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ORIGINAL ARTICLE

# Association between dietary patterns and cardiovascular mortality in patients with metabolic dysfunction-associated steatotic liver disease

Yu-Jin Kwon[1] · Hye Sun Lee[2] · Ji-Won Lee[3,4]

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## Abstract

**Purpose** Given the heightened cardiovascular risk in patients with metabolic dysfunction-associated steatotic liver disease (MASLD), identifying dietary patterns associated with reduced cardiovascular risk is essential. This study aimed to investigate the association between adherence to various dietary patterns and cardiovascular disease (CVD) mortality in a middle-aged Korean MASLD population.

**Methods** Baseline data from 32,091 adults aged 40 years and older enrolled in the Korean Genome and Epidemiology Study (KoGES) between 2004 and 2013 were analyzed. Dietary intake was assessed using a validated semi-quantitative food frequency questionnaire, and principal component analysis was applied to identify distinct dietary patterns. The primary outcome was CVD mortality, assessed using Cox proportional hazards models adjusted for confounders, including age, sex, body mass index, smoking status, alcohol intake, physical activity, total calorie intake, hypertension, diabetes, and dyslipidemia.

**Results** Adherence to the Korean Mediterranean-style diet was associated with a significantly reduced risk of CVD mortality in MASLD patients, with those in the highest Korean Mediterranean-style diet pattern quartile having a 33% lower risk than those in the lowest quartile (hazards ratio: 0.67, 95% confidence interval: 0.45–1.00, $p = 0.048$). Other dietary patterns, including the processed food and dairy diet, animal protein-rich diet, grain-based diet, as well as refined carbohydrate and fat-rich diet, were not significantly associated with CVD mortality.

**Conclusions** Adherence to Korean Mediterranean-style diet pattern was associated with a lower risk of CVD mortality in Korean adults with MASLD, highlighting its potential as an effective dietary strategy for managing cardiovascular risk in MASLD patients, even in non-Western populations.

**Keywords** Dietary pattern · Metabolic dysfunction-associated steatotic liver disease · Cardiovascular disease · Mortality

✉ Hye Sun Lee
hslee1@yuhs.ac

✉ Ji-Won Lee
INDI5645@yuhs.ac

1 Department of Family Medicine, Yonsei University College of Medicine, Yongin Severance Hospital, Yongin, Republic of Korea

2 Biostatistics Collaboration Unit, Department of Research Affairs, Yonsei University College of Medicine, Seoul, Republic of Korea

3 Department of Family Medicine, Yonsei University College of Medicine, Severance Hospital, Seoul, Republic of Korea

4 Institute for Innovation in Digital Healthcare, Yonsei University, Seoul, Republic of Korea

## Introduction

Metabolic dysfunction-associated steatotic liver disease (MASLD), previously referred to as nonalcoholic fatty liver disease (NAFLD), is characterized by the accumulation of excess fat in the liver, accompanied by overweight/obesity, type 2 diabetes mellitus (T2DM), or the presence of metabolic abnormalities [1]. MASLD represents a growing public health challenge, with recent estimates indicating it affects over one-third of the global population [2]. The condition is closely associated with an increased risk of developing serious hepatic complications, such as steatohepatitis, cirrhosis, liver failure, and liver cancer [2]. Beyond liver-related morbidity, MASLD patients are also at heightened risk of cardiovascular disease (CVD), which has become the leading cause of death in this population [3].

Given the significant cardiovascular risk, the management of MASLD extends beyond liver-specific interventions to encompass strategies aimed at reducing CVD-related outcomes [2, 3]. Lifestyle modifications, particularly adopting healthier dietary patterns and increasing physical activity, remain central to managing MASLD [4]. Among these, dietary patterns, which consider the variation along with the combination of foods and nutrients consumed habitually, provide a more comprehensive view of dietary intake and its impact on health [5]. Numerous studies have shown that dietary indices, such as the Mediterranean diet (MD) and low-carbohydrate diets, are associated with improved metabolic health and reduced liver fat accumulation [6–8]. However, research specifically linking dietary patterns with cardiovascular mortality in MASLD patients remains scarce, particularly in non-Western populations.

The MD, known for its cardioprotective effects, has garnered attention as a potentially beneficial dietary pattern for reducing cardiovascular risk in MASLD patients [8]. Emphasizing high intakes of vegetables, fruits, nuts, olive oil, and legumes, along with a moderate to high intake of fish, the MD provides a balanced nutritional profile known to promote heart health [9]. Despite its potential, few studies have explored the association of the MD with cardiovascular outcomes within Asian populations, where dietary habits differ substantially from those in Western countries.

Therefore, this study aimed to identify major dietary patterns among Korean adults with MASLD and to assess their associations with CVD mortality, with a focus on the potential cardioprotective effect of the Korean Mediterranean-style diet pattern.

## Methods

### Study participants

This study was designed as a population-based prospective cohort study utilizing baseline data from the KoGES_HEXA cohort (2004–2013), which included a total of 173,195 participants aged 40 years and older. The full dataset is publicly accessible on the National Institutes of Health Korea website (https://nih.go.kr/ko/main/contents.do?menuNo=300569). For the purpose of this study, data were accessed on October 15, 2023. To create our final study population, we excluded individuals based on the following criteria: (1) with total energy intake in the extreme ranges (lower 0.25 percentile and upper 99.75 percentile) ($n = 468$); (2) consuming more than 30 g/day of alcohol for males and 20 g/day for females ($n = 14,149$); (3) passing away within 1 year of the baseline survey ($n = 134$); (4) missing mortality data ($n = 39,632$); (5) missing fatty liver index (FLI) components, such as gamma-GTP, triglyceride levels, height, weight, or waist circumference (WC) ($n = 9154$); (6) missing nutritional data ($n = 1227$); (7) with a history of acute liver disease ($n = 640$); and (8) non-eligibility to the criteria for MASLD ($n = 75,700$). After these exclusions were applied, the final sample comprised 32,091 participants, of whom 225 had CVD-related deaths (Fig. 1). All participants provided voluntary informed consent. The Institutional Review Board (IRB) at Yongin Severance Hospital reviewed and approved the study (IRB approval number: 9-2021-0066).

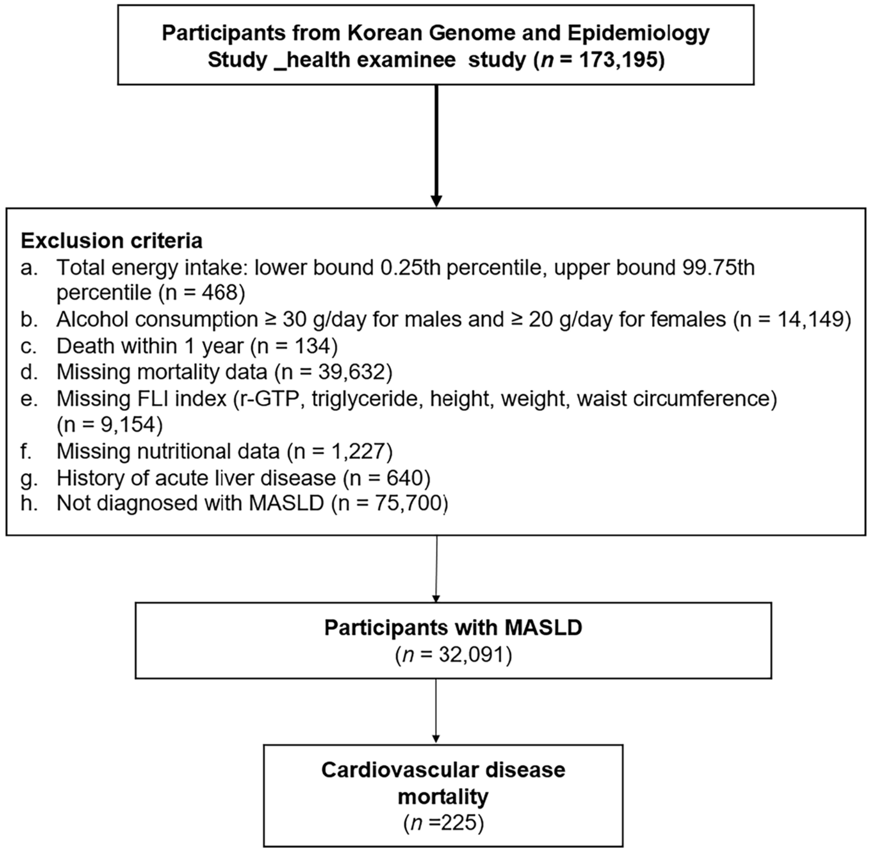
### Dietary assessment

The dietary intake of participants was assessed using a validated Korean semi-quantitative food frequency questionnaire (FFQ), which included 106 food items. Expert dietitians conducted face-to-face interviews in the homes of participants to ensure the accuracy of the responses. The FFQ covers a range of common Korean foods, categorized by standardized portion sizes, and has been validated in prior research [10]. For the analysis of dietary patterns, food items were grouped into 16 food categories (Supplementary Table 1). Participants reported the frequency of consuming each food item, which was converted to weekly intake frequency for analysis. Portion sizes were standardized based on median values from the Korean National Health and Nutrition Examination Survey, and were categorized into small, medium, or large sizes. Visual aids showing portion sizes were provided to facilitate accurate reporting. Further methodological details can be found on the KoGES website (http://www.cdc.go.kr/CDC/eng/main.jsp).

### Covariates

All health assessments were conducted by trained medical professionals. Blood pressure (BP) was measured twice while participants were seated, and blood samples were drawn after an 8-h fast. Levels of glycated hemoglobin (HbA1c), fasting blood glucose (FBG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and triglycerides were assessed using the Hitachi 7600 analyzer (Tokyo, Japan) until August 2002, and the ADVIA 1650 system (Siemens, Tarrytown, NY) thereafter. Participants self-reported smoking status, alcohol, and physical activity level. Hypertension (HTN) was defined as systolic BP (SBP) ≥ 140 mmHg, diastolic BP (DBP) ≥ 90 mmHg, physician diagnosis, or current antihypertensive treatment [11]. DM was determined based on FBG ≥ 126 mg/dL, HbA1c ≥ 6.5%, physician diagnosis, or current antidiabetic medication use [12]. Dyslipidemia was characterized by TC ≥ 240 mg/dL, TG ≥ 200 mg/dL, HDL-C < 40 mg/dL, or current treatment for lipid disorders [13].

**Fig. 1** Flowchart of participant selection




## Definition of MASLD

MASLD was diagnosed based on evidence of hepatic steatosis from blood biomarkers, in combination with at least one of the following five cardiometabolic risk factors:

1) overweight or obesity: defined as a body mass index (BMI) ≥ 23 kg/m² or WC ≥ 90 cm for men and ≥ 80 cm for women, 2) elevated BP: SBP ≥ 130 mmHg, DBP ≥ 85 mmHg, or the use of antihypertensive medications, 3) hypertriglyceridemia: TG levels ≥ 150 mg/dL or being on treatment for elevated triglycerides, 4) low HDL-C: HDL-C levels < 40 mg/dL for men and < 50 mg/dL for women, 5) elevated blood glucose: FPG ≥ 100 mg/dL, 2-h postprandial glucose ≥ 140 mg/dL, HbA1c ≥ 5.7%, or the use of glucose-lowering medications.

The FLI was calculated using the following formula:

$$\mathrm{FLI} = \frac{e^{(0.953\times\ln(\mathrm{TGs})+0.139\times\mathrm{BMI}+0.718\times\ln(\gamma\mathrm{GTP})+0.053\times\mathrm{WC}-15.745)}}{1+e^{0.953\times\ln(\mathrm{TGs})+0.\,139\times\mathrm{BMI}+0.718\times\ln(\gamma\mathrm{GTP})+0.053\times\mathrm{WC}-15.745)}}\times 100$$

Hepatic steatosis was defined as an FLI score greater than 30 [14].

## Study outcomes

Mortality data for KoGES participants was linked to the Korean National Statistics Office records, which include information on the causes of death. A unique keycode identification system enabled accurate tracking of the mortality status of each participant from the start of the study until death, study completion, or last contact. The International Classification of Diseases (ICD) codes from the National Mortality Index were used to categorize causes of death. Mortality data were collected from January 2001 through December 2019. CVD mortality included deaths under ICD-10 codes I00–I99.

## Statistical analysis

Participants were divided according to CVD mortality. Continuous data are presented as means ± standard deviations (SD), and categorical data as numbers and percentages. Independent two sample t-test was used for continuous variables, and the chi-squared test was applied to categorical variables to compare participants' clinical characteristics.

Factor analysis using principal component analysis (PCA) was perfomed to identify major dietary pattern including 16 food groups. Factors with eigenvalues greater than 1.0 were retained, as visualized in the scree plot, and orthogonal varimax rotation was applied to simplify the interpretation. Five major dietary patterns were identified, accounting for 57.4% of the total variance. The Keiser–Meyer–Olkin value was

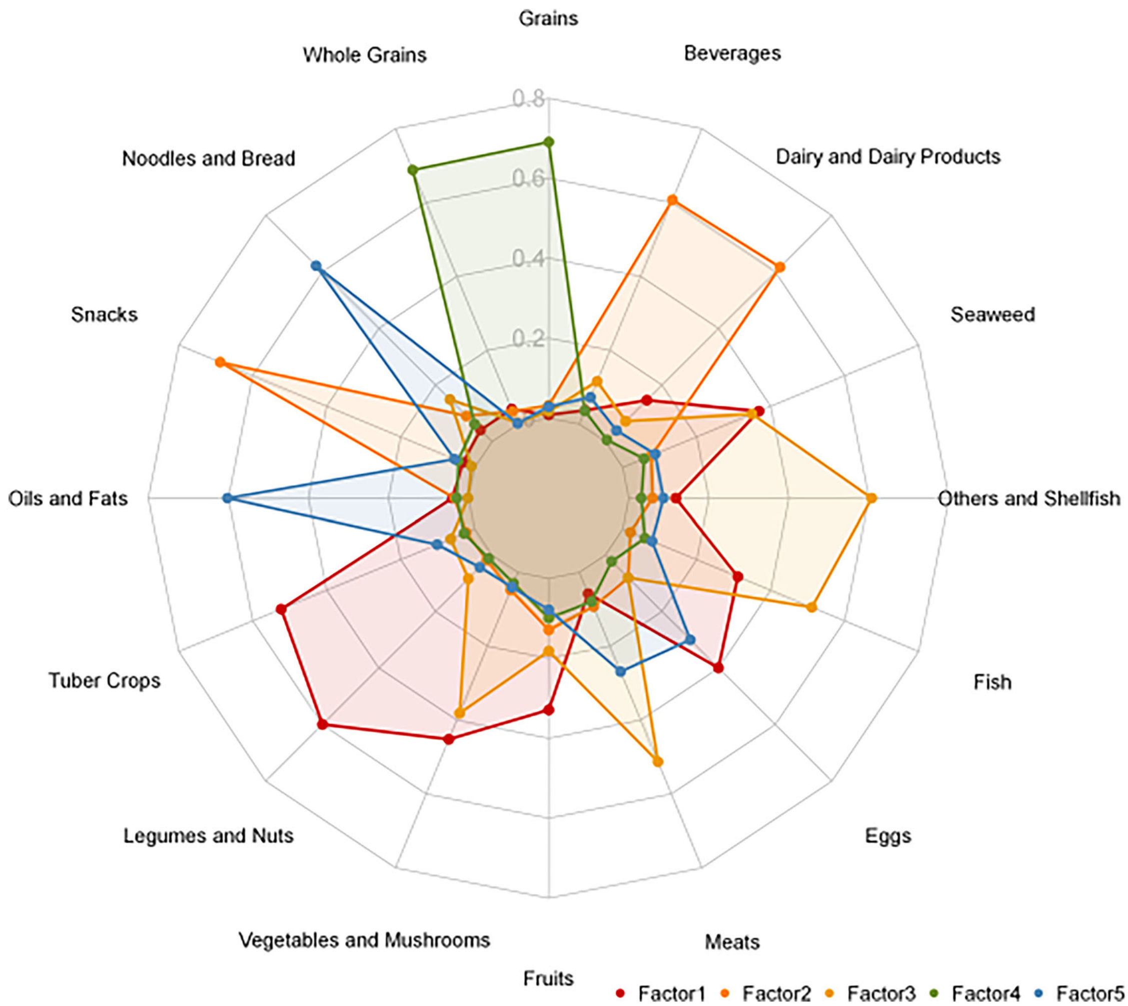



**Fig. 2** Radar chart depicting the distribution of scores across 16 food categories for five dietary patterns

0.756. Food groups with factor loadings greater than 0.20 were included in the analysis. Factor scores for each dietary pattern were calculated by summing the weighted intakes of food groups contributing to each pattern (Fig. 2 and Supplementary Table 2). The cumulative incidence of CVD mortality was assessed using Kaplan-Meier curves, with differences between dietary patterns evaluated via the log-rank test. Cox proportional hazard models were used to estimate the association between dietary patterns and CVD mortality, with hazard ratios (HR) and 95% confidence intervals (CIs) calculated. Model 1 was adjusted for age and sex. Model 2 included BMI, smoking status, alcohol intake, and regular exercise. Model 3 added total calorie intake, HTN, diabetes, and dyslipidemia. To evaluate the consistency of the associations across different population groups, subgroup analyses were conducted according to sex, hypertension, diabetes, and dyslipidemia status. All analyses were conducted using SAS software (version 9.4; SAS Institute Inc., Cary, NC) and R (version 4.1.1; R Foundation for Statistical Computing, Vienna, Austria), with a significance level set at $p < 0.05$ for all two-tailed tests.

## Results

### Baseline characteristics of the study population

Table 1 presents the baseline characteristics of the study population according to CVD mortality status. Among the 31,866 participants, 225 experienced CVD-related death. Compared to survivors, individuals who died from CVD were more likely to be men and older (both $p < 0.05$). They also had significantly higher WC, SBP, DBP, fasting glucose, and HbA1c levels (all $p < 0.05$). In contrast, total cholesterol and HDL-cholesterol levels were significantly lower in the CVD mortality group. hs-CRP levels were modestly higher, whereas no significant differences were observed for triglycerides, gamma-GTP, AST, or ALT. The prevalence of hypertension and diabetes was also

Table 1 Baseline characteristics of study population

| | Alive | CVD mortality | *P*-value |
|---|---|---|---|
| N | 31,866 | 225 | |
| Sex (men) | 16,819(52.8) | 147(65.3) | <0.001 |
| Age (years) | 54.7 ± 8.3 | 61.2 ± 8.1 | <0.001 |
| BMI (kg/m$^2$) | 26.5 ± 2.6 | 26.6 ± 2.7 | 0.697 |
| WC (cm) | 88.8 ± 6.5 | 90.9 ± 6.6 | <0.001 |
| Systolic BP (mmHg) | 127.6 ± 14.6 | 133.1 ± 17.6 | <0.001 |
| Diastolic BP (mmHg) | 79.0 ± 9.6 | 80.6 ± 11.0 | 0.015 |
| Glucose (mg/dl) | 101.0 ± 25.3 | 108.2 ± 31.5 | 0.001 |
| HbA1c (%) | 6.0 ± 0.9 | 6.3 ± 1.0 | 0.003 |
| Total cholesterol (mg/dl) | 204.0 ± 37.6 | 197.9 ± 40.7 | 0.015 |
| HDL-C (mg/dl) | 47.3 ± 10.6 | 45.0 ± 10.5 | 0.001 |
| Triglycerides (mg/dl) | 188.0 ± 112.4 | 187.6 ± 110.9 | 0.953 |
| hsCRP | 0.2 ± 0.4 | 0.3 ± 0.5 | 0.096 |
| AST (IU/L) | 26.8 ± 30.5 | 28.2 ± 15.0 | 0.167 |
| ALT (IU/L) | 30.1 ± 30.1 | 28.7 ± 19.8 | 0.293 |
| Gamma-GTP | 46.0 ± 51.1 | 52.7 ± 65.2 | 0.113 |
| Smokers, n (%) | 12,867 (40.5) | 118 (52.7) | 0.001 |
| Alcohol drinkers, n (%) | 17,305 (54.5) | 120 (53.3) | 0.724 |
| Regular exercise, n (%) | 16,135 (50.8) | 108 (48.0) | 0.409 |
| Hypertension, n (%) | 7517 (23.6) | 92 (36.1) | <0.001 |
| Diabetes mellitus, n (%) | 4236 (13.3) | 49 (21.8) | 0.002 |
| Dyslipidemia, n (%) | 24,376 (76.5) | 168 (74.5) | 0.519 |
| Total energy intake (kcal/day) | 1773.4 ± 533.9 | 1683.1 ± 513.8 | 0.012 |
| Carbohydrate (%) | 71.9 ± 6.9 | 72.8 ± 7.6 | 0.071 |
| Fat (%) | 13.6 ± 5.3 | 12.8 ± 6.0 | 0.043 |
| Protein (%) | 13.3 ± 2.6 | 13.0 ± 2.6 | 0.065 |
| Calcium (mg) | 434.2 ± 251.3 | 383.0 ± 223.2 | 0.001 |
| Phosphorus (mg) | 893.9 ± 343.8 | 829.7 ± 332.1 | 0.005 |
| Fe(mg) | 10.0 ± 4.8 | 9.1 ± 4.4 | 0.005 |
| Vit.A (R.E.) | 486.3 ± 347.0 | 430.1 ± 295.6 | 0.005 |
| Niacin (mg) | 14.7 ± 6.0 | 14.0 ± 6.1 | 0.048 |
| Vit.C (mg) | 102.5 ± 65.5 | 94.7 ± 61.7 | 0.074 |
| Zinc (ug) | 8.1 ± 3.6 | 7.5 ± 3.2 | 0.008 |
| Vit.B6 (mg) | 1.6 ± 0.7 | 1.5 ± 0.6 | 0.006 |
| Folate (ug) | 216.5 ± 120.3 | 195.4 ± 105.7 | 0.003 |
| Retinol (ug) | 66.9 ± 60.8 | 54.4 ± 54.1 | 0.001 |
| Carotene (ug) | 2440.8 ± 1888.2 | 2189.2 ± 1554.5 | 0.017 |
| Fiber (g) | 5.7 ± 2.9 | 5.3 ± 2.7 | 0.027 |
| Vit.E (mg) | 8.1 ± 4.3 | 7.3 ± 3.9 | 0.005 |

*AST* aspartate aminotransferase, *ALT* alanine aminotransferase, *BMI* body mass index, *WC* waist circumference, *BP* blood pressure; Glycated hemoglobin, *Gamma-GGT* gamma-glutamyl transferase; Hba1c, *CRP* C-reactive protein, *CVD* cardiovascular disease, *HDL* high-density lipoprotein cholesterol, *LDL* low-density lipoprotein cholesterol

significantly higher among those who died from CVD (both $p < 0.05$). Regarding dietary intake, individuals with CVD mortality consumed fewer total calories and had significantly lower intakes of various micronutrients, including calcium, phosphorus, iron, vitamin A, niacin, vitamin C, zinc, vitamin B6, folate, retinol, carotene, fiber, and vitamin E (all $p < 0.05$).

## Dietary patterns

The factor analysis identified five distinct dietary patterns based on 16 food groups. The loading matrix is shown in Fig. 2 and Supplementary Table 2. Each pattern was labeled as follows: Korean Mediterranean-style diet pattern, processed food and dairy diet, animal protein-rich diet, grain-based diet, as well as refined carbohydrate and fat-rich diet. The Korean Mediterranean-style diet pattern was heavily loaded with legumes (0.721), vegetables (0.628), seaweed (0.588), fish (0.537), tubers (0.536), and fruits (0.512), representing rich in plant-based foods and seafood. The processed food and dairy diet pattern was characterized by a high consumption of snacks (0.870), beverages (0.786), and dairy products (0.778), indicating a preference for dairy and processed snacks. The animal protein-rich diet pattern included high intakes of others, shellfish (0.749), and meat (0.714), focusing on animal protein. The grain-based diet pattern was associated with grains (0.879) and negatively associated with whole grains (−0.868), suggesting a preference for refined carbohydrates like rice and other grains over whole grains. The refined carbohydrate and fat-rich diet pattern was characterized by high intakes of noodles and bread (0.774), as well as oils and fats (0.767), rich in processed carbohydrates and fats.

The red, orange, yellow, green, and blue lines represent the Korean Mediterranean-style diet pattern, processed food and dairy diet, animal protein-rich diet, grain-based diet, as well as refined carbohydrate and fat-rich diet patterns, respectively. The radial axis shows the score range from 0–0.8. The chart illustrates variations in consumption across categories, with certain dietary patterns exhibiting higher scores in specific categories, indicating distinct characteristics of food intake among the patterns.

## Dietary patterns and CVD mortality in MASLD

Figure 3 presents the Kaplan–Meier survival curves analyzing the cumulative rates of cardiovascular mortality relative to different dietary patterns. A marginally significant difference in survival was observed for the Korean Mediterranean-style diet pattern (Factor 1), with the highest adherence group (Q4) demonstrating lower cardiovascular mortality compared to the lowest (Q1) (log-rank test,

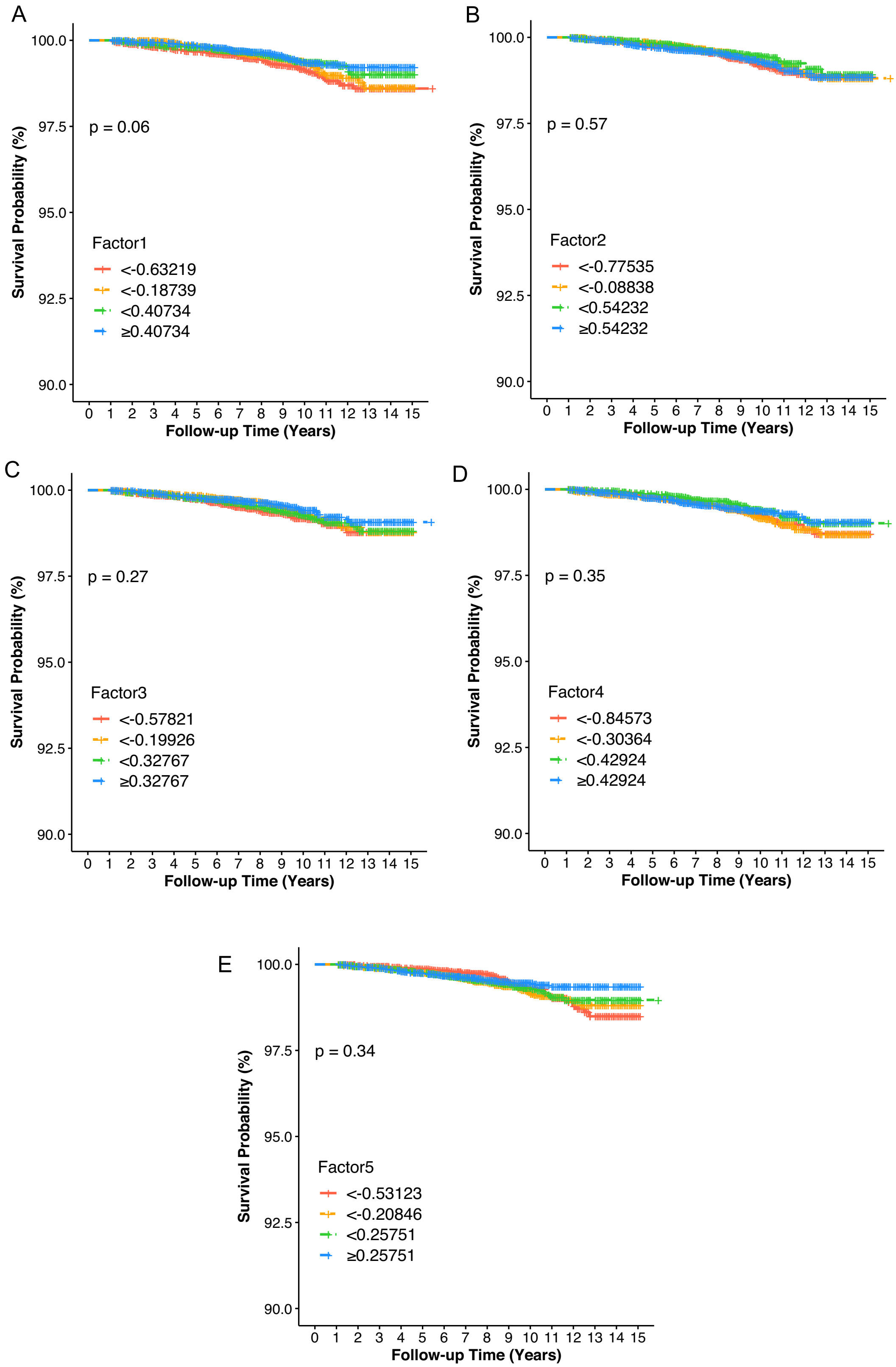



**Fig. 3** Kaplan–Meier curves for cardiovascular mortality in patients with metabolic dysfunction-associated steatotic liver disease (MASLD) based on five dietary patterns and stratified by quartiles. (**A**) Korean Mediterranean-style diet pattern, (**B**) Processed food and dairy diet, (**C**) Animal protein-rich diet, (**D**) Grain-based diet, (**E**) Refined carbohydrate and fat-rich diet

**Table 2** Cox proportional hazards regression analysis of cardiovascular mortality in MASLD participants by dietary patterns

| | Unadjusted | | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|---|---|
| | HR (95% CI) | *p* | HR (95% CI) | *p* | HR (95% CI) | *p* | HR (95% CI) | *p* |
| Korean Mediterranean-style diet | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.81 (0.57–1.15) | 0.235 | 0.76 (0.54–1.07) | 0.12 | 0.76 (0.53–1.07) | 0.114 | 0.78 (0.55–1.10) | 0.159 |
| Q3 | 0.68 (0.48–0.98) | 0.04 | 0.65 (0.45–0.93) | 0.02 | 0.63 (0.44–0.91) | 0.015 | 0.67 (0.46–0.97) | 0.035 |
| Q4 | 0.63 (0.44–0.92) | 0.015 | 0.61 (0.42–0.88) | 0.008 | 0.61 (0.42–0.89) | 0.010 | 0.67 (0.45–1.00) | 0.048 |
| Processed food and dairy diet pattern | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.89 (0.62–1.28) | 0.528 | 0.99 (0.69–1.42) | 0.97 | 1.00 (0.70–1.44) | 0.987 | 1.07 (0.75–1.55) | 0.701 |
| Q3 | 0.77 (0.53–1.12) | 0.17 | 0.82 (0.56–1.20) | 0.313 | 0.81 (0.56–1.19) | 0.283 | 0.89 (0.61–1.31) | 0.563 |
| Q4 | 0.94 (0.66–1.34) | 0.73 | 1.07 (0.75–1.54) | 0.701 | 1.03 (0.71–1.48) | 0.888 | 1.20 (0.82–1.76) | 0.355 |
| Animal protein-rich diet pattern | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.81 (0.57–1.17) | 0.262 | 0.87 (0.61–1.25) | 0.449 | 0.88 (0.61–1.26) | 0.479 | 0.90 (0.63–1.30) | 0.587 |
| Q3 | 0.90 (0.63–1.27) | 0.544 | 1.03 (0.72–1.46) | 0.879 | 1.02 (0.72–1.46) | 0.905 | 1.11 (0.77–1.59) | 0.575 |
| Q4 | 0.70 (0.48–1.01) | 0.057 | 0.83 (0.57–1.21) | 0.326 | 0.84 (0.58–1.23) | 0.379 | 0.99 (0.66–1.49) | 0.958 |
| Grain-based diet pattern | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 1.03 (0.72–1.46) | 0.88 | 1.12 (0.79–1.58) | 0.539 | 1.11 (0.78–1.57) | 0.572 | 1.04 (0.72–1.48) | 0.85 |
| Q3 | 0.77 (0.53–1.12) | 0.168 | 0.89 (0.61–1.30) | 0.542 | 0.89 (0.61–1.30) | 0.536 | 0.81 (0.54–1.19) | 0.277 |
| Q4 | 0.83 (0.58–1.20) | 0.33 | 1.00 (0.69–1.44) | 0.993 | 0.99 (0.68–1.43) | 0.941 | 0.92 (0.63–1.35) | 0.681 |
| Refined carbohydrate and fat-rich diet pattern | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 1.08 (0.76–1.54) | 0.656 | 1.19 (0.83–1.69) | 0.343 | 1.20 (0.84–1.71) | 0.307 | 1.17 (0.82–1.67) | 0.387 |
| Q3 | 0.99 (0.69–1.42) | 0.952 | 1.23 (0.85–1.78) | 0.268 | 1.24 (0.86–1.80) | 0.246 | 1.27 (0.88–1.84) | 0.203 |
| Q4 | 0.76 (0.52–1.13) | 0.176 | 1.02 (0.69–1.52) | 0.916 | 1.03 (0.69–1.55) | 0.869 | 1.14 (0.75–1.74) | 0.534 |

Model 1: adjusted for age and sex

Model 2: adjusted for age, sex, BMI, smoking, alcohol drinking, regular exercise

Model 3: adjusted for age, sex, BMI, smoking, alcohol drinking, regular exercise, total calorie intake, HTN, dyslipidemia, and diabetes

$p = 0.06$). No significant differences were observed for the processed food and dairy diet (Factor 2; $p = 0.57$), animal protein-rich diet (Factor 3; $p = 0.27$), grain-based diet (Factor 4; $p = 0.35$), or refined carbohydrate and fat-rich diet (Factor 5) (log-rank test, $p = 0.34$).

For each dietary pattern, the red, yellow, green, and blue curves represent Quartile 1, Quartile 2, Quartile 3, and Quartile 4, respectively, illustrating the cumulative probability of cardiovascular mortality over time, with each dietary pattern showing varying mortality risks across quartiles.

Table 2 presents the results of the Cox proportional hazards regression analysis for the association between dietary patterns and CVD mortality in MASLD patients. The Korean Mediterranean-style diet pattern was significantly associated with a reduced risk of CVD mortality. In the fully adjusted model (Model 3), participants in Q4 of the MD pattern had a 33% lower risk of CVD mortality than those in Q1 (HR: 0.67, 95% CI: 0.45–1.00, $p = 0.048$) Table 3. This protective association was consistent across all models. In contrast, the processed food and dairy diet pattern showed no significant association with CVD mortality after adjustment for confounders. The HR for the Q4 compared to the Q1 was 1.20 (95% CI: 0.82–1.76, $p = 0.355$) in the fully adjusted model (Model 3). Similarly, the animal protein-rich diet pattern was not significantly associated with CVD mortality in the adjusted models. For the grain-based diet pattern, no significant association was observed in the fully adjusted model (HR: 0.92, 95% CI: 0.63–1.35, $p = 0.681$). Lastly, the refined carbohydrate and fat-rich diet pattern exhibited no significant association in the fully adjusted model (HR: 1.14, 95% CI: 0.75–1.74, $p = 0.534$).

## Subgroup analyses of the Korean mediterranean-style diet pattern on CVD mortality in MASLD

To further explore the significant association observed between adherence to the Korean Mediterranean-style diet

**Table 3** Subgroup analyses of cardiovascular mortality in MASLD participants according to Korean mediterranean-style diet pattern scores, stratified by sex, hypertension, diabetes, and dyslipidemia status

| | Unadjusted HR (95% CI) | *p* | Model 1 HR (95% CI) | *p* | Model 2 HR (95% CI) | *p* | Model 3 HR (95% CI) | *p* |
|---|---|---|---|---|---|---|---|---|
| Men | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.81 (0.53–1.23) | 0.327 | 0.72 (0.47–1.10) | 0.127 | 0.72 (0.47–1.09) | 0.118 | 0.74 (0.49–1.13) | 0.165 |
| Q3 | 0.81 (0.53–1.24) | 0.336 | 0.70 (0.45–1.07) | 0.099 | 0.68 (0.45–1.05) | 0.085 | 0.73 (0.47–1.13) | 0.153 |
| Q4 | 0.60 (0.36–0.98) | 0.042 | 0.49 (0.30–0.80) | 0.005 | 0.48 (0.29–0.80) | 0.004 | 0.53 (0.31–0.89) | 0.017 |
| Women | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.93 (0.50–1.75) | 0.823 | 0.89 (0.47–1.66) | 0.708 | 0.91 (0.48–1.70) | 0.758 | 0.91 (0.48–1.71) | 0.762 |
| Q3 | 0.60 (0.30–1.20) | 0.15 | 0.61 (0.31–1.21) | 0.157 | 0.59 (0.29–1.19) | 0.141 | 0.59 (0.29–1.21) | 0.149 |
| Q4 | 0.84 (0.46–1.55) | 0.581 | 0.85 (0.46–1.57) | 0.607 | 0.90 (0.49–1.67) | 0.739 | 0.95 (0.49–1.84) | 0.874 |
| Without HTN | | | | | | | | |
| Q1 | | | | | | | | |
| Q2 | 0.67 (0.43–1.03) | 0.069 | 0.62 (0.40–0.96) | 0.031 | 0.61 (0.39–0.94) | 0.027 | 0.63 (0.40–0.98) | 0.039 |
| Q3 | 0.68 (0.44–1.05) | 0.083 | 0.64 (0.42–1.00) | 0.049 | 0.62 (0.40–0.97) | 0.037 | 0.67 (0.42–1.05) | 0.078 |
| Q4 | 0.53 (0.33–0.85) | 0.009 | 0.51 (0.32–0.82) | 0.005 | 0.52 (0.33–0.84) | 0.007 | 0.59 (0.36–0.97) | 0.038 |
| With HTN | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 1.13 (0.64–2.01) | 0.669 | 1.10 (0.62–1.96) | 0.739 | 1.11 (0.63–1.97) | 0.718 | 1.11 (0.62–1.98) | 0.719 |
| Q3 | 0.69 (0.36–1.33) | 0.27 | 0.66 (0.34–1.28) | 0.219 | 0.66 (0.34–1.27) | 0.21 | 0.67 (0.34–1.31) | 0.243 |
| Q4 | 0.85 (0.46–1.57) | 0.61 | 0.83 (0.45–1.54) | 0.553 | 0.83 (0.44–1.54) | 0.547 | 0.84 (0.44–1.63) | 0.616 |
| Without Diabetes | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.80 (0.54–1.19) | 0.276 | 0.76 (0.51–1.12) | 0.166 | 0.76 (0.51–1.12) | 0.161 | 0.78 (0.53–1.16) | 0.219 |
| Q3 | 0.77 (0.52–1.14) | 0.186 | 0.73 (0.49–1.09) | 0.12 | 0.70 (0.47–1.05) | 0.087 | 0.74 (0.49–1.12) | 0.151 |
| Q4 | 0.54 (0.35–0.84) | 0.006 | 0.51 (0.33–0.80) | 0.003 | 0.52 (0.33–0.81) | 0.004 | 0.55 (0.35–0.88) | 0.013 |
| With diabetes | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.79 (0.38–1.67) | 0.544 | 0.72 (0.34–1.51) | 0.385 | 0.74 (0.35–1.55) | 0.424 | 0.77 (0.36–1.62) | 0.487 |
| Q3 | 0.37 (0.15–0.97) | 0.042 | 0.34 (0.13–0.88) | 0.026 | 0.36 (0.14–0.92) | 0.034 | 0.39 (0.15–1.03) | 0.059 |
| Q4 | 0.94 (0.46–1.93) | 0.87 | 0.93 (0.46–1.92) | 0.853 | 0.97 (0.47–1.99) | 0.929 | 1.16 (0.53–2.54) | 0.716 |
| Without dyslipidemia | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 1.11 (0.54–2.28) | 0.766 | 1.01 (0.49–2.07) | 0.986 | 1.00 (0.49–2.04) | 0.991 | 0.98 (0.47–2.02) | 0.948 |
| Q3 | 0.68 (0.30–1.53) | 0.351 | 0.64 (0.29–1.45) | 0.287 | 0.65 (0.29–1.46) | 0.298 | 0.64 (0.28–1.46) | 0.29 |
| Q4 | 1.16 (0.57–2.35) | 0.68 | 1.04 (0.51–2.12) | 0.909 | 1.07 (0.52–2.18) | 0.859 | 1.07 (0.50–2.30) | 0.863 |
| With dyslipidemia | | | | | | | | |
| Q1 | ref | | ref | | ref | | ref | |
| Q2 | 0.74 (0.49–1.10) | 0.131 | 0.70 (0.47–1.04) | 0.079 | 0.70 (0.47–1.04) | 0.081 | 0.73 (0.49–1.08) | 0.118 |
| Q3 | 0.69 (0.46–1.03) | 0.072 | 0.66 (0.44–0.99) | 0.044 | 0.63 (0.42–0.96) | 0.03 | 0.68 (0.45–1.04) | 0.073 |
| Q4 | 0.50 (0.32–0.78) | 0.002 | 0.49 (0.31–0.77) | 0.002 | 0.50 (0.32–0.78) | 0.002 | 0.55 (0.34–0.89) | 0.015 |

Model 1 was adjusted for age and sex. Model 2 was further adjusted for BMI, smoking status, alcohol drinking, and regular exercise. Model 3 included additional adjustments for total calorie intake, hypertension, dyslipidemia, and diabetes. In subgroup analyses stratified by sex, hypertension, diabetes, and dyslipidemia status, the stratifying variable was excluded from the corresponding model to avoid over-adjustment

pattern and CVD mortality among MASLD participants, we conducted subgroup analyses stratified by sex, hypertension, diabetes, and dyslipidemia status (Table 3). Among men, those in the highest quartile (Q4) of adherence to the dietary pattern had a significantly lower risk of CVD mortality compared to the lowest quartile (Q1), with a fully adjusted hazard ratio (HR) of 0.53 (95% CI: 0.31–0.89; $p = 0.017$). However, this association was not statistically significant in women across all quartiles. When stratified by hypertension status, a significant inverse association was observed in participants without hypertension, particularly in Q4 (HR: 0.59; 95% CI: 0.36–0.97; $p = 0.038$), while no significant association was seen among those with hypertension. Among participants without diabetes, those in Q4 showed a significantly reduced risk of CVD mortality (HR: 0.55; 95% CI: 0.35–0.88; $p = 0.013$), whereas no significant association was observed among those with diabetes. Finally, among those with dyslipidemia, higher adherence to the dietary pattern was associated with a significantly lower risk of CVD mortality in Q4 (HR: 0.55; 95% CI: 0.34–0.89; $p = 0.015$). No such associations were observed in those without dyslipidemia. These findings suggest that the protective effects of Korean Mediterranean-style diet pattern on CVD mortality may be more pronounced among men, and in individuals without hypertension or diabetes, as well as in those with dyslipidemia.

## Discussion

This study examined the relationship between dietary patterns and CVD mortality in a middle-aged and older Korean population with MASLD. Our findings suggest that adherence to the Korean Mediterranean-style diet pattern, which shares characteristics with the MD, is associated with a significantly reduced risk of CVD mortality among MASLD patients, whereas other dietary patterns showed no significant associations.

These results indicate that, similar to the well-established cardiovascular benefits observed in Western populations [15–18], the MD may also effectively reduce cardiovascular risk in MASLD patients within Asian populations, despite substantial differences in regional dietary habits. A meta-analysis of 19 prospective studies reported an inverse association between adherence to the MD and the risk of all-cause mortality, supporting these findings [19]. The reduction in mortality risk was observed across both Mediterranean and non-Mediterranean regions, though it was more pronounced in Mediterranean countries, underscoring the adaptability and potential universal benefit of the diet [19].

The MD, characterized by high intakes of vegetables, fruits, nuts, olive oil, legumes, and moderate to high consumption of fish, has long been recognized for its cardiovascular benefits [15, 20–23]. Previous studies, including the landmark PREDIMED (PREvención con DIeta MEDiterránea) trial, demonstrated that higher adherence to the MD was associated with reduced levels of oxidized LDL cholesterol [15]. Furthermore, a combined analysis of the MedLey randomized controlled trial and EPIC-InterAct study found that adherence to the MD, assessed using a biomarker score, was associated with a lower risk of T2DM [22]. A systematic review and meta-analysis of randomized controlled trials revealed that the MD contributed to a modest but significant reduction in both SBP and DBP [23].

Consistent with previous findings, our study demonstrated that participants in the highest quartile (Q4) of adherence to the Korean Mediterranean-style diet pattern had a 33% lower risk of CVD mortality compared to those in the lowest quartile (Q1). Our results contribute to the existing body of evidence indicating that the MD can reduce CVD mortality risk in populations with elevated metabolic risks. Although prior studies conducted in patients with metabolic syndrome and cancer survivors have shown that the MD is associated with lower all-cause and CVD mortality [24, 25], research on its impact specifically on CVD mortality in MASLD patients remains limited. The benefits of the MD are largely attributed to its anti-inflammatory, antioxidant, and lipid-lowering properties, stemming from nutrient-dense and minimally processed foods that provide essential vitamins, healthy fats, and polyphenols [20, 21, 26]. By reducing hepatic fat and improving lipid profiles [6, 8], the MD improves the metabolic disturbances associated with MASLD. The balanced intake of unsaturated fats, fiber, and antioxidants in the MD can improve insulin sensitivity and reduce systemic inflammation, both of which are critical in managing MASLD and reducing CVD risk.

Asian dietary habits differ from those in Western countries, with lower overall fat intake and higher reliance on rice and soy-based foods [27]. In this study, factor analysis identified specific dietary characteristics, including high loadings of legumes and nuts, vegetables and mushrooms, seaweed, fish, tuber crops, and fruits under Factor 1, labeled as the Korean Mediterranean-style diet pattern, but low loadings of oils and fats. This pattern reflects lower fat intake in typical Korean diets than in Western diets, suggesting that adapting the MD for Korean MASLD patients may offer cardioprotective benefits while respecting traditional dietary practices. Our study of a Korean MASLD population provides evidence that the cardiovascular benefits of the MD may extend to non-Western settings, supporting that diets with healthy fat and plant-based nutrients offer universal protective effects against CVD, irrespective of cultural differences.

Our subgroup analyses provide additional insights into the population-specific effectiveness of the Korean Mediterranean-style diet pattern in reducing CVD mortality among individuals with MASLD. The protective association was particularly evident in men, individuals without hypertension or diabetes, and those with dyslipidemia. These findings suggest potential heterogeneity in dietary responsiveness depending on baseline cardiometabolic conditions.

The stronger association observed in men may reflect sex-specific differences in dietary metabolism or cardiovascular risk profiles. The lack of significance in women could be partially attributed to lower event rates or hormonal factors influencing cardiovascular outcomes [28]. Furthermore, the significant benefits observed in individuals without hypertension or diabetes highlight the importance of early dietary intervention in relatively metabolically stable populations before irreversible vascular damage occurs. Interestingly, participants with dyslipidemia demonstrated a pronounced benefit, suggesting that individuals with lipid abnormalities may derive substantial cardiovascular protection from increased consumption of plant-based and marine-derived foods. These components are rich in fiber, antioxidants, and omega-3 fatty acids, which are known to exert lipid-lowering, anti-inflammatory, and endothelial-protective effects [29]. Collectively, these findings support the clinical relevance of promoting a traditional Korean Mediterranean-style diet pattern—particularly among high-risk subgroups such as men and individuals with dyslipidemia—as part of a comprehensive strategy to mitigate cardiovascular risk in patients with MASLD.

Conversely, the processed food and dairy diet, animal protein-rich diet, grain-based diet, and refined carbohydrate and fat-rich diet patterns were not significantly associated with CVD mortality in our study. This may be due to the mixed composition of these patterns, which include both potentially beneficial and harmful foods. For instance, the processed food and dairy diet combined nutrient-rich dairy products with ultra-processed snacks and sugar-sweetened beverages, potentially negating any positive effects [30]. The animal protein-rich diet, high in red meat and shellfish, may not have shown an effect due to the adverse cardiovascular impact of excessive red and processed meat intake [31]. Similarly, the grain-based diet, dominated by refined grains and lacking whole grains, likely reflects traditional dietary habits centered on white rice, which may promote insulin resistance and inflammation in metabolically vulnerable individuals [27]. The refined carbohydrate and fat-rich diet also showed no association, possibly because the presence of unsaturated fats was counterbalanced by high-glycemic, nutrient-poor carbohydrates. Additionally, the inability to distinguish between types of fat intake may have limited interpretation. These null findings underscore the importance of overall dietary quality and the synergy between food components. Future studies should incorporate more detailed food classification and objective dietary markers to better understand these complex relationships.

Our study has several limitations should be acknowledged. First, this is an observational study, precluding definitive conclusions regarding causality. Second, dietary intake was assessed using FFQ, which may not capture long-term dietary habits accurately. Furthermore, the FFQ was self-reported, potentially leading to recall bias. Third, despite a large sample size, our findings may not be generalizable to other populations, particularly those outside Asia. Finally, potential interactions between dietary patterns and other lifestyle factors, such as physical activity or medication use, were not considered, which may influence cardiovascular outcomes.

Despite these limitations, this study has several notable strengths. First, it is the first study to examine the impact of the Korean Mediterranean-style diet pattern on CVD mortality in a Korean MASLD population, filling a significant gap in understanding non-Western dietary influences on MASLD outcomes. Second, the large sample size, long follow-up period, and use of a well-established cohort enhance the reliability and robustness of our findings.

## Conclusion

Adherence to the Korean Mediterranean-style diet pattern, which closely resembles the MD, was associated with a reduced risk of CVD mortality in Korean adults with MASLD, highlighting its potential cardioprotective effects in non-Western populations. These findings suggest that the MD could be an effective dietary strategy for MASLD management, particularly for reducing cardiovascular risk. Further research, including randomized controlled trials, is warranted to confirm these findings and clarify the mechanisms through which dietary patterns impact cardiovascular health in MASLD.

### Data availability

No datasets were generated or analysed during the current study.

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1007/s12020-025-04365-x.

**Author contributions** Conceptualization, Y.J.K., H.S.L., and J.W.L.; methodology, H.S.L.; software, Y.C.L., H.S.L., Y.J.K., and J.W.L.; validation, H.S.L.; formal analysis, Y.J.K., H.S.L., and J.W.L.; investigation, Y.J.K., H.S.L., and J.W.L.; resources, Y.J.K., H.S.L., and J.W.L.; data curation, Y.J.K., H.S.L., and J.W.L.; writing—original draft preparation, Y.J.K., H.S.L., and J.W.L.; writing—review and editing, H.S.L. and J.W.L.; supervision, J.W.L.; All authors have read and agreed to the published version of the manuscript.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no competing interests.

**Data transparency** Information about the KoGES dataset and the data-sharing procedures can be found on the website of the National Research Institute of Health, under the Korea Disease Control and Prevention Agency, Ministry for Health and Welfare, Korea (https://nih.go.kr/ko/main/contents.do?menuNo=300566, accessed on 26th June 2024). R source codes are available upon request.

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