronic hepatitis C patients with insulin resistance syndrome. World J Gastroenterol. 2007;13(46):6213–8.
20. Gudat U, Bungert S, Kemmer F, Heinemann L. The blood glucose Lowering effects of exercise and Glibenclamide in patients with type 2 diabetes mellitus. Diabet Med. 1998;15(3):194–8.
21. Park S, Park SK, Jee YS. Effects of walking training at different speeds on body composition, muscle contractility, and immunocytes in the elderly: A single-blinded randomized controlled trial. Arch Gerontol Geriatr. 2023;106:104871.
22. Nutt JG, Marsden CD, Thompson PD. Human walking and higher-level gait disorders, particularly in the elderly. Neurology. 1993;43(2):268–79.
23. Moy FM, Bulgiba A. The modified NCEP ATP III criteria maybe better than the IDF criteria in diagnosing metabolic syndrome among Malays in Kuala Lumpur. BMC Public Health. 2010;10:678.
24. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, Gordon DJ, Krauss RM, Savage PJ, Smith SC Jr, Spertus JA, Costa F, American Heart Association. National heart, lung, and blood institute. Diagnosis and management of the metabolic syndrome: an American heart association/ national heart, lung, and blood institute.Scientific statement. Circulation. 2005;112(17):2735–52.
25. Liao YY, Yang KC, Lee MJ, Huang KC, Chen JD, Yeh CK. Multifeature analysis of an ultrasound quantitative diagnostic index for classifying nonalcoholic fatty liver disease. Sci Rep. 2016;6:35083.
26. Adkins MC, Halvorsen RA Jr, duCret RP. CT evaluation of atypical hepatic fatty metamorphosis. J Comput Assist Tomogr. 1990;14(6):1013–5.
27. Kang H. Sample size determination and power analysis using the G*Power software. J Educ Eval Health Prof. 2021;18:17.

28. Sedgwick P. Sample size: how many participants are needed in a trial? BMJ. 2013;346:f1041.
29. Taylor AH, Cable NT, Faulkner G, Hillsdon M, Narici M, Van Der Bij AK. Physical activity and older adults: A review of health benefits and the effectiveness of interventions. J Sports Sci. 2004;22(8):703–25.
30. Piercy KL, Troiano RP. Physical activity guidelines for Americans from the US department of health and human services. Circ Cardiovasc Qual Outcomes. 2018;11(11):e005263.
31. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377–81.
32. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, Macera CA, Heath GW, Thompson PD, Bauman A. Physical activity and public health: updated recommendation for adults from the American college of sports medicine and the American heart association. Med Sci Sports Exerc. 2007;39(8):1423–34.
33. Keating SE, Hackett DA, George J, Johnson NA. Exercise and non-alcoholic fatty liver disease: a systematic review and meta-analysis. J Hepatol. 2012;57(1):157–66.
34. Stine JG, Long MT, Corey KE, Sallis RE, Allen AM, Armstrong MJ, Conroy DE, Cuthbertson DJ, Duarte-Rojo A, Hallsworth K, Hickman IJ, Kappus MR, Keating SE, Pugh CJA, Rotman Y, Simon TL, Vilar-Gomez E, Wong VW, Schmitz KH. Physical activity and nonalcoholic fatty liver disease: A roundtable statement from the American college of sports medicine. Med Sci Sports Exerc. 2023;55(9):1717–26.
35. Chun MY. Validity and reliability of Korean version of international physical activity questionnaire short form in the elderly. Korean J Fam Med. 2012;33(3):144–51.
36. Maddison R, Ni Mhurchu C, Jiang Y, Vander Hoorn S, Rodgers A, Lawes CM, Rush E. International physical activity questionnaire (IPAQ) and new Zealand physical activity questionnaire (NZPAQ): A doubly labelled water validation. Int J Behav Nutr Phys Act. 2007;4:62.
37. Kim JY, Yi ES. Analysis of the relationship between physical activity and metabolic syndrome risk factors in adults with intellectual disabilities. J Exerc Rehabil. 2018;14(4):592–7.
38. Cockerill FR 3rd, Wilson JW, Vetter EA, Goodman KM, Torgerson CA, Harmsen WS, Schleck CD, Ilstrup DM, Washington JA 2nd, Wilson WR. Optimal testing parameters for blood cultures. Clin Infect Dis. 2004;38(12):1724–30.
39. Ferraioli G, Soares Monteiro LB. Ultrasound-based techniques for the diagnosis of liver steatosis. World J Gastroenterol. 2019;25(40):6053–62.
40. Hamaguchi M, Kojima T, Itoh Y, Harano Y, Fujii K, Nakajima T, Kato T, Takeda N, Okuda J, Ida K, Kawahito Y, Yoshikawa T, Okanoue T. The severity of ultrasonographic findings in nonalcoholic fatty liver disease reflects the metabolic syndrome and visceral fat accumulation. Am J Gastroenterol. 2007;102(12):2708–15.
41. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. Med Sci Sports Exerc. 1998;30(6):992–1008.
42. Kozlov S, Caprnda M, Chernova O, Matveeva M, Alekseeva I, Gazdikova K, Gaspar L, Kruzliak P, Filipova S, Gabbasov Z. Peak responses during exercise treadmill testing using individualized ramp protocol and modified Bruce protocol in elderly patients. Folia Med (Plovdiv). 2020;62(1):76–81.
43. Fritz CO, Morris PE, Richler JJ. Effect size estimates: current use, calculations, and interpretation. J Exp Psychol Gen. 2012;141(1):2–18.
44. Prasertsri P, Phoemsapthawee J, Kuamsub S, Poolpol K, Boonla O. Effects of long-term regular continuous and intermittent walking on oxidative stress, metabolic profile, heart rate variability, and blood pressure in older adults with hypertension. J Environ Public Health. 2022;2022:5942947.
45. Kim DY, Seo BD, Kim DJ. Effect of walking exercise on changes in cardiorespiratory fitness, metabolic syndrome markers, and high-molecular-weight adiponectin in obese middle-aged women. J Phys Ther Sci. 2014;26(11):1723–7.
46. Pavlou KN, Steffee WP, Lerman RH, Burrows BA. Effects of dieting and exercise on lean body mass, oxygen uptake, and strength. Med Sci Sports Exerc. 1985;17(4):466–71.
47. Strasser B. Physical activity in obesity and metabolic syndrome. Ann N Y Acad Sci. 2013;1281(1):141–59.
48. Mendoza SG, Carrasco H, Zerpa A, Briceno Y, Rodriguez F, Speirs J, Glueck CJ. Effect of physical training on lipids, lipoproteins, apolipoproteins, lipases, and endogenous sex hormones in men with premature myocardial infarction. Metabolism. 1991;40(4):368–77.
49. Park JH, Park H, Lim ST, Park JK. Effects of a 12-week healthy-life exercise program on oxidized low-density lipoprotein cholesterol and carotid intima-media thickness in obese elderly women. J Phys Ther Sci. 2015;27(5):1435–9.
50. Albright C, Thompson DL. The effectiveness of walking in preventing cardiovascular disease in women: a review of the current literature. J Womens Health (Larchmt). 2006;15(3):271–80.
51. Kim JW, Ko YC, Seo TB, Kim YP. Effect of circuit training on body composition, physical fitness, and metabolic syndrome risk factors in obese female college students. J Exerc Rehabil. 2018;14(3):460–5.
52. Li S, Kim JY, Sim YJ. Effects of 10-week combined training on lipid metabolic regulatory hormones and metabolic syndrome index according to exercise dose in obese male college students. J Exerc Rehabil. 2020;16(1):101–7.
53. Nicklas BJ, Dennis KE, Berman DM, Sorkin J, Ryan AS, Goldberg AP. Lifestyle intervention of hypocaloric dieting and walking reduces abdominal obesity and improves coronary heart disease risk factors in obese, postmenopausal, African-American and Caucasian women. J Gerontol Biol Sci Med Sci. 2003;58(2):181–9.
54. Nicklas BJ, Wang X, You T, Lyles MF, Demons J, Easter L, Berry MJ, Lenchik L, Carr JJ. Effect of exercise intensity on abdominal fat loss during calorie restriction in overweight and obese postmenopausal women: a randomized, controlled trial. Am J Clin Nutr. 2009;89(4):1043–52.
55. Lee J, Kim T, Yang H, Bae SH. Prevalence trends of non-alcoholic fatty liver disease among young men in Korea: A Korean military population-based cross-sectional study. Clin Mol Hepatol. 2022;28(2):196–206.
56. Gan L, Chitturi S, Farrell GC. Mechanisms and implications of age-related changes in the liver: nonalcoholic fatty liver disease in the elderly. Curr Gerontol Geriatr Res. 2011;2011:831536.
57. Heeren J, Scheja L. Metabolic-associated fatty liver disease and lipoprotein metabolism. Mol Metab. 2021;50:101238.
58. Scorletti E, Carr RM. A new perspective on NAFLD: focusing on lipid droplets. J Hepatol. 2022;76(4):934–45.
59. Hsiao PJ, Kuo KK, Shin SJ, Yang YH, Lin WY, Yang JF, Chiu CC, Chuang WL, Tsai TR, Yu ML. Significant correlations between severe fatty liver and risk factors for metabolic syndrome. J Gastroenterol Hepatol. 2007;22(12):2118–23.
60. Park HS, Kim MW, Shin ES. Effect of weight control on hepatic abnormalities in obese patients with fatty liver. J Korean Med Sci. 1995;10(6):414–21.
61. Hagström H, Simon TG, Roelstraete B, Stephansson O, Söderling J, Ludvigsson JF. Maternal obesity increases the risk and severity of NAFLD in offspring. J Hepatol. 2021;75(5):1042–8.
62. Johnson NA, George J. Fitness versus fatness: moving beyond weight loss in nonalcoholic fatty liver disease. Hepatology. 2010;52(1):370–81.
63. Hill JO, Thiel J, Heller PA, Markon C, Fletcher G, DiGirolamo M. Differences in effects of aerobic exercise training on blood lipids in men and women. Am J Cardiol. 1989;63(3):254–6.
64. Hickman IJ, Jonsson JR, Prins JB, Ash S, Purdie DM, Clouston AD, Powell EE. Modest weight loss and physical activity in overweight patients with chronic liver disease results in sustained improvements in Alanine aminotransferase, fasting insulin, and quality of life. Gut. 2004;53(3):413–9.
65. Solomon TP, Haus JM, Marchetti CM, Stanley WC, Kirwan JP. Effects of exercise training and diet on lipid kinetics during free fatty acid-induced insulin resistance in older obese humans with impaired glucose tolerance. Am J Physiol Endocrinol Metab. 2009;297(2):E552–9.
66. Korenblat KM, Fabbrini E, Mohammed BS, Klein S. Liver, muscle, and adipose tissue insulin action is directly related to intrahepatic triglyceride content in obese subjects. Gastroenterology. 2008;134(5):1369–75.
67. Park HS, Sim SJ, Park JY. Effect of weight reduction on metabolic syndrome in Korean obese patients. J Korean Med Sci. 2004;19(2):202–8.
68. Kotronen A, Juurinen L, Tiikkainen M, Vehkavaara S, Yki-Järvinen H. Increased liver fat, impaired insulin clearance, and hepatic and adipose tissue insulin resistance in type 2 diabetes. Gastroenterology. 2008;135(1):122–30.
69. Villani R, Magnati GP, Tuccari G, Sangineto M, Romano AD, Cassano T, Serviddio G. Liver fat content assessed by conventional B-mode ultrasound and metabolic profile in non-diabetic patients: implications for clinical practice. Ultrasound. 2023;31(3):177–85.

Publisher's note