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# The effect of dietary approaches to stop hypertension (DASH) diet on fatty liver and cardiovascular risk factors in subjects with metabolic syndrome: a randomized controlled trial

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## Abstract

**Background** Metabolic syndrome (MetS) as a multifactorial disorder is associated with non-communicable diseases. The dietary approaches to stop hypertension (DASH) diet is a healthy dietary pattern. We investigated the effect of the DASH diet on fatty liver and cardiovascular risk factors in subjects with MetS.

**Methods** 60 Subjects with MetS were assigned into the intervention group (DASH diet) or the control group (a healthy diet). Fatty liver index (FLI), hepatic steatosis index (HSI), waist circumference (WC), weight, body mass index (BMI), triglyceride (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-c) and high-density lipoprotein cholesterol (HDL-c) were evaluated at the beginning and after intervention. Equations of fatty liver indices such as FLI and HSI are based on liver enzymes, anthropometric variables, sex and having diabetes.

**Results** 30 subjects in the intervention group and 29 subjects in the control group completed the study. We found a significant reduction in the intervention group compared to the control group in FLI (-13.06 ± 10.03 vs. -2.90 ± 6.82; $P < 0.001$), HSI (-2.72 ± 2.59 vs. -0.81 ± 3.80; $P = 0.02$), WC (-6.02 ± 4.24 vs. -2.24 ± 4.28; $P = 0.001$), weight (-3.39 ± 2.53 vs. -1.51 ± 2.72; $P = 0.008$), BMI (-1.25 ± 0.93 vs. -0.56 ± 1.01; $P = 0.008$), DBP (-5.16 ± 3.92 vs. -1.50 ± 7.04; $P = 0.01$), SBP (-6.97 ± 8.21 vs. -1.36 ± 6.83; $P = 0.006$), TG (-18.50 ± 14.32 vs. 0.60 ± 23.81; $P < 0.001$), TC (-16.10 ± 17.94 vs. -5.07 ± 23.62; $P = 0.04$) and LDL-c (-13.50 ± 9.58 vs. -4.90 ± 18.28; $P = 0.02$). These results remained significant after adjusting for confounding factors, except for TC ($P = 0.25$).

**Conclusions** The DASH diet was more effective than the control diet in managing fatty liver and cardiovascular risk factors.

**Trial registration** The trial was registered on 21 October 2022 at Iranian Registry of Clinical Trials (IRCT20180201038585N12, URL: https://irct.behdasht.gov.ir/trial/66161).

**Keywords** Metabolic syndrome, DASH diet, Fatty liver, Cardiovascular

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## Introduction

Metabolic syndrome (MetS), which is a collection of metabolic dysregulations, is a main cause for the development of various diseases [1, 2]. The prevalence of MetS in adults varies from 20% to more than 35% [3]. About one-third of Iranian adults are affected by metabolic syndrome [4]. It has been confirmed that metabolic dysregulations in MetS contributed to the progression of fatty liver disease [5]. Scoring tools like fatty liver index (FLI) and hepatic steatosis index (HSI) are designed to evaluate fatty liver [6]. Individuals with MetS have higher cardiovascular risks compared to the subjects without MetS [7]. Unhealthy lifestyle behaviors such as following unhealthy dietary patterns, lack of exercise, alcohol consumption, and insufficient quantity and/or quality of sleep increase the risk of MetS [8].

The dietary approaches to stop hypertension (DASH) diet has been designed for managing elevated blood pressure [9]. This dietary regime emphasizes on reduction of dietary intake of saturated fat, cholesterol, red and processed meats, sugar-sweetened beverages, and sodium [10]. In addition, the DASH diet recommends a high intake of whole grains, vegetables, fruits, low-fat dairy products, legumes, and nuts [10]. Adherence to DASH diet provides adequate amounts of fiber, calcium, potassium and magnesium [11]. Some investigations demonstrated a positive impact of DASH diet on cardiovascular risk factors in individuals with NAFLD, hypertension, and obesity [12–15]. Only Azadbakht et al. [16] and Saneei et al. [17] examined the impact of DASH diet among individuals with MetS, and their results were inconsistent. To our knowledge, there is no clinical trial determining the impact of DASH diet on fatty liver in subjects with MetS. We aimed to examine the effect of DASH diet on fatty liver indices and cardiovascular outcomes among individuals with MetS. Compared to the control diet, the DASH diet was hypothesized to be more effective in managing fatty liver and cardiovascular risk factors in subjects with MetS.

## Methods

### Participants

This two-arm parallel randomized controlled trial (RCT) was carried out in Yazd, Iran. Recruitment of participants was conducted between October and November 2022 in Diabetes Research Center affiliated with Shahid Sadoughi University of Medical Sciences, Yazd, Iran. Individuals aged between 30 and 60 years who had MetS and signed a written informed consent were included. Diagnosis of MetS was performed based on International Diabetes Federation (IDF) criteria [18]. We excluded those with hypothyroidism, Cushing's syndrome, Wilson disease, kidney diseases, history of hepatitis, hemochromatosis, bypass surgery, pregnancy and lactation, and those taking calcium channel blockers, synthetic estrogens, vitamin D, vitamin E, and omega-3.

### Trial design

The present study was designed to investigate the effect of 12-week adherence to DASH diet on fatty liver indices (FLI and HSI), body composition variables such as waist circumference (WC), weight and body mass index (BMI), blood pressure, and lipid profile in subjects with MetS. Before signing a written informed consent, subjects were notified about the study details. The ethical committee of Baqiyatallah University of Medical Sciences Tehran, Iran confirmed the study protocol (IR.BMSU.BAQ.REC.1401.016). The trial was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The protocol of trial was registered on 21 October 2022 at the website of Iranian clinical trials with code number IRCT20180201038585N12 (URL: https://irct.behdasht.gov.ir/trial/66161). 60 subjects were divided into groups (30 subjects in the intervention group and 30 subjects in the control group). A trained person who was not involved in the study divided the participants into intervention and control groups by a computer-generated random numbers Table [19] using a stratified randomization method based on gender (male/female) and age (30–45 and 45–60 years). The subjects in the intervention group were requested to follow DASH diet rich in fruits, vegetables, whole grains, low-fat dairy products, and low in saturated fats, cholesterol, refined grains, and sugar-sweetened beverages with a distribution of macronutrients as follows: 50–55% carbohydrate, 15–20% protein, and 30% total fat. The control group followed a diet containing 50–55% carbohydrate, 15–20% protein, and 30% total fat. We designed the diets as energy-restricted. The DASH diet is rich in food groups such as vegetables, fruits, low-fat dairy products, nuts, seeds and legumes. These food groups provide high amounts of fibers and micronutrients especially potassium, magnesium, vitamin C, vitamin A and folate. In addition, the DASH diet has low servings of meats, fats and oils. On the other hand, the control group received a healthy diet that had a balanced amount of different food groups and lower content of fibers and micronutrients than the DASH diet. Both study groups in our study received energy-restricted diets and same macronutrients distribution, and the diets were different in terms of food groups and micronutrient levels. This design was done in order to adjust the effects of energy restriction and macronutrient ratio on fatty liver and cardiovascular risk factors, and to achieve the beneficial effects of DASH diet more clearly compared to a common healthy diet. Calculation of the energy requirement for each participant was performed using the Harris-Benedict Eq. [20]. The energy intake of each participant with BMI between 25–31 kg/m$^2$ was considered to be 500 kcal lower than the total energy requirement and the energy intake of each participant with BMI higher than 31 kg/m$^2$ was considered to be 700 kcal lower than the total energy requirement. We checked the dietary intakes of subjects and trained them to follow the diets every 4 weeks via phone interviews. The subjects received text messages twice a week to maintain an appropriate level of adherence to the study protocols. Allocation concealment was conducted utilizing opaque sealed envelopes. According to the values of WC in the study of Razavi Zade et al. [14], 95% confidence interval, with $\alpha = 0.05$ and $\beta = 0.2$, the sample size needed was estimated to be 60.

### Measurements

Measuring dietary intake, physical activity, blood tests, blood pressure, fatty liver severity, and body composition was performed at the beginning and after intervention. We utilized a 3-day (1 weekend day and 2 nonconsecutive weekdays) food record to evaluate dietary intakes [21]. Nutritionist IV (N-Squared Computing, Salem, OR, USA) modified for Iranian foods was used to assess the dietary intakes.

A validated metabolic equivalent of task (MET) questionnaire was used to evaluate physical activity [22, 23].

10 ml of blood was collected from participants after 10 h fasting. Measuring triglyceride (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-c), high-density lipoprotein cholesterol (HDL-c), alanine transaminase (ALT), aspartate transaminase (AST), and gamma-glutamyl transpeptidase (GGT) was performed by Pars Azmoon kits (made in Iran) utilizing an autoanalyzer (AVIDA 1800 chemistry system; Siemens, United Kingdom).

A trained person measured diastolic blood pressure (DBP) and systolic blood pressure (SBP) based on standard protocols via a sphygmomanometer (Microlife BP AG1-10).

Fatty liver severity was estimated utilizing validated indices such as FLI [24] and HSI [25]. FLI and HSI were calculated based on following equations:

$$FLI = [e^{0.953 \times \log e\ (TG)\ + 0.139 \times BMI + 0.718 \times \log e\ (GGT)\ + 0.053 \times WC - 15.745}] \div 1 + [e^{0.953 \times \log e\ (TG)\ + 0.139 \times BMI + 0.718 \times \log e\ (GGT)\ + 0.053 \times WC - 15.745}] \times 100.$$

$$HSI = 8 \times (ALT\ /\ AST) + BMI + 2\ (\text{if type 2 diabetes}) + 2\ (\text{if female}).$$

A digital Seca scale (Seca, Germany) and a stadiometer (Seca, Hamburg, Germany) were used to measure the weight and height of participants, respectively. To determine each individual's BMI, the following equation was used: weight (kg)/height squared (m$^2$).

### Statistical analysis

Statistical analysis was done by SPSS software version 24 using an intention-to-treat method. Assessment of normality of variables was performed using Kolmogorov–Smirnov test. Differences in continuous and categorical variables between two groups were compared using an independent t-test and chi-square test, respectively. Comparison of the variables before and after the intervention in each group was performed using paired t-test. In addition, comparisons between two groups were done by independent t-test. Univariate analysis of covariance (ANCOVA) was used to adjust the effects of confounding factors. P value $\leq 0.05$ was considered to be significant.

## Results

### Characteristics of subjects

60 subjects were divided into groups. One subject was excluded from study due to non-referral, and, 30 subjects (15 males and 15 females) in the intervention group and 29 subjects (15 males and 14 females) in the control group completed the study (Fig. 1). As reported in Table 1, there was no significant difference between groups in age, gender distribution, smoking, education, physical activity and height ($P > 0.05$). None of the subjects reported side effects during the study.

### Dietary intakes

The dietary intakes of participants were represented in Table 2. At the beginning of the trial, no significant difference was found between groups in intake of energy, carbohydrate, protein, fat, potassium, sodium, magnesium, vitamin C, vitamin A, folate, fiber, vegetables, fruits, fats and oils, nuts, seeds and legumes, simple sugars, meats. However, intervention group compared to control group had higher intake of grains ($P < 0.001$) and lower intake of dairy products ($P = 0.02$). There was no significant difference between the intervention group and the control group in percentage of calorie reduction ($27.94 \pm 5.56$ vs. $28.51 \pm 5.52$; $P = 0.69$). After intervention, we found no significant difference between groups in energy intake, carbohydrate, protein, fat, sodium, simple sugars and grains. The intervention group compared to control group consumed higher amounts of potassium, vitamin C, vitamin A, folate, fiber, vegetables, fruits, nuts, seeds and legumes, and dairy products ($P < 0.001$) and lower servings of meats, fats and oils ($P < 0.001$). In addition, intake of magnesium was higher in the intervention group (0.006).

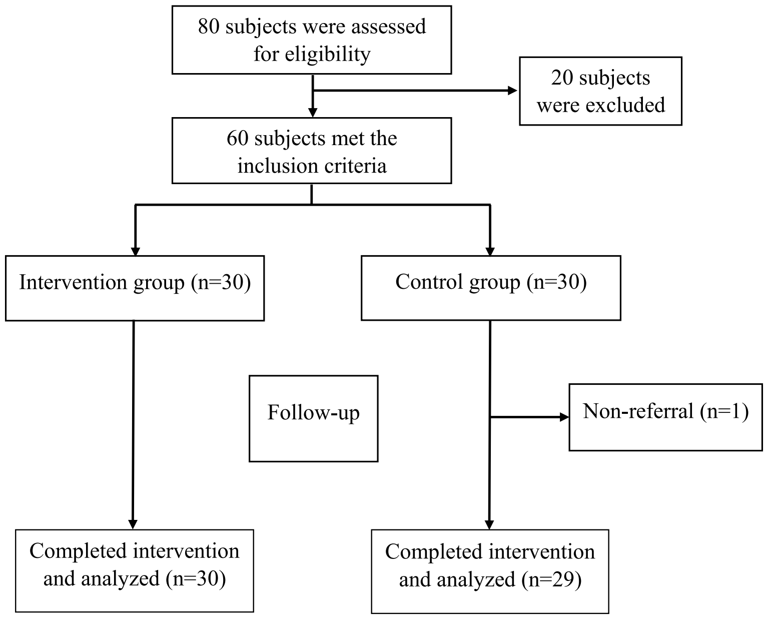


**Fig. 1** eligibility, screening, and follow-up

**Table 1** Baseline characteristics of subjects with MetS

| Variables | | Intervention group (*n* = 30) | Control group (*n* = 30) | *P* |
|---|---|---|---|---|
| **Age**, y | | 44.43 ± 6.06 | 45.60 ± 7.07 | 0.49 |
| **Height**, cm | | 165.33 ± 9.12 | 163.70 ± 10.57 | 0.52 |
| **Gender** | Male, n (%) | 15 (50.0) | 15 (50.0) | 0.99 |
| Female, n (%) | 15 (50.0) | 15 (50.0) | | |
| **Smoking** | No, n (%) | 21 (70.0) | 22 (73.3) | 0.77 |
| | Yes, n (%) | 9 (30.0) | 8 (26.7) | |
| **Education** | Under diploma, n (%) | 5 (16.7) | 7 (23.4) | 0.87 |
| | Diploma, n (%) | 9 (30.0) | 10 (33.3) | |
| | Bachelor's degree, n (%) | 11 (36.6) | 9 (30.0) | |
| | Master's degree, n (%) | 5 (16.7) | 4 (13.3) | |
| **Physical activity** | Low, n (%) | 21 (70.0) | 22 (73.3) | 0.95 |
| | Moderate, n (%) | 8 (26.7) | 7 (23.4) | |
| | High, n (%) | 1 (3.3) | 1 (3.3) | |

*P* values of age and height are computed by independent t-test and data are expressed as mean ± standard deviation (SD), while P values of gender, smoking, education and physical activity are computed by chi-square and data are expressed as numbers (percentage)

*MetS* Metabolic syndrome, *PA* Physical activity

## Outcomes

At the beginning of the study, there were no significant differences between groups in FLI ($P = 0.57$), HSI ($P = 0.34$), ALT ($P = 0.55$) and GGT ($P = 0.50$). Only, AST was significantly higher in the intervention group compared to the control group ($P = 0.04$). After intervention, a significant reduction was observed in the intervention group compared to the control group in FLI (-13.06 ± 10.03 vs. -2.90 ± 6.82; P < 0.001), HSI (-2.72 ± 2.59 vs. -0.81 ± 3.80; $P = 0.02$), ALT (-9.53 ± 7.40 vs. -2.30 ± 7.11; $P = < 0.001$), AST (-4.40 ± 4.87 vs. -1.26 ± 6.78; $P = 0.04$) and GGT (-5.93 ± 6.06 vs. -2.03 ± 5.45; $P = 0.01$) (Table 3).

In addition, there was no significant difference between groups in WC ($P = 0.81$), weight ($P = 0.33$), and BMI ($P = 0.52$) at the baseline. After intervention, results of within group comparisons demonstrated

**Table 2** Dietary intakes in subjects with MetS

| Variables | Intervention group (*n* = 30) | Control group (*n* = 30) | *P* |
|---|---|---|---|
| **Energy intake**, kcal/d | | | |
| Baseline | 2117.50 ± 130.54 | 2093.16 ± 118.67 | 0.45 |
| After intervention | 1540.16 ± 283.92 | 1481.16 ± 284.84 | 0.42 |
| **Carbohydrate**, g/d | | | |
| Baseline | 293.96 ± 24.36 | 289.26 ± 25.26 | 0.46 |
| After intervention | 199.31 ± 36.48 | 193.07 ± 37.13 | 0.51 |
| **Protein**, g/d | | | |
| Baseline | 65.74 ± 10.78 | 66.92 ± 9.91 | 0.66 |
| After intervention | 69.37 ± 12.79 | 64.60 ± 12.42 | 0.14 |
| **Fat**, g/d | | | |
| Baseline | 75.40 ± 17.48 | 74.25 ± 15.18 | 0.78 |
| After intervention | 51.77 ± 9.54 | 50.04 ± 9.62 | 0.48 |
| **Potassium**, g/d | | | |
| Baseline | 1845.55 ± 357.04 | 1982.91 ± 360.65 | 0.14 |
| After intervention | 3376.62 ± 562.29 | 2634.73 ± 748.65 | < 0.001 |
| **Sodium**, g/d | | | |
| Baseline | 2279.67 ± 426.55 | 2147.75 ± 279.76 | 0.16 |
| After intervention | 1622.37 ± 550.83 | 1752.78 ± 623.25 | 0.39 |
| **Magnesium**, g/d | | | |
| Baseline | 317.60 ± 71.53 | 311.33 ± 54.09 | 0.70 |
| After intervention | 407.73 ± 79.56 | 344.82 ± 92.38 | 0.006 |
| **Vitamin C**, g/d | | | |
| Baseline | 44.90 ± 5.62 | 46.33 ± 4.19 | 0.26 |
| After intervention | 65.32 ± 5.06 | 53.78 ± 7.17 | < 0.001 |
| **Vitamin A**, g/d | | | |
| Baseline | 331.09 ± 69.35 | 348.87 ± 70.74 | 0.33 |
| After intervention | 525.62 ± 44.23 | 460.14 ± 69.24 | < 0.001 |
| **Folate**, g/d | | | |
| Baseline | 202.78 ± 40.76 | 207.36 ± 31.30 | 0.62 |
| After intervention | 347.07 ± 61.43 | 277.97 ± 74.71 | < 0.001 |
| **Fiber**, g/d | | | |
| Baseline | 16.54 ± 5.91 | 16.90 ± 4.34 | 0.78 |
| After intervention | 31.85 ± 8.45 | 21.67 ± 10.06 | < 0.001 |
| **Vegetables**, serving/d | | | |
| Baseline | 1.26 ± 0.64 | 1.23 ± 0.67 | 0.69 |
| After intervention | 3.73 ± 0.44 | 2.73 ± 0.73 | < 0.001 |
| **Fruits**, serving/d | | | |
| Baseline | 2.06 ± 0.76 | 1.93 ± 0.69 | 0.33 |
| After intervention | 4.06 ± 0.63 | 2.73 ± 0.74 | < 0.001 |
| **Grains**, serving/d | | | |
| Baseline | 13.03 ± 0.55 | 12.30 ± 0.74 | < 0.001 |
| After intervention | 6.36 ± 1.40 | 6.96 ± 1.47 | 0.11 |
| **Nuts, seeds and legumes**, serving/d | | | |
| Baseline | 0.23 ± 0.50 | 0.26 ± 0.52 | 0.80 |
| After intervention | 1.46 ± 0.51 | 0.53 ± 0.50 | < 0.001 |
| **Dairy products**, serving/d | | | |
| Baseline | 1.33 ± 0.60 | 1.66 ± 0.47 | 0.02 |
| After intervention | 2.10 ± 0.30 | 1.70 ± 0.46 | < 0.001 |

**Table 2** (continued)

| Variables | Intervention group ($n=30$) | Control group ($n=30$) | *P* |
|---|---|---|---|
| **Meats**, serving/d | | | |
| Baseline | 4.96 ± 0.85 | 4.93 ± 0.82 | 0.87 |
| After intervention | 2.73 ± 0.44 | 4.10 ± 0.30 | < 0.001 |
| **Fats and oils**, serving/d | | | |
| Baseline | 5.96 ± 0.66 | 6.03 ± 0.61 | 0.68 |
| After intervention | 2.63 ± 1.03 | 4.26 ± 0.44 | < 0.001 |
| **Simple sugars**, serving/d | | | |
| Baseline | 4.90 ± 0.71 | 4.63 ± 1.06 | 0.25 |
| After intervention | 1.10 ± 0.30 | 1.16 ± 0.37 | 0.45 |

Values are presented as mean ± standard deviation (SD)

*P*: resulted from comparisons between two groups by independent t-test

*MetS* Metabolic syndrome

that both groups had a significant reduction in WC, weight and BMI. However, adherence to DASH diet compared to healthy diet resulted in a greater reduction in WC (-6.02 ± 4.24 vs. -2.24 ± 4.28; $P=0.001$), weight (-3.39 ± 2.53 vs. -1.51 ± 2.72; $P=0.008$) and BMI (-1.25 ± 0.93 vs. -0.56 ± 1.01; $P=0.008$) (Table 3).

Values of blood pressure and lipid profile are presented in Table 4. At the baseline, there was no significant difference between intervention group and control group in DBP ($P=0.93$) and SBP ($P=0.06$). Intervention group compared to control group showed a significant change in DBP (-5.16 ± 3.92 vs. -1.50 ± 7.04; $P=0.01$) and SBP (-6.97 ± 8.21 vs. -1.36 ± 6.83; $P=0.006$) after intervention.

At the beginning of the study, levels of TG ($P=0.16$), TC ($P=0.55$), HDL-c ($P=0.42$) and LDL-c ($P=0.16$) were not significantly different between two groups. After intervention, there was a significant reduction in intervention group compared to the control group in TG (-18.50 ± 14.32 vs. 0.60 ± 23.81; $P<0.001$), TC (-16.10 ± 17.94 vs. -5.07 ± 23.62; $P=0.04$), and LDL-c (-13.50 ± 9.58 vs. -4.90 ± 18.28; $P=0.02$). However, we found no significant difference between groups in HDL-c (-0.90 ± 3.40 vs. -1.40 ± 5.46; $P=0.67$).

After adjusting for confounding factors, the results remained unchanged, except for TC ($P=0.25$).

## Discussion

### We demonstrated that DASH diet improves fatty liver and cardiovascular risk factors in subjects with MetS

Findings of the study of Razavi Zade et al. [14] that was conducted among patients with NAFLD suggested that 8-week adherence to DASH diet resulted in a significant reduction of liver steatosis severity and liver enzymes. Intake of vegetables, fruits, and whole grains is inversely associated with the severity of fatty liver [10, 11]. Polyphenols as bioactive components of vegetables and fruits can attenuate the production of lipids in the liver, activate the clearance of fat and improve the factors contributing to the fatty liver progression like oxidative stress and inflammation [26, 27]. It has been revealed that a combination of polyphenols has greater benefits on fatty liver than supplementation with a single polyphenol [28, 29]. There is supporting evidence that whole grains intake reduces lipid accumulation in hepatocytes [30], but refined grains intake triggers the accumulation of TGs in the liver [30, 31]. Dorosti et al. [32] showed an improvement in fatty liver features after following a high-whole grains diet for 12 weeks. Whole grains, fruits, and vegetables provide high amounts of dietary fibers [33]. Fibers can increase the abundance of health-promoting bacteria in the gut and promote the function of gut microbiota [34, 35]. Short-chain fatty acids (SCFAs) acetate, propionate, and butyrate produced from the broken down of fermentable dietary fibers can promote the hepatic clearance of fat, increase insulin sensitivity, and attenuate inflammatory pathways activity [36–38].

Obesity and fatty liver are interlinked, and several above-mentioned mechanisms by which the DASH diet reduces the severity of fatty liver, also can decrease the level of obesity. In addition, intake of fibers increases the time of gastric emptying and satiety, and decreases appetite as well as the absorption of macronutrients [39]. Because of lower energy content of fruits and vegetables, high consumption of these food groups leads to reduction of calorie intake without change in volume of food [40]. In the study of Perry et al. [41], obese people who followed a DASH diet for 12 weeks under controlled feeding conditions indicated a reduction in body weight, and body fat mass. Said et al. [42] illustrated that adherence to DASH diet for 12 weeks ameliorates BMI in adults. Nevertheless, in the study of Saneei et al. [17], 6-week adherence to DASH diet did not change body

**Table 3** Effect of DASH diet on fatty liver and body composition in subjects with MetS

| Variables | Intervention group (*n* = 30) | Control group (*n* = 30) | $P^{\dagger}$ | $P^{\dagger\dagger}$ |
|---|---|---|---|---|
| **FLI** | | | | |
| Baseline | 77.66 ± 16.17 | 79.83 ± 13.67 | 0.57 | < 0.001 |
| After intervention | 64.60 ± 21.66 | 76.93 ± 14.03 | 0.01 | |
| *P* | < 0.001 | 0.02 | | |
| Mean change of FLI | -13.06 ± 10.03 | -2.90 ± 6.82 | < 0.001 | |
| **HSI** | | | | |
| Baseline | 42.87 ± 4.68 | 44.19 ± 5.87 | 0.34 | 0.02 |
| After intervention | 40.15 ± 4.30 | 43.38 ± 6.45 | 0.02 | |
| *P* | < 0.001 | 0.25 | | |
| Mean change of HSI | -2.72 ± 2.59 | -0.81 ± 3.80 | 0.02 | |
| **ALT** | | | | |
| Baseline | 38.26 ± 10.95 | 36.40 ± 13.19 | 0.55 | < 0.001 |
| After intervention | 28.73 ± 11.34 | 34.10 ± 11.97 | 0.08 | |
| *P* | < 0.001 | 0.08 | | |
| Mean change of ALT | -9.53 ± 7.40 | -2.30 ± 7.11 | < 0.001 | |
| **AST** | | | | |
| Baseline | 29.63 ± 8.39 | 25.33 ± 7.68 | 0.04 | 0.05 |
| After intervention | 25.23 ± 8.11 | 24.06 ± 6.01 | 0.53 | |
| *P* | < 0.001 | 0.31 | | |
| Mean change of AST | -4.40 ± 4.87 | -1.26 ± 6.78 | 0.04 | |
| **GGT** | | | | |
| Baseline | 35.86 ± 9.27 | 37.43 ± 8.73 | 0.50 | 0.01 |
| After intervention | 29.93 ± 9.07 | 35.40 ± 7.64 | 0.01 | |
| *P* | < 0.001 | 0.05 | | |
| Mean change of GGT | -5.93 ± 6.06 | -2.03 ± 5.45 | 0.01 | |
| **WC** | | | | |
| Baseline | 105.53 ± 7.94 | 105.0 ± 9.80 | 0.81 | 0.001 |
| After intervention | 99.51 ± 7.85 | 102.76 ± 8.62 | 0.13 | |
| *P* | < 0.001 | 0.008 | | |
| Mean change of WC | -6.02 ± 4.24 | -2.24 ± 4.28 | 0.001 | |
| **Weight** | | | | |
| Baseline | 83.37 ± 11.22 | 80.46 ± 11.90 | 0.33 | 0.008 |
| After intervention | 79.98 ± 11.19 | 78.95 ± 11.87 | 0.72 | |
| *P* | < 0.001 | 0.005 | | |
| Mean change of Weight | -3.39 ± 2.53 | -1.51 ± 2.72 | 0.008 | |
| **BMI** | | | | |
| Baseline | 30.49 ± 3.12 | 29.98 ± 3.11 | 0.52 | 0.008 |
| After intervention | 29.24 ± 3.11 | 29.42 ± 3.15 | 0.82 | |
| *P* | < 0.001 | 0.005 | | |
| Mean change of BMI | -1.25 ± 0.93 | -0.56 ± 1.01 | 0.008 | |

Values are presented as mean ± standard deviation (SD). *P*: resulted from comparisons within groups by paired t-test

$P^{\dagger}$: resulted from comparisons between two groups by independent t-test. $P^{\dagger\dagger}$: resulted from comparisons mean changes between two groups by Univariate analysis of covariance after adjusting for energy intake. *DASH* Dietary approaches to stop hypertension, *MetS* Metabolic syndrome, *FLI* Fatty liver index, *HSI* Hepatic steatosis index, *ALT* Alanine transaminase, *AST* Aspartate transaminase, *GGT* Gamma-glutamyl transpeptidase, *WC* Waist circumference, *BMI* Body mass index

composition in adolescents with MetS. A meta-analysis of RCTs that was conducted by Lari et al. [15] supported the therapeutic impact of DASH diet on weight, BMI, and WC. The findings of experimental and clinical investigations in this area support our findings.

A recent meta-analysis of RCTs authenticated the blood pressure-lowering effect DASH diet [9]. Another

**Table 4** Effect of DASH diet on blood pressure and lipid profile in subjects with MetS

| Variables | Intervention group (*n* = 30) | Control group (*n* = 30) | *P* † | *P* †† |
|---|---|---|---|---|
| **DBP**, mmHg | | | | |
| Baseline | 86.26 ± 6.53 | 86.43 ± 10.02 | 0.93 | 0.04 |
| After intervention | 81.10 ± 7.22 | 84.93 ± 7.83 | 0.06 | |
| *P* | < 0.001 | 0.25 | | |
| Mean change of DBP | -5.16 ± 3.92 | -1.50 ± 7.04 | 0.01 | |
| **SBP**, mmHg | | | | |
| Baseline | 125.13 ± 10.42 | 130.56 ± 10.96 | 0.06 | 0.01 |
| After intervention | 118.16 ± 11.30 | 129.20 ± 13.74 | 0.001 | |
| *P* | < 0.001 | 0.28 | | |
| Mean change of SBP | -6.97 ± 8.21 | -1.36 ± 6.83 | 0.006 | |
| **TG**, mg/dl | | | | |
| Baseline | 180.03 ± 65.42 | 207.16 ± 81.23 | 0.16 | 0.007 |
| After intervention | 161.53 ± 64.78 | 207.76 ± 89.06 | 0.02 | |
| *P* | < 0.001 | 0.37 | | |
| Mean change of TG | -18.50 ± 14.32 | 0.60 ± 23.81 | < 0.001 | |
| **TC**, mg/dl | | | | |
| Baseline | 210.70 ± 35.16 | 204.83 ± 41.51 | 0.55 | 0.25 |
| After intervention | 194.60 ± 42.52 | 199.76 ± 47.07 | 0.65 | |
| *P* | < 0.001 | 0.25 | | |
| Mean change of TC | -16.10 ± 17.94 | -5.07 ± 23.62 | 0.04 | |
| **HDL-c**, mg/dl | | | | |
| Baseline | 43.23 ± 7.51 | 45.06 ± 9.93 | 0.42 | 0.98 |
| After intervention | 42.33 ± 6.88 | 43.66 ± 7.93 | 0.48 | |
| *P* | 0.15 | 0.17 | | |
| Mean change of HDL-c | -0.90 ± 3.40 | -1.40 ± 5.46 | 0.67 | |
| **LDL-c**, mg/dl | | | | |
| Baseline | 140.06 ± 26.70 | 129.26 ± 31.92 | 0.16 | 0.01 |
| After intervention | 126.56 ± 28.34 | 124.36 ± 36.29 | 0.79 | |
| *P* | < 0.001 | 0.15 | | |
| Mean change of LDL-c | -13.50 ± 9.58 | -4.90 ± 18.28 | 0.02 | |

Values are presented as mean ± standard deviation (SD). *P*: resulted from comparisons within groups by paired t-test

*P* †: resulted from comparisons between two groups by independent t-test. *P* ††: resulted from comparisons mean changes between two groups by Univariate analysis of covariance after adjusting for energy intake and BMI. *DASH* Dietary approaches to stop hypertension, *MetS* Metabolic syndrome, *DBP* Diastolic blood pressure, *SBP* Systolic blood pressure, *TG* Triglyceride, *TC* Total cholesterol, *HDL-c* High-density lipoprotein cholesterol, *LDL-c* Low-density lipoprotein cholesterol, *BMI* Body mass index

meta-analysis of RCTs that was conducted by Guo et al. [12] concluded that following a DASH diet for more than 8 weeks has a greater impact on DBP. Some important nutrients can affect hypertension by various mechanisms [43]. Potassium ameliorates elevated blood pressure via increasing endothelial vasodilation and natriuresis, reducing sensitivity to catecholamines, Angiotensin II, nicotinamide adenine dinucleotide phosphate (NADPH) oxidase and asymmetric dimethyl arginine, attenuating oxidative stress and inflammation and stimulating insulin sensitivity [43, 44]. Reduction of dietary sodium reduces endothelial cell stiffness and level of asymmetric dimethyl arginine, and stimulates production of nitric oxide [45, 46]. Magnesium (high in whole grains, nuts, and green leafy vegetables) via blocking calcium channels, stimulating the synthesis of nitric oxide and prostaglandin E, and attenuating the activity of inflammatory pathways acts as a blood pressure-lowering factor [44, 47, 48]. In summary, the blood pressure-lowering effect of DASH diet is well-known.

The study of Lima et al. [13] concluded that following the DASH diet for 6 months leads to a significant reduction in total cholesterol, TG, and LDL-c levels. However, DASH diet did not change levels of HDL-c [13]. A recent meta-analysis of RCTs indicated that following a DASH diet significantly improves TG [12]. However, the results of another meta-analysis of RCTs conducted by Lari et al. [15] showed that the DASH diet in an effective strategy in management of elevated TC and LDL-c, but it has no significant impact on HDL-c levels. It is an opinion that low-fat dietary patterns can decrease HDL-c levels [49–51]. As a result, one of the important reasons for the lack of beneficial impact of DASH diet on HDL-c can be its low-fat nature. Fibers can ameliorate lipid profile and reduce lipid peroxidation [39]. Soluble dietary fiber by absorbing and sequestering cholesterol attenuate hepatic absorption of cholesterol and increases cholesterol excretion [39, 40]. In addition, the consumption of legumes leads to a decrease in intrahepatic fat production [52]. Antioxidant compounds like polyphenols and carotenoids by regulating hepatic lipogenesis and hepatic $\beta$-oxidation improve blood lipid levels [53, 54].

As an important strength, this was the first study that determined the effect of DASH diet on the severity of fatty liver in subjects with MetS. The duration of the follow-up was relatively short, and this was a limitation of our RCT. As an important limitation, we did not evaluate the effects of intervention on our main outcomes in the middle of intervention period (week 6). As another limitation, accuracy of fatty liver indices is lower than liver biopsy and ultrasound in estimating the severity of fatty liver.

## Conclusions

In conclusion, the DASH diet compared to a common healthy diet was more effective in managing fatty liver and cardiovascular risk factors. The outcomes of this RCT suggest that DASH diet can be considered as a therapeutic approach in management of MetS and fatty liver disease. More well-designed clinical trials are needed to clarify the therapeutic effects of DASH diet.

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#### Authors' contributions
K.P, M.H and A.S: conducted the study; M.H: provided material and technical support; A.S: carried out the statistical analysis, and interpreted the finding; A.S: drafted the manuscript; K.P: critically revised the manuscript and supervised the study. All authors reviewed the final manuscript.

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#### Availability of data and materials
The data and materials of the current study is available from the corresponding author on reasonable request.

### Declarations

#### Ethics approval and consent to participate
The ethical committee of Baqiyatallah University of Medical Sciences in Tehran confirmed the study protocol and written informed consent. All participants signed the written informed consent before the beginning of the trial (IR.BMSU.BAQ.REC.1401.016).

#### Consent for publication
Not applicable.

#### Competing interests
The authors have declared no competing interests.

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