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Short-term Effects of Eating Behavior Modification on Metabolic Syndrome-Related Risks in Overweight and Obese Korean Adults

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Background: We investigated whether eating behavior modification improves metabolic syndrome (MetS)-related risks in overweight/obese Korean adults, and identified dietary factors that improve metabolic status.

Methods: Among 159 volunteers, 71 with a body mass index ≥23 kg/m^2 and without other chronic diseases participated in the 8-week intervention, among which 54 participants who completed the intervention were included in the analyses. At baseline, patients were categorized either metabolically healthy obese (MHO; <3 MetS risk factors, n=42) or metabolically unhealthy obese (MUHO; ≥3 MetS risk factors, n=12), and then educated regarding how to choose healthy foods and meals.

Results: Lipid profiles and anthropometric and glycemic parameters were significantly improved among all participants after the intervention. Changes in waist circumference (P= 0.025), and glycemic parameters (glucose, P=0.046, insulin, P=0.005, C-peptide, P=0.041) were positively correlated with changes in calorie intake from snacks. Changes in visceral fat area were negatively correlated with changes in total calorie intake (P=0.046), and positively correlated with those in calorie intake from dietary fats (P=0.039). In addition, changes in insulin (P=0.013) and C-peptide (P=0.008) concentrations were negatively correlated with changes in dietary fiber intake at dinner. After the intervention, 83.3% of initially MUHO participants became MHO and 16.7% of MHO participants became MUHO.

Conclusion: Eating behavior modification may be an important strategy to improve metabolic factors in overweight/obese people.

Key words: Eating, Behavior, Overweight, Obesity, Metabolic syndrome

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INTRODUCTION

Obesity, a global health issue, is a problematic metabolic disorder[1] that may increase the risks of hypertension, dyslipidemia, metabolic syndrome (MetS), type 2 diabetes, and cardiovascular disease (CVD).[2,3] The World Health Organization (WHO; 2018) reported that 39% of adults aged 18 years and older were overweight (body mass index [BMI] ≥25 kg/m^2) and 13% were obese (BMI

≥ 30 kg/m^2) in 2016 and 39 million children under the age of 5 were overweight or obese in 2020.[4] The WHO report also estimated that more than one billion people will be obese by 2030.[5] In contrast, Korean obesity guidelines define obesity as a BMI ≥ 25 kg/m^2, and overweight as a BMI ≥ 23 and < 25.0 kg/m^2 (Korean Society for the Study of Obesity, Seoul, Korea). The Korean National Health Examination and Nutrition Survey (KNHANES) has reported that 43.1% of male adults and 27.4% of female adults were obese (BMI ≥ 25 kg/m^2) in 2020.[6] However, it has been suggested that the obesity criteria for Koreans need revision, although consensus on revised criteria has not been established; the current obesity criteria for Koreans have therefore remain unchanged for the time being. Nonetheless, obesity-related disease continues to increase among Korean people with BMI ≥ 23 kg/m^2 (public hearing, the Korean Society for the Study of Obesity, Seoul, Korea; September 1, 2016). However, not all overweight and obese people have cardiometabolic risk factors (i.e., increased waist circumference [WC]), blood pressure, serum triglyceride [TG]) and fasting glucose concentrations, and reduced serum high-density lipoprotein cholesterol [HDL-C] concentrations).[7-10] Overweight and obese people can be classified according to both BMI and metabolic health status.[9] Metabolically healthy obese (MHO) individuals have a BMI ≥ 25 kg/m^2 while maintaining acceptable insulin sensitivity, lipid profiles, inflammatory response and/or blood pressure, such that they have less than two of five MetS risk factors.[7-11] Metabolically unhealthy obese (MUHO) individuals have a BMI ≥ 25 kg/m^2 and three or more MetS risk factors.[12] According to Rasaei et al.,[11] MHO individuals are more likely to have cardiometabolic risk factors than those who are considered metabolically healthy normal weight (MHNW);[12] interestingly, the cardiometabolic risks observed in MHO people are likely to be much lower than those shown in MUHO ones.[7] Therefore, MHO may be considered an intermediate status that may progress to cardiometabolic disease. This novel approach to identify individuals with MHO and MUHO highlights the need for optimal and individualized treatment of overweight and obesity.[8,9] According to Stelmach-Mardas and Walkowiak,[10] the traditional lifestyle intervention for MHO and MUHO aims to reduce body weight by limiting daily calorie intake and increasing physical exercise. Most of the dietary interventions suggest energy restriction by reducing the usual calorie intake by approximately 500 kcal per day or lowering the proportion of carbohydrates less than 50% in daily calorie intake.[10,13] Many weight loss interventions to improve metabolic profiles of people with MHO and MUHO have been assessed, but few studies have analyzed factors other than losing weight that may improve metabolic status.[8,10]

This study aimed to investigate whether eating behavior modification improves MetS-related risk factors in overweight and obese Korean adults according to Korean guidelines, and to identify the specific factors that improve metabolic status, including eating habits and dietary factors (e.g., calorie intake, and macronutrient composition. etc.).

METHODS

Study participants

Study participants (≥ 21 years) were recruited through public advertisement. Initially, 159 Korean adults participated in the baseline screening, of which 88 were excluded (51 were categorized as MHNW; 37 either had a diagnosis of another chronic disease, such as diabetes, dyslipidemia, CVD, coronary heart disease, stroke, and cancer, or were taking medications). After screening, 71 participants were enrolled in the eating behavior modification intervention for 8 weeks. During the intervention, 17 participants dropped out due to personal reasons (i.e., relocation, leg fracture, or work conflicts), such that 54 participants were included in the analyses. The study goal was explained to them and written informed consent was obtained. The study protocol was approved by the Institutional Review Board of Dong-A University (IRB No. 2-104709-AB-N-01-201603-BR-001-10).

Study design

The participants undertook the eating behavior modification for overweight and obese adults (BMI ≥ 23 kg/m^2 or WC ≥ 90 cm in men, WC ≥ 85 cm in women) in accordance with Korean obesity guidelines for 8 weeks.[6,14] Each participant visited our clinic twice, at week 0 (baseline) and week 8 (after), for measurement of their anthropometric parameters and collection of basic information, fasting blood samples, and food records. Basic information included demographics, medical history, and family history. Based on the data obtained at week 0, participants were categorized into two groups:

MHO (none or 1–2 MetS risk factors) and MUHO (≥ 3 MetS risk factors). Education regarding eating behavior modification was provided to the participants at their first visit. In addition, cell phone text messages were sent to the participants every 2 weeks during the intervention period to motivate them to follow the program.

Dietary education

Eating behavior education was provided by a registered clinical dietitian, with the content having been developed by the research team based on the guidelines of Korean Dietetic Association and Dietary Reference Intakes for Koreans (KDRIs) 2015. At the first visit, subgroups of participants received education together, and then also had individualized counseling for 1 hour. The content of the education materials included materials addressing, "What is metabolic syndrome?" and "Recommendation for eating behavior modification." An example of the latter is as follows: (1) regular and healthy eating patterns by using the food exchange table, food model, and calorie table for restaurant foods eaten outside the home; (2) healthy food choice method (appropriate amounts of mixed grains, rice, beans, vegetables, and dairy foods, and reduced amounts of simple sugars and alcohol); (3) smart tips for eating out; and (4) cooking strategies to reduce the intake of sodium and saturated fats. In personalized counseling, the optimal total calorie intake (TCI) for a healthy body weight was calculated based on the estimated individual basal metabolic rate and ideal body weight. After that, each participant was encouraged to make a basic 1-day meal plan for a day based on the calculated TCI using the food exchange table with guidance from the dietitian. Participants were able to easily contact the dietitian during the education and intervention period if they had questions about the modification.

Dietary survey

A registered clinical dietitian provided the participants with written and verbal instructions as to how to record their dietary intake and lifestyle. Information on each participant's usual diet was obtained using a 24-hour recall survey. To assess the dietary intake during the intervention period, dietary records for three days (2 weekdays and 1 weekend day) were recorded by each participant and confirmed by a dietitian at the week 8 visit. Nutrient content from the diet records of each individual was analyzed using the Computer Aided Nutritional analysis program (CAN-pro 4.0; Korean Nutrition Society, Seoul, Korea).

Anthropometric measurements, and basic parameters

Anthropometric measurements and basic parameters were measured while the participants wore light clothes and had removed their shoes. Height, weight, body fat percentage, and skeletal muscle mass and visceral fat area (VFA) were measured using an automatic body composition analyzer (N20; AIIA Communication Inc., Seongnam, Korea) without metallic materials. BMI was computed as body weight in kilograms divided by the square of the height in meters (kg/m^2). The WC was measured using a measuring tape. Blood pressure was measured at the arm while seated after a period of rest using an automatic blood pressure monitor (HEM-7220; Omron, Matsusaka, Japan).

Blood collection, serum lipid profiles, and glycemic parameters

Blood samples were collected in plain tubes and ethylenediaminetetraacetic acid (EDTA)-treated tubes in the morning after an 8-hour fast. Blood samples were separated into serum or plasma by a centrifuge, aliquoted and stored at −80°C before analyses. Serum TG concentrations and total cholesterol were measured using kits on a Hitachi 7150 autoanalyzer (Hitachi, Tokyo, Japan). After precipitation of serum chylomicrons with dextran sulfate magnesium, the concentrations of low-density lipoprotein cholesterol (LDL-C) and HDL-C in the supernatant were analyzed enzymatically. The serum glucose concentration was measured using a glucose oxidase method with a Beckman glucose analyzer (Beckman Instruments, Irvine, CA, USA). The glycosylated hemoglobin (HbA1c) concentration was measured using a glycated hemoglobin analyzer (SD A1cCare; SD Biosensor Inc., Suwon, Korea). The serum insulin and C-peptide concentrations were assessed using radioimmunoassay methods. The homeostasis model assessment insulin resistance (HOMA-IR) was calculated using HOMA method developed by Matthews et al.[15]

Statistical analyses

All statistical analyses were performed using IBM SPSS version 24.0 (IBM Corp., Armonk, NY, USA). Proportions were tested us-

ing the chi-square method; differences in within-group means before and after the intervention were assessed using a general linear model with adjustment for confounding factors (i.e., age and sex); differences between the baseline values and those obtained after the intervention between the MHO and MUHO group were assessed using Student t-test. Spearman's correlation test was used to describe associations between eating behavior modification and MetS-related parameters. Results were described as mean ± standard error, percentages, or correlation coefficient. A two-tailed *P*-value less than 0.05 was considered significant.

RESULTS

Baseline characteristics of study participants

Table 1 presents the baseline characteristics of all of the participants and each gender group. The mean age and percentages of current cigarette smokers and current alcohol drinkers among the total participants were 42.6 ± 1.77 years, 9.3%, and 74.1%, respectively. The men were slightly younger than the women ($P < 0.01$), but the percentages of participants who smoked cigarettes and drank alcohol were not significantly different between men and women. The percentage of participants who ate three meals per day was reported to be 38.9%, and 55.6% ate two meals per day, while 5.6% ate irregularly. The percentages of participants who frequently skipped breakfast, frequently overate, or ate outside the home more than four times per week were 38.9%, 18.5%, and 27.8%, respectively. There were no significant differences in these parameters between male and female participants. In addition, study participants were also categorized as being MHO (n = 42, 77.8%) or MUHO (n = 12, 22.2%) at baseline.

Table 1. Baseline characteristics of study participants

Variable	Total (n = 54)	Women (n = 34)	Men (n = 20)
Age (yr)	42.6 ± 1.77	47.2 ± 2.16	35.0 ± 2.22*
Post-menopause	-	19 (55.9)	-
Current cigarette smoker	5 (9.3)	2 (5.9)	3 (15.0)
Current alcohol drinker	40 (74.1)	21 (61.8)	19 (95.0)
Meal frequency per day			
3	21 (38.9)	16 (47.1)	5 (25.0)
2	30 (55.6)	16 (47.1)	14 (70.0)
Irregular	3 (5.6)	3 (5.9)	1 (5.0)
Breakfast skipping per week			
0–1	18 (33.3)	14 (41.2)	4 (20.0)
2–3	15 (27.8)	10 (29.4)	5 (25.0)
≥ 4	21 (38.9)	10 (29.4)	11 (55.0)
Overeating per week			
0–1	10 (18.5)	6 (17.6)	4 (20.0)
2–3	34 (63.0)	23 (67.6)	11 (55.0)
≥ 4	10 (18.5)	5 (14.7)	5 (25.0)
Eating out per week			
0–1	9 (16.7)	7 (20.6)	2 (10.0)
2–3	30 (55.6)	22 (64.7)	8 (40.0)
≥ 4	15 (27.8)	5 (14.7)	10 (50.0)
MetS RF number			
0	9 (16.7)	7 (20.6)	2 (10.0)
1–2	33 (61.1)	27 (64.7)	11 (55.0)
≥ 3	12 (22.2)	5 (14.7)	7 (35.0)

Values are presented as mean ± standard error or number (%); tested by Student t-test or chi-square test.
*$P < 0.01$ compared with women tested by Student t-test.
MetS, metabolic syndrome; RF, risk factor.

Metabolic status-related parameters before and after the intervention

Table 2 presents the anthropometric parameters at baseline and after 8 weeks of the eating behavior modification intervention. The BMI ($P = 0.087$), and body fat mass ($P = 0.069$) tended to be reduced, and skeletal muscle mass ($P = 0.098$) tended to be increased in the MHO group after the intervention. On the other hand, body weight ($P = 0.033$), and BMI ($P = 0.044$) were slightly, but significantly reduced in the MUHO group. Specifically, the increase in skeletal muscle mass and reduction in VFA tended to be greater in MUHO than in MHO participants ($P = 0.092$, $P = 0.085$, respectively). Table 3 presents the biochemical parameters at baseline and after 8 weeks of eating behavior modification intervention. The levels of HbA1c ($P = 0.029$), HOMA-IR ($P = 0.049$), and LDL-C ($P = 0.037$) were significantly decreased, and those of HDL-C ($P = 0.052$), and total-C ($P = 0.050$) tended to be decreased in the MHO group. On the other hand. TG ($P = 0.072$) tended to be increased in the MHO group. The levels of HbA1c ($P = 0.076$) tended to decrease in the MUHO group. Specifically, the improvement in HOMA-IR tended to be greater and reductions of TG were greater in the MUHO than in MHO group ($P = 0.075$, $P = 0.010$, respectively).

Daily calorie intake and macronutrient intakes before and after the intervention

Table 4 presents the participants' daily TCI and proportion of

Table 2. Anthropometric parameters at baseline and after the intervention

Variable	MHO (n=42)		*P*	MUHO (n=12)		*P*	*P1*	*P2*
	Baseline	After		Baseline	After			
Weight (kg)	70.9±1.61	70.6±1.65	0.189	76.6±3.70	75.5±3.42	0.033	0.050	0.151
BMI (kg/m^2)	26.2±0.39	26.0±0.39	0.087	27.4±0.54	27.0±0.51	0.044	0.047	0.428
Waist (cm)	89.4±1.22	89.1±1.15	0.519	94.1±1.44	94.0±1.39	0.874	0.019	0.873
SBP (mmHg)	120.4±2.54	119.4±2.19	0.444	138.6±3.09	139.9±3.82	0.693	0.001	0.437
DBP (mmHg)	77.2±1.65	77.7±1.66	0.673	89.0±2.58	88.4±2.89	0.763	0.001	0.651
Body fat (kg)	23.4±0.81	22.8±0.85	0.069	23.5±1.32	22.9±1.25	0.124	0.915	0.859
SMM (kg)	26.0±0.85	27.3±1.14	0.098	29.4±2.14	34.0±3.36	0.104	0.044	0.092
VFA (cm^2)	105.2±4.05	105.3±4.46	0.439	127.4±8.03	124.1±8.28	0.303	0.049	0.085

Values are presented as mean±standard error. *P* indicates differences in the values before and after the intervention assessed using general linear model with adjustment for age and sex; *P1*, differences in the baseline values between MHO and MUHO groups assessed using Student t-test; *P2*, differences in the changed values between MHO and MUHO groups assessed using Student t-test.
MHO, metabolically healthy obese; MUHO, metabolically unhealthy obese; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; SMM, skeletal muscle mass; VFA, visceral fat area.

Table 3. Biochemical markers at baseline and after the intervention

Variable	MHO (n=42)		*P*	MUHO (n=12)		*P*	*P1*	*P2*
	Baseline	After		Baseline	After			
HbA1c (%)	5.45±0.06	5.38±0.05	0.029	5.90±0.16	5.69±0.17	0.076	0.008	0.110
HOMA-IR	3.07±0.70	2.83±0.48	0.049	8.94±2.59	7.56±1.86	0.237	0.024	0.075
Glucose (mg/dL)	93.9±3.20	95.1±1.63	0.648	109.7±6.36	106.8±6.74	0.702	0.026	0.508
Insulin (μIU/mL)	11.6±1.65	10.3±0.94	0.455	31.6±8.85	19.0±5.72	0.305	0.047	0.110
C-Pep (ng/dL)	2.35±0.22	2.29±0.13	0.791	4.69±0.76	3.56±0.50	0.326	0.011	0.150
TG (mg/dL)	96.4±6.41	109.3±8.42	0.072	256.0±82.4	197.3±42.1	0.216	0.001	0.010
HDL-C (mg/dL)	59.7±1.83	57.4±1.50	0.052	49.0±5.93	49.9±5.87	0.631	0.025	0.181
LDL-C (mg/dL)	129.5±4.70	122.3±4.68	0.037	124.3±14.3	118.1±10.6	0.577	0.049	0.906
Total-C (mg/dL)	199.6±5.20	192.8±4.69	0.050	208.1±12.5	196.1±10.5	0.250	0.045	0.526

Values are presented as mean±standard error. *P* indicates p-values for differences in the values before and after the intervention assessed using a general linear model with adjustment for age and sex; *P1*, differences in the baseline parameter values between MHO and MUHO groups assessed using Student t-test; *P2*, post-intervention differences in the parameter values between MHO and MUHO groups assessed using Student t-test.
MHO, metabolically healthy obese; MUHO, metabolically unhealthy obese; HbA1c, glycosylated hemoglobin; HOMA-IR, homeostatic model assessment for insulin resistance; C-Pep, C-peptide; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; Total-C, total cholesterol.

calorie intake derived from macronutrients at baseline and after the intervention. There were no statistically significant differences between the MHO and MUHO groups at baseline. The proportion of the TCI derived from dietary fat tended to decrease after the intervention in both groups. In addition, the TCI and proportions of the TCI derived from carbohydrate or protein were not significantly different in the MHO and MUHO groups during the intervention. In addition, the amount of daily macronutrient intakes ingested as carbohydrates ($P=0.024$), vegetable fats ($P=0.024$), and vegetable proteins ($P=0.030$) were significantly increased after the intervention in the MUHO group, but not significantly changed in the MHO group. The magnitude of the changes in these values for these nutrients groups were also statistically significantly different between the MHO and MUHO groups ($P=0.016$, $P=0.027$, and $P=0.006$, respectively). Regarding micronutrients, the daily intakes of vitamin E ($P=0.027$), pantothenic acid ($P=0.020$), and vegetable calcium ($P=0.026$) were significantly increased and those of total calcium ($P=0.074$), copper ($P=0.073$), and manganese ($P=0.093$) after intervention in the MUHO group, but not significantly changed in the MHO group (data not shown in the table).

Proportions and amounts of calorie intake according to meal distribution at baseline and after the intervention

Fig. 1 shows the proportion and amount of calorie intake accord-

Table 4. Daily calorie and macronutrient intakes at baseline and after intervention

Per day	MHO (n=42)		*P*	MUHO (n=12)		*P*	*P1*	*P2*
	Baseline	After		Baseline	After			
TCI (kcal)	1,839±97.7	1,752±85.3	0.290	1,723±120.4	2,049±243.9	0.234	0.555	0.089
Carbohydrate (%)	53.7±1.70	56.8±1.11	0.116	53.0±4.20	58.0±3.04	0.324	0.655	0.602
Fat (%)	29.2±1.30	26.8±0.89	0.097	28.6±3.43	25.2±2.43	0.098	0.551	0.651
Protein (%)	17.1±0.67	16.4±0.45	0.392	18.5±1.83	16.8±0.88	0.471	0.162	0.640
Macronutrient (g)								
Carbohydrate (g)	239.0±11.5	243.7±11.0	0.998	211.8±21.1	285.3±24.8	0.024	0.268	0.016
Fat (g)	60.4±4.57	52.7±3.83	0.115	53.8±8.55	60.8±11.40	0.567	0.498	0.217
Vegetable fat (g)	26.7±1.53	25.3±1.90	0.566	20.8±4.86	31.3±4.88	0.030	0.128	0.027
Animal fat (g)	33.7±4.23	27.4±3.06	0.133	33.0±8.03	29.5±7.70	0.527	0.939	0.809
Protein (g)	78.9±5.61	70.7±4.08	0.153	76.7±12.2	85.9±10.6	0.606	0.860	0.081
Vegetable protein (g)	31.8±1.64	30.1±1.57	0.401	30.4±3.41	40.8±3.51	0.030	0.691	0.006
Animal protein (g)	47.1±5.15	40.5±3.62	0.186	46.3±12.20	45.1±8.76	0.891	0.948	0.676
Dietary fiber (g)	18.3±1.10	18.6±1.10	0.945	19.0±1.95	23.9±2.50	0.093	0.736	0.078
Cholesterol (mg)	350.2±34.0	371.7±27.3	0.684	348.2±62.5	400.2±74.5	0.718	0.977	0.803

Values are presented as mean±standard error. *P* indicates *P*-values for differences in the values before and after the intervention assessed using a general linear model with adjustment for age and sex; *P1*, differences in the baseline parameter values between MHO and MUHO groups assessed using Student t-test; *P2*, post-intervention differences in the parameter values between MHO and MUHO groups assessed using Student t-test.
MHO, metabolically healthy obese; MUHO, metabolically unhealthy obese; TCI, total calorie intake.

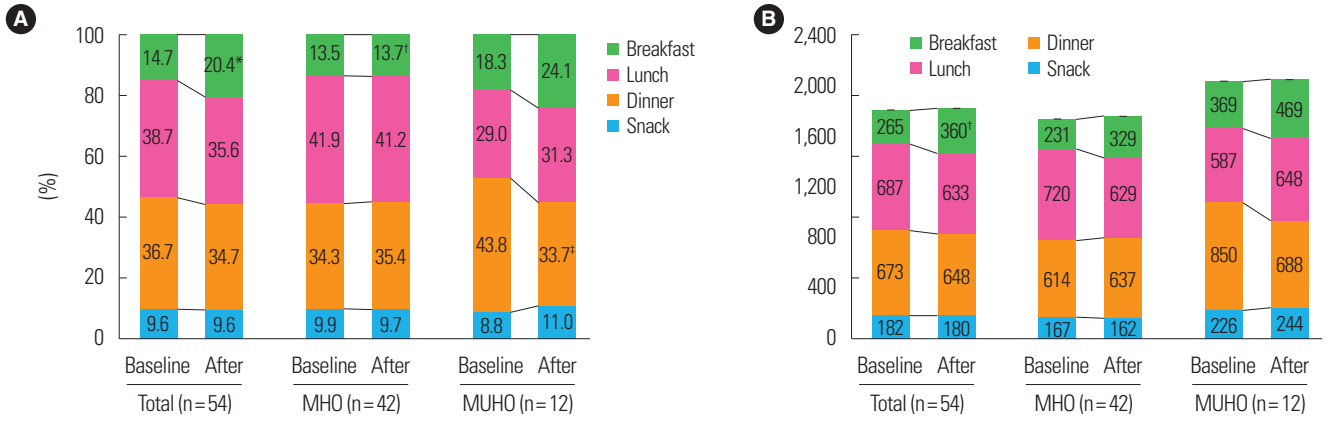

Figure 1. Proportions (A) and amounts (B) of calorie intake according to meal distribution at baseline and after the eating behavior intervention. Values are presented as mean±standard error. **P*<0.01, †*P*<0.05, ‡*P*<0.1, indicate *P*-values for differences in the values before and after the intervention assessed using paired t-test. MHO, metabolically healthy obese; MUHO, metabolically unhealthy obese.

ing to meal distribution before and after the intervention. During the intervention, the proportion of calorie intake derived from breakfast consumption increased significantly in all participants ($P<0.01$), and in the MHO group ($P<0.05$). Calorie intake derived from dinner consumption tended to be decreased in the MUHO group (from 43.8% to 33.7%, $P=0.061$) (Fig. 1A). Similar patterns were observed when assessing the calorie intake according to meal distribution after the intervention, even though the statistical significance became weak (Fig. 1B).

Correlations between changes in metabolic parameters and calorie intake derived from macronutrients

Fig. 2 shows the relationship between changes in VFA and in daily calorie intake from TCI and macronutrients. Changes in VFA were negatively correlated with those in TCI ($r=-0.296$, $P=0.046$), and tended to be negatively correlated with calorie intake from breakfast ($r=-0.254$, $P=0.089$), and proportion of calorie intake from carbohydrates ($r=-0.288$, $P=0.053$). Meanwhile, changes in VFAs were positively correlated with those in the proportion of

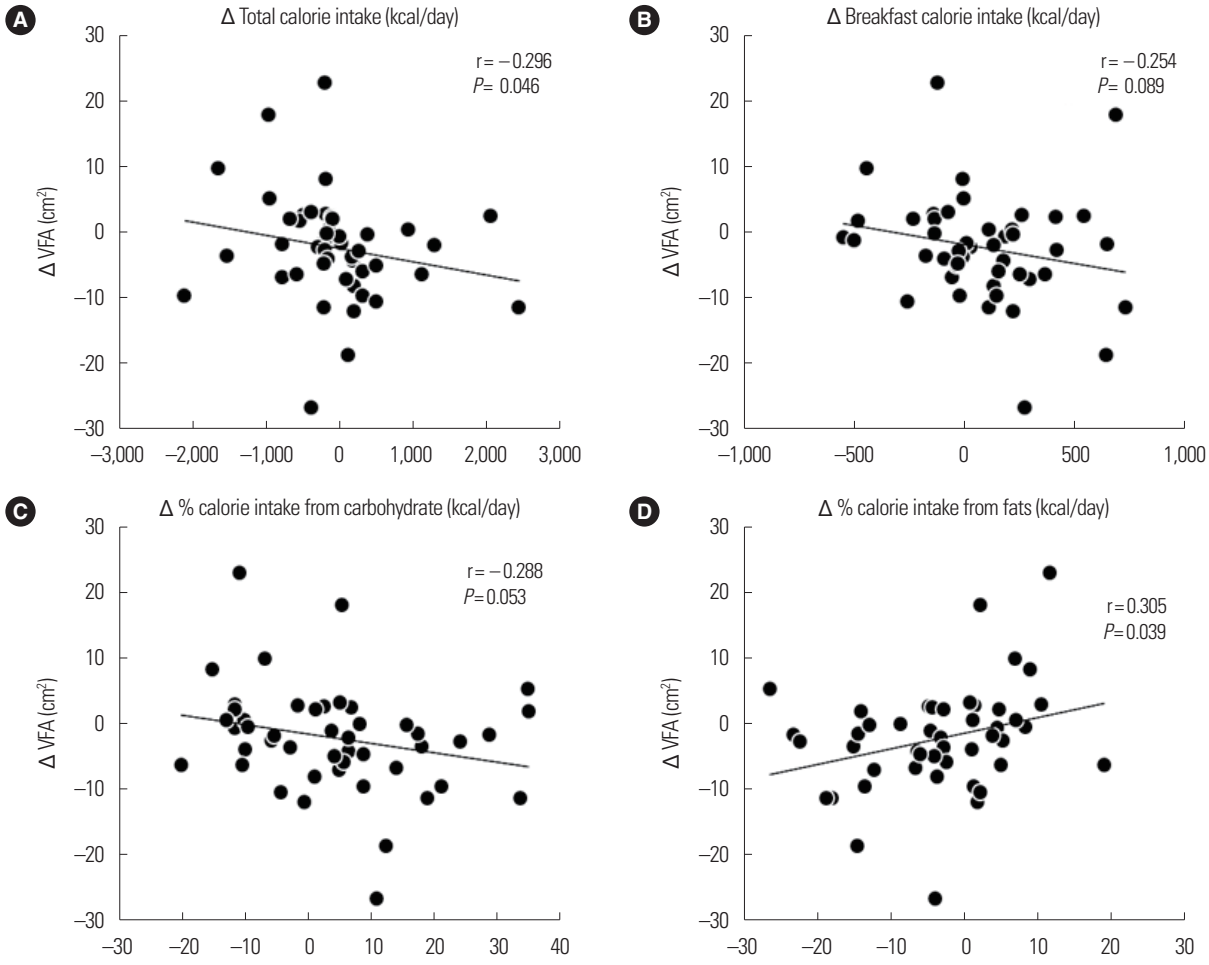

Figure 2. Relationship between the visceral fat area (VFA) and total calorie intake (A), breakfast calorie intake (B), percent (%) calorie intake from carbohydrate (C) and from fats (D) before and after the eating behavior intervention. r = correlation coefficient, *P*-value < 0.05 indicates significant correlations between the changes in VFA and those in daily calorie intake and proportion of calorie intake derived from macronutrients status. Correlations were analyzed using Spearman's correlation test.

calorie intake from fats (r = 0.305, *P* = 0.039). The relationship between the changes in calorie intake from snacks and those in WC measurements and glycemic parameters are presented in Supplementary Fig. 1. Changes in WC values were positively correlated with those in snack calorie intake (r = 0.305, *P* = 0.025). Moreover, changes in glucose (r = 0.273, *P* = 0.046), insulin (r = 0.375, *P* = 0.005), C-peptide (r = 0.279, *P* = 0.041) concentrations were positively correlated with snack calorie intake. In addition, the relationship between the changes in insulin and C-peptide and those in dietary fiber intake are presented in Supplementary Fig. 2. Changes in dietary fiber intake, particularly at dinner time, were negatively correlated with those in insulin (r = −0.337, *P* = 0.013) and C-peptide (r = −0.355, *P* = 0.008) values.

After-intervention change of MHO and MUHO status as compared to categorization at baseline

Among the MUHO participants (n = 12) at baseline, 10 were categorized as MHO (83.3%) after the intervention, and only two remained MUHO (16.7%). Among the MHO participants (n = 42) at baseline, 36 remained MHO (85.7%), and six were categorized as MUHO (14.3%) after the intervention. The results may be explained by the MUHO group having relatively better adherence to eating behavior modification. Specifically, six participants who had been categorized as MHO at baseline were categorized as MUHO due deterioration of their metabolic status.

DISCUSSION

This study aimed to investigate if eating behavior modification improves MetS-related risk factors in overweight, obese Korean adults, and to identify the dietary factors that improve metabolic status. Improvements in the participants' body weight, BMI, body fat, skeletal muscle mass, HbA1c, HOMA-IR, total cholesterol, and kidney functions were measured in all participants after the intervention. Both eating behavior and dietary factors, such as breakfast consumption, decreased TCI, decreased calorie intake from snacks, and increased dietary fiber intake contributed to the improvements in metabolic parameters.

With regard to the participants' baseline characteristics, the percentage of current alcohol drinkers was 74.1%. It was considerably higher compared with that reported by the KNHANES study 2008–2013 (about 10%).[16] In this study, the majority of overweight and obese participants frequently engaged in unfavorable lifestyle and eating behaviors, such as drinking alcohol, irregular timing of meals, skipping breakfast, and overeating. Nevertheless, in this study, the participants' body weight and BMI both decreased significantly. The eating behavior modification undertaken by participants in this study did not suggest strict energy restriction, which was different from other studies.[13,17,18] Our results are partly supported by several previous studies that have reported that unfavorable eating patterns and dietary factors influenced MetS and cardiometabolic health.[19,20]

The eating behavior education program included a recommendation that the participants eat breakfast, and the proportion of breakfast calorie intake increased in both groups. In addition, the proportion of calories ingested during dinner intake in the MUHO group tended to decrease. Daily nutrient intake from macronutrients, carbohydrate, vegetable fat, and vegetable protein intakes increased significantly only in the MUHO group ($P < 0.01$). Moreover, body weight, and BMI were significantly reduced, and the changes in skeletal muscle mass, VFAs and HOMA-IR tended towards improved metabolic status, and that of TG was significantly improved in the MUHO group. The results of previous studies indicated the cardiometabolic profiles of the MUHO group might be expected to show more improvement than those of the MHO group.[7,10] Indeed, as the MHO group was already "metabolically healthy" at baseline, their metabolic status-related parameters were not much changed.[7] In addition, dietary and metabolic improvements in the MUHO group may indicate that adherence to the intervention may have been greater in the MUHO group than in the MHO group. Burgess et al.[21] reported that lifestyle modification intervention in obese adults also aimed to improve adherence to the components of the intervention. These results were supported by previous studies stating the importance of adherence to a weight loss program in obesity.

Many previous studies have reported metabolic improvements after implementing an energy-restricted dietary intervention rather than through an understanding of eating behavior and dietary factors.[10,21,22] Arab et al.[23] reported that VFA decreased along with the reduction of TCI in overweight and obese patients with nonalcoholic fatty liver disease. However, this study showed that changes in VFA were negatively correlated with those in TCI ($P = 0.046$). Specifically, calorie intake from breakfast tended to be negatively correlated with VFA. although the effect did not reach the statistical significance ($P = 0.089$). This result implied that increasing TCI owing to better breakfast intake contributed more to decreased VFA than did reducing TCI as a result of skipping breakfast; this is because breakfast intake might have affected the proportion of calorie intake and prevented overeating at the next meal. Moreover, changes in the proportion of calorie intake from carbohydrates tended to be negatively correlated with VFAs, even though the effect did not reach the statistical significance ($P = 0.053$), and that from fats was positively correlated with VFA ($P = 0.039$). Recently, many studies have reported that the proportion of macronutrients intake might affect metabolic status, as has been shown for a low-carbohydrate and high-fat diet.[24,25] Ahluwalia et al.[19] reported that adhering to national dietary guidelines, such as KDRIs can reduce inflammation and the risk of MetS. In this study, changes in calorie intake from snacks were positively correlated with those in WC, glucose, insulin, and C-peptide values. The nutrients consumed from snacks were the main sources of carbohydrates. Therefore, we assumed that carbohydrate intake from snacks negatively affected glycemic parameters. Changes in dietary fiber intakes tended to be negatively correlated with insulin and C-peptide concentrations. Specifically, changes in dietary fiber intake at dinner were significantly correlated with those in insulin and C-peptide ($P = 0.013$,

and $P = 0.008$, respectively). This result was similar to that found by Anderson et al.[26]

As mentioned above, 10 of the MUHO participants (n = 12) at baseline were classified as MHO (83.3%) after the intervention and only two remained MUHO (16.7%). Among the MHO participants (n = 42), 36 remained MHO (85.7%) after the intervention, but six became classified as MUHO (14.3%) due to deterioration of their metabolic status The results may be explained as the MUHO group having had relatively greater adherence to the eating behavior modification. In addition, some studies have reported that MHO status is unstable and may worsen to metabolic unhealthy status.[27-29]

This study has several limitations. First, the number of participants in the MUHO group was relatively small. For example, some of metabolic and dietary changes observed in the MUHO group were numerically greater than the MHO group, but it did not reach the statistical significance due to the small number of subjects in the MUHO group. Second, the 8-week intervention period was relatively short. Future studies with a larger number of participants and longer study period must be performed to improve the statistical power. In addition, this study did not emphasize the participants doing exercise, because it focused on eating behavior modification.

However, physical exercise is one of several important factors that may improve body composition and MetS risk.[10] In follow-up studies, exercise needs to be considered together with eating behavior modification. Despite these limitations, eating behavior modifications (rather than strict energy-restriction) increased adherence to a weight loss program among obese participants, such that metabolic status improved to a greater degree with eating behavior intervention than when strictly restricting energy intake, even though the improvement in adiposity is not particularly great. The key finding from this study is that obesity treatment did not depend on strict calorie restriction alone, but rather eating behavior modification, such as breakfast consumption, decreased TCI, and decreased calorie intake from snack, and increased dietary fiber intake.

In conclusion, this study demonstrated that changes in the eating behavior may be important for metabolic improvement in overweight and obese people, thereby preventing type 2 diabetes and CVD.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

Study concept and design: OYK and EMK; acquisition of data: HK, EY, and OYK; analysis and interpretation of data: HK, EY, OYK, and EMK; drafting of the manuscript: HK and OYK; critical revision of the manuscript: EY, OYK, and EMK; statistical analysis: EY and OYK; obtained funding: OYK; administrative, technical, or material support: OYK and EMK; and study supervision: OYK and EMK.

SUPPLEMENTARY MATERIALS

Supplementary Figures 1 and 2 can be found via https://doi.org/10.7570/jomes21074.

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