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Effects of monitoring dietary biomarkers and providing vegetable juice on metabolic syndrome components in adults with an overweight or obese body mass index in Ulaanbaatar: a randomized controlled trial

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Abstract

Background Mongolian people have traditionally had poor vegetable intake habits, which is a cause of increasing prevalence of metabolic syndrome. Monitoring vegetable intake through the dietary biomarkers such as skin carotenoid level, and urinary sodium-to-potassium (Na/K) ratio (represents intake status of salt and vegetable), has been recently suggested to be useful to improve dietary habits. Vegetable juices are an easy way to consume vegetable-derived ingredients. This study aimed to examine the following two points in adults with an overweight or obese body mass index (BMI) in Ulaanbaatar; (1) relationships between these dietary biomarkers and metabolic syndrome components, and (2) effects of an intervention combining regular monitoring of these dietary biomarkers and provision of vegetable juices on values of the dietary biomarkers and metabolic syndrome components.

Methods Ninety-four Mongolian adults with BMI ≥ 25 living in Ulaanbaatar were analyzed. (1) Relationships between baseline values of dietary biomarkers and metabolic syndrome components were analyzed by simple correlation and multiple regression analyses. (2) Participants were randomly allocated to control, monitoring, and monitoring + vegetable juice groups. During the 8-week intervention, the monitoring and monitoring + vegetable juice groups were monitored their dietary biomarkers and blood pressure every two weeks, and the monitoring + vegetable juice group was additionally provided with vegetable juice every day. Changes in dietary biomarkers and metabolic syndrome components before and after intervention were compared among the three groups.

Results (1) The skin carotenoid levels were negatively correlated with blood triglyceride levels, whereas the urinary Na/K ratio was positively associated with systolic and diastolic blood pressure. (2) Through the intervention, the monitoring + vegetable juice group showed significant increase in skin carotenoid level (+ 1.72), decrease in urinary Na/K ratio (− 0.80 mol/mol), and decrease in waist circumference (− 2.63 cm) compared to the control group (+ 0.28, + 0.45, and + 0.22, respectively).

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Conclusions The combination of the monitoring dietary biomarkers and providing vegetable juice was suggested to be effective in improving dietary habits and metabolic syndrome components including waist circumference in Mongolian adults with an overweight or obese BMI.

Trial registration UMIN-CTR Clinical Trial UMIN000051715 on July 26, 2023.

Keywords Obesity, Metabolic syndrome, Dietary biomarkers, Vegetable intake, Vegetable juice, Carotenoid, Urinary sodium-to-potassium ratio, Waist circumference, Dietary guidance, Dietary habit

Background

The prevalence of metabolic syndrome that is a combination of clustering risk factors, such as obesity, dyslipidemia, hyperglycemia and hypertension, and eventually leads to cardiovascular diseases (CVDs) and diabetes [1, 2], is increasing also in Asia including Mongolia [3, 4]. Mongolia has faced increased mortality from non-communicable diseases [5], such as CVDs. The average body mass index (BMI, kg/m^2) of Mongolian adults is 25.5. According to the WHO criteria (≥ 25.0: overweight, ≥ 30.0: obese), 49.4% of the Mongolian population is overweight or obese, and 18.5% is obese [6, 7]. The average waist circumference of Mongolian females and males have been reported to be 85.7 cm and 87.3 cm, respectively, and 53% of the Mongolian population is considered to be at high obesity risk according to the reference values for obesity in Asian countries (80 cm for females and 90 cm for males), as indicated by WHO in collaboration with the International Association for the Study of Obesity [6, 8]. The prevalence of overweight or obese BMI is particularly high in urban areas such as Ulaanbaatar [6].

According to the 4th National STEPS SURVEY by the Mongolian National Center for Public Health, the average vegetable intake and salt intake in Mongolia is 2.3 servings/day and 10.5 g/day, respectively [6], both of which deviate from the WHO recommendation (5 servings/day and 5 g/day) [7]. This is due to Mongolia's extremely dry climate, which is not suitable for growing vegetables, and its traditional food customs [9]. As many epidemiological studies have shown [10, 11], insufficient vegetable intake and excessive salt intake may contribute to the increase in metabolic syndrome in Mongolia.

Vegetables are an important source of many nutrients, including minerals, vitamins, dietary fiber, and phytochemicals. As for carotenoids, phytochemicals from vegetables, many epidemiological studies showed a negative association between serum level of carotenoid and metabolic syndrome components [12–14]. Intervention studies have shown that carotenoid intake inhibits adipocyte accumulation, differentiation, and hypertrophy [15, 16]. Potassium, consumed from vegetables as well as fruits and potatoes, is known to promote urinary excretion of sodium by inhibiting sodium reabsorption in the kidneys [17]. Hence, in recent years, in addition to salt reduction, active potassium intake has also been considered important for blood pressure control. This is supported by epidemiological studies showing that a lower urinary sodium to potassium (Na/K) ratio, which represents the balance between sodium and potassium intake, is associated with a lower risk of hypertension and cardiovascular disease [18]. As for vitamins, vitamins A, C, and D have been reported to be effective in preventing obesity and its induced inflammation [19–22]. Vegetable-derived dietary fibers have been reported to improve hyperglycemia and hyperlipidemia by various mechanisms including inhibition of absorption and effects on intestinal bacteria [23–26].

In recent years, visualizing vegetable intake using a device that measures skin carotenoid levels optically and noninvasively has been utilized in Japan to encourage vegetable intake [13, 27]. This is based on the finding of a significant correlation between skin carotenoid levels, with outputs ranging from 0.1 to 12.0, and vegetable intake estimated by a self-administered diet history questionnaire [13]. It has also been suggested that vegetable intake instructions based on skin carotenoid levels could increase vegetable intake awareness and behavior [28]. Similarly, it has been reported that measurement of the urinary Na/K ratio, which represents the intake of sodium and potassium, and health instructions based on the measurement results of annual health checkups in a municipality in Japan, the urinary Na/K ratio, and the systolic and diastolic blood pressure of examinees (residents) significantly decreased the following year [29]. Thus, visualizing dietary biomarkers such as skin carotenoid levels and the urinary Na/K ratio, which are difficult to determine objectively, is expected to be effective in improving dietary habits. In addition, increasing access to food is considered an important way to improve the intake of nutritious food [30]. Vegetable juice could be an effective candidate for increasing access to vegetables because of its convenience and long shelf life. Previous studies in Japanese adults have confirmed an increase in blood and skin carotenoid levels, a decrease in the urinary Na/K ratio, and improvements in waist circumference and systolic blood pressure with continuous consumption of vegetable juice [31], and vegetable juice consumption is expected to play a beneficial role in the supplementation of vegetable-derived ingredients.

This study examined the following two points in adults with an overweight or obese BMI living in Ulaanbaatar; (1) relationships between dietary biomarkers such as skin carotenoid level and urinary Na/K ratio and metabolic syndrome components by a cross-sectional analysis, and (2) effects of a monitoring dietary biomarkers (the skin carotenoid level and the urinary Na/K ratio) or a combination of the monitoring and providing vegetable juice on the dietary biomarkers and metabolic syndrome components.

Methods

Participants

People working in hospital, research institutes, or private companies in Ulaanbaatar who met the enrolment criteria for the study (healthy Mongolian, age $\geq$ 20 years, and BMI $\geq$ 25 kg/m^2 on physical examination within the past year) were recruited. The exclusion criteria included a history of serious cardiovascular or gastrointestinal disease, pregnancy or lactation, and allergy to vegetable juices. A total of 100 participants were selected for the study. The sample size was calculated with reference to a previous report [27] using the same vegetable juice as in the current study, aiming to observe a significant increase in skin carotenoid levels. Specifically, in that report, drinking vegetable juice for 4 weeks increased skin carotenoid levels by 0.6 (effect size) compared to the non-drinking group, with a standard deviation of 0.9. In this 8-week drinking period study, an effect size of 0.9 was expected, with a power of 0.9 and an alpha of 0.0167 (Bonferroni-adjusted), which was calculated to be 27 participants per group. Considering dropouts, the number of participants was set at about 33 per group. Although a slight effect on waist circumference has been observed in a previous report [31] using the vegetable beverage used in this study, we considered this to be insufficient as a basis for sample size calculation. Metabolic syndrome components, including abdominal circumference, were considered secondary endpoints. The study procedures and recruitment were conducted in accordance with the Declaration of Helsinki and Ethical Guidelines for Medical Research Involving Human Subjects. The study was approved by the Ministry of Health Medical Ethics Review Committee Resolution (No. 283) and the ethics board of KAGOME CO., LTD (2020-R05). All the participants provided written informed consent. The study was also registered in the University Hospital Medical Information Network (UMIN) Clinical Trial Registry (UMIN000051715).

Study design

In the beginning of May 2022, all participants answered a self-administered questionnaire regarding their medical history, habitual medications, current smoking habits, frequency of alcohol consumption, and allergies. They were also assessed for metabolic syndrome components (BMI, waist circumference, systolic and diastolic blood pressure, serum total-, low-density lipoprotein [LDL], high-density lipoprotein [HDL] cholesterol, blood triglycerides, and blood Hemoglobin A1c [HbA1c]) in a hospital: BMI and waist circumference were measured by medical staffs, and blood indices were measured in the hospital laboratory using common blood biochemistry testing methods. Their dietary biomarkers (skin carotenoid level and urinary Na/K ratio) were measured by medical staffs or researchers in participants' workplace. Relationships between the baseline values of dietary biomarkers and metabolic syndrome components were analyzed (a cross-sectional analysis) for all participants.

The participants were divided into three groups: control, monitoring, and monitoring + vegetable juice groups, using a stratified randomization method so that age, sex ratio, BMI, and workplace were not biased among the groups. The researcher who held the randomization sequence were not involved with the recruitment of participants or baseline data collection. Blinding of participants was not possible due to the nature of the study. Participants were informed of their group allocation at their workplace. The intervention period was 8 weeks, from the beginning of May to the end of June 2022. After the intervention, all participants underwent the same assessment as before the intervention. During the intervention period, the skin carotenoid level, the urinary Na/K ratio, and the blood pressure were measured every 2 weeks (zero [before-intervention], 2, 4, 6, and 8 weeks [after-intervention]) for the participants in the monitoring and monitoring + vegetable juice groups, and immediate feedback was provided to the participants in their workplace. The monitoring + vegetable juice group was provided with one pack of vegetable juice daily (200 mL; KAGOME CO., LTD., Aichi, Japan) at any given time. Nutrition fact label values of the vegetable juice (/200 mL) shows energy 68 kcal, protein 2.4 g, fat 0 g, carbohydrate 15.7 g, dietary fiber 2 g, sodium 110 mg, potassium 700 mg, lycopene 16 mg, and β-carotene 7950 μg. The control group did not receive the regular monitoring (dietary biomarkers and blood pressure) and vegetable juices during the intervention period. All participants were not restricted regarding dietary changes during the intervention period because this study was conducted with the expectation that monitoring dietary biomarkers and providing vegetable juices would promote improved dietary habits which were evaluated by skin carotenoid level and urinary N/K ratio.

Regular monitoring

The skin carotenoid levels were measured using a Multiple Spatially Resolved Reflection Spectroscopy Sensor, Vegecheck® (KAGOME CO., LTD., Aichi, Japan), as previously reported [13, 27]. The measurement results were presented as the values of 0.1 to 12.0, positively correlated with vegetable intake as determined by BDHQ (brief-type self-administered diet history questionnaire) in Japanese population [13]. The urinary Na/K ratio was measured using a urinary Na/K ratio-measuring device (HEU-001F; OMRON Healthcare Co., Ltd., Kyoto, Japan) using a spot urine collected in the morning, as previously reported [18]. Several epidemiological studies have reported that a higher urinary Na/K ratio is associated with higher sodium intake, lower potassium intake, and a higher risk of hypertension and cardiovascular diseases [18, 29, 32–35]. Systolic and diastolic blood pressure were measured using an upper arm sphygmomanometer (HEM-7200; OMRON Healthcare Co., Ltd.).

Statistical analysis

Those who missed the pre-intervention baseline assessment after enrollment and assignment and those who did not receive all post-intervention assessment were considered dropouts.

A cross-sectional analysis was performed on all participants who underwent the pre-intervention baseline assessment. Correlations between dietary biomarkers and metabolic syndrome components were analyzed using Pearson's correlation coefficient. Welch's *t*-test was used to compare blood triglyceride levels within the two groups divided by the median skin carotenoid level and systolic and diastolic blood pressure within the two groups divided by the urinary Na/K ratio = 2.0 (the target value of the urinary Na/K ratio, validated by Salman et al. to examine the association between metabolic syndrome components and dietary biomarkers [33]). Multiple regression analyses were performed to evaluate the relationship between dietary biomarkers and metabolic syndrome components. Blood triglyceride levels or systolic and diastolic blood pressure were considered objective variables, whereas skin carotenoid levels or urinary Na/K ratios were considered explanatory variables. Age, sex, waist circumference, use of medication for diseases (hyperlipidemia or hypertension), current smoking habits, and current drinking habits (habitual drinking if drinking more than once a month) were considered adjustment factors in the analyses.

To evaluate the effects of the interventions, changes in dietary biomarkers and metabolic syndrome components between before and after intervention were compared among three groups using the Tukey–Kramer test.

Data that could not be obtained were considered missing. Data are presented as the mean ± standard deviation (SD). Analyses were performed using the R statistical package (×64 4.0.2, R Foundation for Statistical Computing, Vienna, Austria), and a *P*-value of < 0.05 was considered statistically significant.

Results

Study participants

The CONSORT diagram (Fig. 1) shows the participants and the process of selecting them for analysis according to each objective. Screening was conducted on 119 people who were willing to participate in this study, and 100 participants who met the criteria were selected and enrolled in this study. Of the 100 participants enrolled in this study and randomly assigned to the three groups ($n = 33$, 33, and 34 in the control, the monitoring, and the monitoring + Vegetable juice group, respectively), 94 underwent the baseline assessment prior to the intervention, while the remaining 6 did not appear for the assessment. The data collected from the 94 participants (67 females and 27 males) at the beginning of May 2022 (baseline) were used to evaluate the association between dietary biomarkers and metabolic syndrome components in adults with an overweight or obese BMI living in Ulaanbaatar. The intervention study was conducted over an 8-week period from the beginning of May to the end of June 2022. During the intervention period, one participant who failed to receive all post-intervention assessment was considered a dropout. Remaining 30 participants in the control group, 31 in the monitoring group, and 32 in the monitoring + vegetable juice group were submitted for analysis of among-group comparisons..

A total of 100 Mongolian adults were enrolled and randomly divided into three groups (control, monitoring, and monitoring + vegetable juice groups). Six people dropped out at the baseline because they did not receive all pre-intervention assessment. A cross-sectional analysis was performed on the 94 participants who received all pre-intervention assessment. One participant in the control group did not receive all post-intervention assessment. Among-group comparisons were conducted on remaining 93 participants (30 in the control, 31 in the monitoring, and 32 in the monitoring + vegetable juice group).

Cross-sectional study: characteristics of the study participants

Table 1 shows the mean values of all measurements of the 94 participants analyzed before the intervention. The

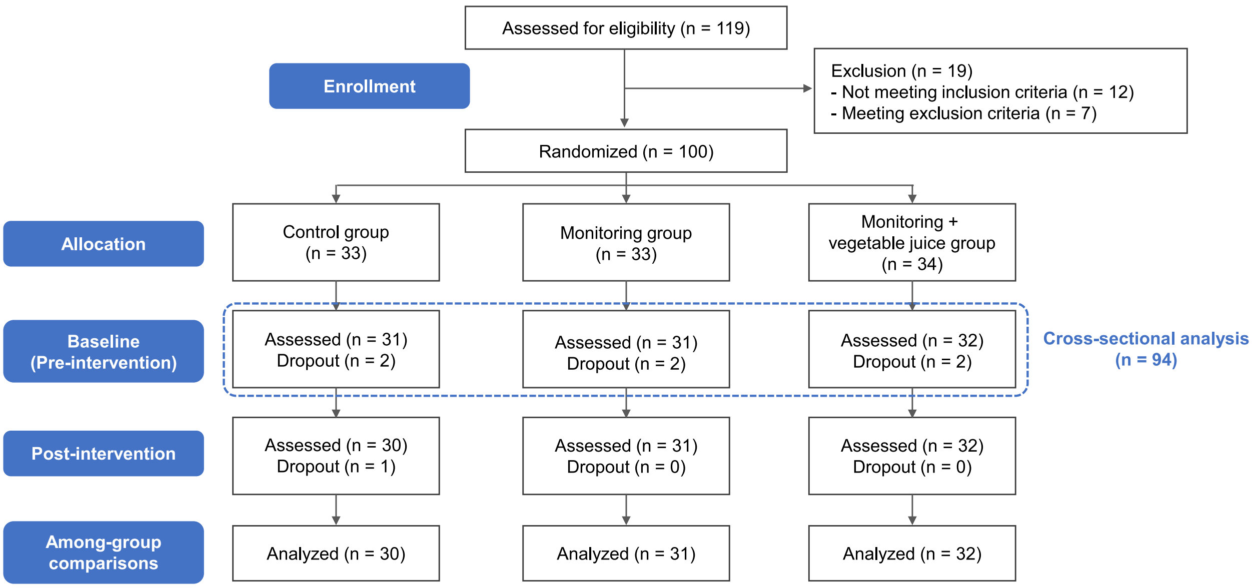

Fig. 1 Flow diagram for the participant selection

Table 1 Baseline characteristics of the participants (Overall and in each group)

	Overall	Control	Monitoring	Monitoring + Vegetable juice
N	94	31	31	32
Age (years)	38.1 ± 11.4	38.5 ± 11.2	36.8 ± 11.8	39.0 ± 11.5
Sex (No.)	F 67, M 27	F 20, M 11	F 24, M 7	F 23, M 9
Anti-hyperlipidemia medication usage (No.)	Y 2, N 90, NA 2	Y 1, N 29, NA 1	Y 0, N 31	Y 1, N 30, NA 1
Anti-hypertensive medication usage (No.)	Y 6, N 86, NA 2	Y 1, N 29, NA 1	Y 2, N 29, NA 0	Y 3, N 28, NA 1
Current smoking habits (No.)	Y 16, N 76, NA 2	Y 3, N 27, NA 1	Y 7, N 24	Y 6, N 25, NA 1
Alcohol intake habits (No.)	Y 70, N 22, NA 2	Y 25, N 5, NA 1	Y 24, N 7	Y 21, N 10, NA 1
Metabolic syndrome components and dietary biomarkers				
BMI (kg/m^2)	30.4 ± 3.7	30.5 ± 4.5	30.1 ± 3.0	30.5 ± 3.6
Waist circumference (cm)	95.6 ± 11.6	95.0 ± 13.3	95.2 ± 9.7	96.6 ± 11.7
SBP (mmHg)	128.4 ± 17.2	128.4 ± 19.0	125.9 ± 15.0	131.0 ± 17.6
DBP (mmHg)	78.2 ± 11.9	77.9 ± 12.4	76.1 ± 8.7	80.5 ± 14.0
TC (mmol/L)	4.82 ± 0.86	4.90 ± 0.78	4.53 ± 0.90	5.04 ± 0.83[b]
LDL (mmol/L)	2.67 ± 0.72	2.73 ± 0.67	2.42 ± 0.71	2.86 ± 0.71[b]
HDL (mmol/L)	1.45 ± 0.36	1.40 ± 0.43	1.45 ± 0.34	1.50 ± 0.29
TG (mmol/L)	1.56 ± 1.38	2.04 ± 1.78	1.18 ± 0.59[a]	1.49 ± 1.39
HbA1c (%)	6.03 ± 0.87	6.03 ± 0.54	6.13 ± 1.26	5.94 ± 0.63
Skin carotenoid level	3.66 ± 1.00	3.43 ± 0.66	3.61 ± 0.87	3.93 ± 1.30
Urinary Na/K ratio (mol/mol)	3.32 ± 1.86	3.10 ± 1.52	3.34 ± 1.71	3.52 ± 2.28

Data are shown as the mean ± SD. There was a statistically significant difference ($P < 0.05$, Tukey-Kramer test) between the groups ([a]: vs. the Control group, [b]: vs. the Monitoring group and no symbol: not significant)

F Female, *M* Male, *Y* Yes, *N* No, *NA* Not applicable, *BMI* Body mass index, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *TC* Total cholesterol, *LDL* Low-density lipoprotein cholesterol, *HDL* High-density lipoprotein cholesterol, *TG* Triglyceride, *HbA1c* Hemoglobin A1c

average age of the participants was 38.0 years, and more than 70% were female. The mean BMI and waist circumference values were 30.4 kg/m^2 and 95.6 cm, respectively, which exceeded the WHO and other standards for obesity [7]. No other metabolic syndrome components exceeded the reference values. As for dietary biomarkers, the mean skin carotenoid level, which has been reported to correlate with vegetable intake, was 3.66. The mean urinary Na/K ratio, which represents the balance of salt and vegetable intake, was 3.32 mol/mol.

Cross-sectional study: relationships between dietary biomarkers and metabolic syndrome components

Regarding the metabolic syndrome components, waist circumference was significantly correlated with various markers, such as blood pressure and blood lipid-related measurements (Fig. 2a). In contrast, BMI showed significant positive correlations only with waist circumference and LDL cholesterol levels. Regarding the dietary biomarkers, skin carotenoid levels were negatively correlated with blood triglyceride levels. The urinary Na/K ratio showed a significant positive correlation with systolic and diastolic blood pressure. A comparison of the blood triglyceride levels between the two groups divided by the median skin carotenoid level (3.5) showed that triglyceride levels in the high skin carotenoid level group ($n=46$) were significantly lower than those in the low skin carotenoid level group ($n=47$) (Fig. 2b). A

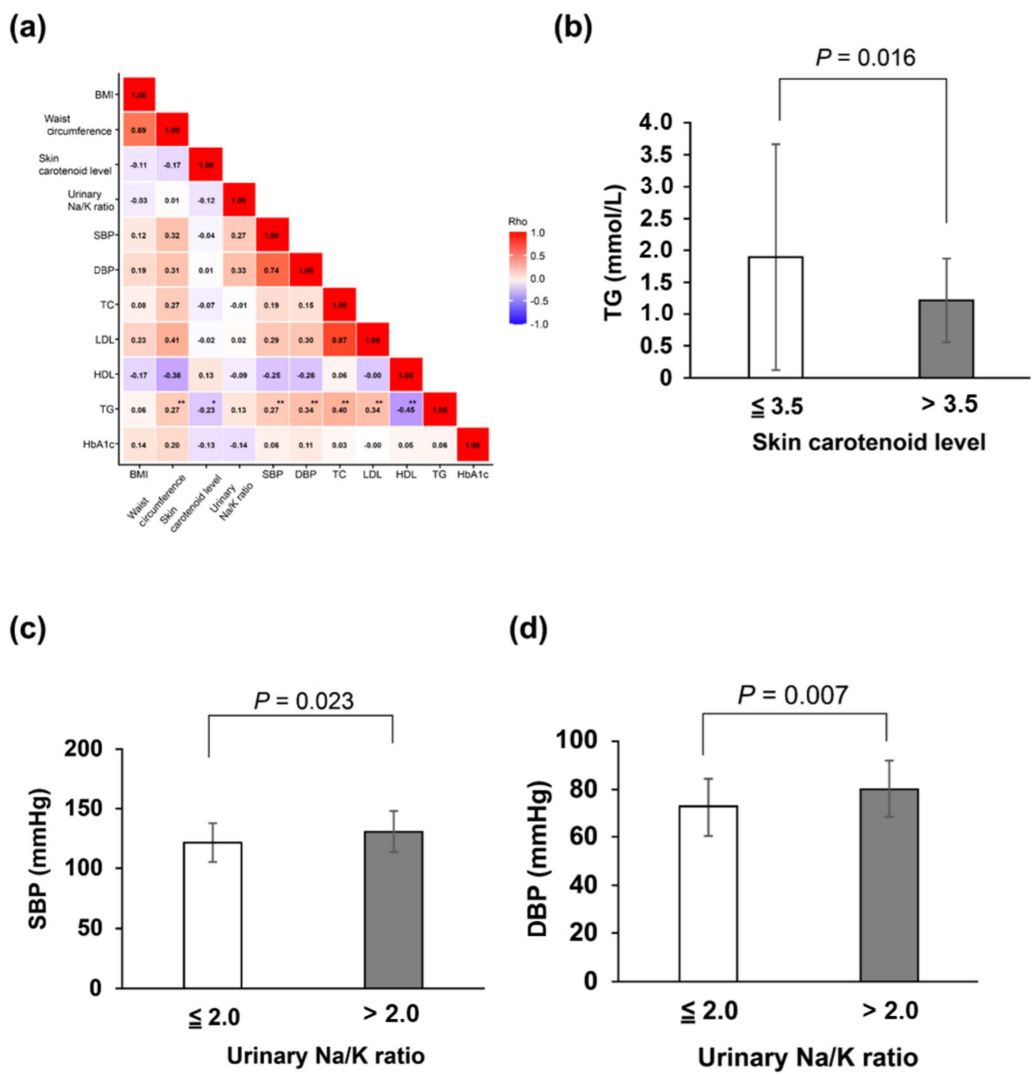

Fig. 2 Relationships between dietary biomarkers and metabolic syndrome components. **a** Correlations between dietary biomarkers and metabolic syndrome components (Pearson's correlation coefficient with *P*-value are shown; $^{**}P< 0.01$, $^{*}P < 0.05$). **b** Comparison of the triglyceride levels between the skin carotenoid level low group (skin carotenoid level ≤ 3.5, $n= 47$) and skin carotenoid level high group (> 3.5 skin carotenoid level, $n = 46$). **c, d** Comparison of the systolic and diastolic blood pressure between the urinary Na/K low group (Na/K ≤ 2.0, $n = 24$) and Na/K high group (> 2.0 Na/K, $n = 69$). Data are shown as the mean ± SD. The *P*-value was by Welch's *t*-test. BMI: Body mass index. Urinary Na/K ratio: Urinary sodium-to-potassium ratio. SBP: Systolic blood pressure. DBP: Diastolic blood pressure. TC: Total cholesterol. LDL: Low-density lipoprotein cholesterol. HDL: High-density lipoprotein cholesterol. TG: Triglyceride. HbA1c: Hemoglobin A1c

comparison of the systolic and diastolic blood pressure between the two groups divided by a urinary Na/K ratio of 2.0 revealed that the low urinary Na/K ratio group ($n = 24$) had significantly lower blood pressure than the high urinary Na/K ratio group ($n = 69$) (Fig. 2c,d).

Multiple regression analyses indicated that the skin carotenoid levels were not significantly associated with the blood triglyceride levels ($P = 0.203$) in the adjusted model. In contrast, the urinary Na/K ratio was positively associated with systolic and diastolic blood pressure, independent of age, sex, waist circumference, use of anti-hypertensive medication, and alcohol intake habits (Table 2).

Intervention study: profile of the intervention groups

Ninety-three participants, excluding dropouts ($n = 30$ in the control group, $n = 31$ in the monitoring group, $n = 32$ in the monitoring + vegetable juice group; Fig. 1), were included in the analysis to evaluate the intervention effects. The profiles of each group before the intervention are shown in Table 1. There were no significant differences in the mean age, sex ratio, mean BMI, or mean waist circumference between the groups. However, some of the measurements had significant differences between the groups. The blood total and LDL cholesterol were significantly higher in the monitoring + vegetable juice group than in the monitoring group ($P = 0.0451$ and $P = 0.0386$, respectively). In addition, the blood triglyceride levels were significantly higher in the control group than in the monitoring group ($P = 0.0359$).

Intervention study: effects on dietary biomarkers and metabolic syndrome components

The changes in dietary biomarkers and metabolic syndrome components between before and after intervention were compared among the three groups (Table 3). The increase in the skin carotenoid levels in the monitoring + vegetable juice group was significantly greater than in the control and monitoring groups ($P < 0.0001$). The decrease in the urinary Na/K ratio of the monitoring and monitoring + vegetable juice groups was greater than that of the control group, with a significant difference between the control and monitoring + vegetable juice groups ($P = 0.027$). The improvements in waist circumference in the monitoring and monitoring + vegetable juice groups were greater than in the control group, with a significant difference between the control and monitoring + vegetable juice groups ($P = 0.045$). The decrease in systolic and diastolic blood pressure in the monitoring + vegetable juice group was greater than in the control group; however, the differences were not statistically significant.

Before and after intervention period, significant changes were observed in several parameters, even in the control group (Additional file 1). In all three groups, skin carotenoid levels were significantly increased, while systolic blood pressure and blood HbA1c were significantly decreased through the intervention period. In contrast, serum total-, LDL-, and HDL-cholesterol levels significantly worsened in all groups.

Discussion

This study aimed to investigate the relationship between dietary biomarkers and metabolic syndrome components in adults with an overweight and obese BMI living in Ulaanbaatar, an urban area of Mongolia, and to investigate the effects of monitoring dietary biomarkers or a combination of such monitoring and providing vegetable juice on these markers and metabolic syndrome components.

The average BMI and waist circumference of the participants were above the WHO and other reference values for obesity [7, 8]. No other metabolic syndrome components exceeded the reference values. The 4th National

Table 2 Adjusted partial regression coefficient between dietary biomarkers and some metabolic syndrome components

	TG		SBP		DBP	
Independent variables	*β*	*P*	*β*	*P*	*β*	*P*
Skin carotenoid level	−0.170	NS				
Urinary Na/K ratio (mol/mol)			1.680	< 0.05	1.805	< 0.01
Age (years)	0.013	NS	0.553	< 0.001	0.256	< 0.05
Sex (male)	1.303	< 0.001	6.076	NS	1.988	NS
Waist circumference (cm)	0.011	NS	0.302	< 0.05	0.237	< 0.005
Anti-hyperlipidemia medication status	−0.372	NS				
Anti-hypertensive medication status			16.403	< 0.05	10.996	< 0.005
Current smoking habits	−0.567	< 0.05				
Alcohol intake habits	0.311	NS	3.429	NS	0.388	NS

TG triglyceride, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *β* regression coefficient, *NS* not significant

Table 3 Changes in dietary biomarkers and metabolic syndrome components among the three groups

	Control ($n=27–30$)	Monitoring ($n=29–31$)	Monitoring + Vegetable juice ($n=31–32$)
Skin carotenoid level	0.28 ± 0.4	0.36 ± 0.51	1.72 ± 0.74[a,b]
Urinary Na/K ratio (mol/mol)	0.45 ± 1.45	− 0.49 ± 1.52	− 0.80 ± 2.41 [a]
BMI (kg/m^2)	− 0.61 ± 1.65	− 0.32 ± 0.68	− 0.44 ± 0.73
Waist circumference (cm)	− 0.22 ± 3.55	− 2.15 ± 3.59	− 2.62 ± 4.45 [b]
SBP (mmHg)	− 8.10 ± 13.34	− 7.77 ± 12.21	− 13.84 ± 13.14
DBP (mmHg)	− 1.00 ± 8.62	− 0.55 ± 8.65	− 4.97 ± 8.01
TC (mmol/L)	0.14 ± 0.63	0.38 ± 0.81	0.18 ± 0.68
LDL (mmol/L)	0.31 ± 0.50	0.51 ± 0.55	0.31 ± 0.62
HDL (mmol/L)	− 0.09 ± 0.17	− 0.08 ± 0.16	− 0.08 ± 0.12
TG (mmol/L)	0.06 ± 0.80	0.25 ± 0.71	− 0.03 ± 1.11
HbA1c (%)	− 0.48 ± 0.51	− 0.37 ± 0.48	− 0.43 ± 0.49

Data are shown as the mean ± SD. There was a statistically significant difference ($P < 0.05$, Tukey-Kramer test) between groups ([a]: vs. the Control group, [b]: vs. the Monitoring group and no symbol: not significant). The value changes were the baseline values subtracted from the values after the intervention.

BMI Body mass index, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *TC* Total cholesterol, *LDL* Low-density lipoprotein cholesterol, *HDL* High-density lipoprotein cholesterol, *TG* Triglyceride, *HbA1c* Hemoglobin A1c

STEPS SURVEY by the Mongolian National Center for Public Health showed that the proportion of people exceeding the reference values for BMI and waist circumference was 49.4 and 53%, respectively, which was greater than the proportion of people exceeding the reference values for other metabolic syndrome components (e.g., systolic and diastolic blood pressure 22.6%, LDL cholesterol 25.3%, triglyceride 31.1%) [6]. Among the dietary biomarkers, the skin carotenoid level was 3.66 ± 1.00. This is lower than that of 811 adults in a rural area in Japan (5.41 ± 1.30, Hirosaki, Aomori) [13], suggesting that the present study participants, Ulaanbaatar residents, had lower carotenoid or vegetable intake than Japanese participants. This is consistent with statistical information showing that the average vegetable intake in Mongolia is 2.3 servings/day (approximately 184 g/day) [6] and that the average vegetable intake in Japan is 280.3 g/day [36]. The urinary Na/K ratio of the participants in the present study was 3.32 ± 1.86 mol/mol, whereas the spot urinary Na/K ratio of 12,877 adults (65.4 ± 13.3 years) in a rural area in Japan (Tome, Miyagi) was 4.9 ± 2.2 mol/mol [29] and the 24-h urinary Na/K ratio of 1145 adults (49 ± 5 years) from other several districts in Japan (Sapporo, Toyama, Aito Town, and Wakayama) was 4.3 ± 1.3 mol/mol [33], indicating that the urinary Na /K ratio of the participants in this study was lower than that in Japan. The salt intake of people living in Mongolia (10.5 g/day) [6] and Japan (10.1 g/day) [36] is quite similar, and the intake of vegetables and fruits, one of the main sources of potassium, is lower in Mongolia than in Japan. Considering these differences in dietary habits, people living in Mongolia may habitually consume potassium-rich foods other than vegetables and fruit, such as potatoes and dairy products [37].

In the present study, correlations were found between the dietary biomarkers and some metabolic syndrome components. Many epidemiological studies have reported that the urinary Na/K ratio is associated with systolic and diastolic blood pressure [18, 29, 32–35]. Similarly, in this study, the urinary Na/K ratio was significantly associated with systolic and diastolic blood pressure independent of age, sex, waist circumference, and anti-hypertensive medication use. When the participants were divided by a urinary Na/K ratio of 2.0 mol/mol, which is the target value with verification [33], the systolic and diastolic blood pressure of the participants with a urinary Na/K ratio ≥ of 2.0 mol/mol was significantly higher than those with a urinary Na/K ratio of < 2.0 mol/mol. Regarding skin carotenoid levels, there was a significant negative correlation with blood triglycerides in the present study, whereas significant positive associations with lower BMI and blood insulin levels in males and with various metabolic syndrome components such as systolic and diastolic blood pressure, HOMA-IR (homeostasis model assessment as an index of insulin resistance), lower blood triglycerides, and higher HDL cholesterol levels in females were confirmed in a previous study [13]. However, after adjusting for age, sex, waist circumference, antihyperlipidemic medication use, smoking, and drinking habits, the significant negative association between blood triglyceride and skin carotenoid levels disappeared. This may have been due to the small sample size. It is also possible that the characteristics of the participants in the present study (age 38.1 ± 11.4, female

71.3%) may have influenced the results. A previous cross-sectional study in Japan has suggested that biological markers correlated with skin carotenoid levels differed by age and sex of the participants [14]. Although further investigation is needed, dietary biomarkers, such as skin carotenoid levels and urinary Na/K ratio, may be useful for screening people with a potential risk of metabolic syndrome.

In the present study, the urinary Na/K ratio was decreased by 0.49 mol/mol in the monitoring group, while it was increased by 0.45 mol/mol in the control group. Kogure et al. reported that in annual health check-ups in a municipality in Japan, the urinary Na/K ratio of the residents decreased by an average of 0.6 mol/mol by the following year just by measuring the urinary Na/K ratio and disclosing the results right away [29]. Despite the differences in the duration of the intervention and environment between the studies, it was assumed that the participants in the monitoring group understood the status of their own urinary Na/K ratio, resulting in an improvement in the urinary Na/K ratio. Likewise, a previous study has shown that continuous and repeated measurements of skin carotenoid levels can increase vegetable intake estimated by a self-administered diet history questionnaire [38]. In the present study, skin carotenoid levels in the monitoring group also increased by 0.36. However, no significant difference was observed between the control and monitoring group s. This study used a design in which the control, monitoring, and monitoring + vegetable juice groups coexisted in the same workplace. Although the control group did not undergo repetitive monitoring of their skin carotenoid levels, they might have been influenced by participants in the other two groups and changed their awareness and behavior regarding their dietary habits. This was considered a negative bias in the present intervention study but could be a positive bias in real-world public health approaches.

The combination of the monitoring and providing vegetable juice had a stronger effect on dietary biomarkers than monitoring alone. The skin carotenoid levels increased by approximately 1.72 after 8 weeks in the monitoring + vegetable juice group, which was significantly higher than in the monitoring group (0.36). The results of the present study were considered valid as a previous study reported an increase in the skin carotenoid level of approximately 0.8–0.9 by 1-month daily intake of the same vegetable juice [27]. The reduction in the urinary Na/K ratio in the monitoring + vegetable juice group (− 0.8 mol/mol) was greater than in the monitoring group (− 0.49 mol/mol). However, it was less than that observed in a previous study (− 1.4 mol/mol) in which vegetable juice and the intervention duration were the same as those in the present study [31]. This inconsistency was probably due to the difference in the before-intervention urinary Na/K ratio of the participants between the previous study (4.9 mol/mol) and the present study (3.5 mol/mol; monitoring + vegetable juice group) [31]. This finding was supported by a previous study in which the reduction in the urinary Na/K ratio by vegetable juice intake was greater in those with higher before-intervention urinary Na/K ratios than in those with lower before-intervention urinary Na/K ratios [39]. In conclusion, monitoring dietary habits could have a positive impact on dietary biomarkers, and combining it with specific support, such as providing vegetable juice, could strengthen this effect.

Regarding metabolic syndrome components, the reduction in waist circumference (− 2.63 cm) in the monitoring + vegetable juice group was significantly greater than in the control group (− 0.22 cm). In a previous study [31], intake of the same vegetable juice for 2 months resulted in a reduction in waist circumference, but the effect (− 0.9 cm) was smaller than that in the present study because the previous study included fewer overweight participants. Several epidemiological and interventional studies have supported the inhibitory effects of vegetable intake on obesity and fat accumulation. For example, the risk of weight gain (OR 0.27 (95% confidence interval 0.08–0.99)) with a vegetable intake of ≥ 4 servings/day and a negative correlation between vegetable intake and waist circumference in females (− 0.36 cm/vegetable serving/day) have been reported [40]. Carotenoids can help to prevent obesity, and several epidemiological studies have reported a relationship between the blood or skin carotenoid level and metabolic syndrome components. Sugiura et al. reported a significant inverse association between serum α-, β-carotene, and β-cryptoxanthin levels and the risk of developing dyslipidemia [12]. Matsumoto et al. reported a significant negative association between the visceral fat area and blood lutein, β-cryptoxanthin, β-carotene, and total carotenoids in females [14]. Matsumoto et al. reported that higher levels of skin carotenoids were associated with higher BMI and blood insulin levels in males, as well as blood pressure, HOMA-IR, triglycerides, and HDL cholesterol levels in females [13]. Östh et al. also reported that β-carotene concentrations were 50% lower in the adipocytes of patients with obesity than in non-obese patients [41]. Li et al. reported that a 2-month continuous tomato juice intervention resulted in decreased serum cholesterol and inflammatory adipokine levels and increased serum adiponectin and lycopene levels [42]. As one of the mechanisms by which carotenoids inhibit obesity, Sekiya et al. reported that neoxanthin, a carotenoid, inhibits fat accumulation in adipocytes [43] and Maeda reported that fucoxanthin, another carotenoid, inhibits visceral fat accumulation by suppressing adipocyte accumulation [44]. Thus, it can be inferred that the carotenoids in vegetable juice partly contributed to the reduction of waist circumference observed in the monitoring + vegetable juice group.

In the present study, systolic and diastolic blood pressure were also largely lowered by the vegetable juice intervention, though the difference was not statistically significant (systolic, − 13.8 mmHg; diastolic, − 5.0 mmHg). Given the hypotensive effect of potassium intake [31, 39, 45] or the association between the urinary Na/K ratio and blood pressure [18, 29, 35], it was considered that potassium intake from vegetable juice possibly contributed to the lowering of blood pressure. However, in the present study, a decrease in blood pressure was observed even in the control group; therefore, the hypotensive effect in the monitoring + vegetable juice group was not significantly different from that in the control group. Blood pressure is known to be sensitive to temperature fluctuations [17]. The study was conducted between May and June. The rise in temperature might have lowered the blood pressure of all participants in the present study, which made it difficult to detect the hypotensive effect of the vegetable juice. A previous study, which was not an intervention with vegetable juices but showed a decrease in blood pressure associated with a decrease in urinary Na/K ratio, had an intervention period of 1 year, and blood pressure before and after the intervention was measured at the same season [29].

The changes in some metabolic syndrome components between before- and after-intervention, particularly blood lipid parameters (serum total, LDL, HDL cholesterol, and triglycerides), worsened overall, including in the control group. Therefore, the effects of carotenoid intake on HDL [46, 47] and LDL cholesterol [48] noted in previous reports were not observed in the present study. This is because the study was conducted at a time when the traditional Mongolian dietary pattern switched from a winter diet ("red" diet consisting mainly of protein such as red meat) to a spring and summer diet ("white" diet consisting mainly of fat such as dairy products) [49]. This dietary pattern switching might influence blood lipid levels and lipid metabolism.

This study has several limitations. First, the timing of the study may not have been optimal for certain markers. As mentioned above, the study was conducted in spring and summer when temperatures rise and dietary patterns change, making it difficult to observe the effects of the intervention. Although this is not limited to Mongolia, the intervention period should be set for 1 year in order to accurately assess the effect of the intervention on blood pressure. If this is difficult to achieve, a period of less temperature fluctuation should be selected. On the other hand, as this may be specific to Mongolia, it was considered necessary to avoid including the switch from the winter diet to the spring and summer diet in the intervention period when examining the effect of the intervention on blood lipids. Second, participants from different study groups coexisted in the same workplace. As mentioned earlier, this may have created a bias in the improvement of dietary habits compared with the control group. This study recruited participants from employees in three workplaces and assigned them to three intervention groups. More detailed studies should be conducted that only assign one group per one workplace and with relatively homogeneous populations (employees). Third, the correlation between skin carotenoid levels measured by the Vegecheck® and vegetable intake has been confirmed in Japanese population [8], but not in Mongolian adults. According to a previous study [50] using the same device as the Vegecheck®, skin carotenoid levels (described as antioxidant levels in their paper) are more affected by differences in diet and stress than by differences in race. We will also examine whether this is true for Mongolian and evaluate the effectiveness of skin carotenoid monitoring with the Vegecheck® in improving dietary habits in detail. Fourth, fasting blood glucose levels, an important component of metabolic syndrome, were not measured in the present study. This was due to equipment reasons as well as the possibility of participants not receiving blood test under fasting conditions. Fasting blood glucose levels should also be evaluated for more detailed studies in the future.

Conclusions

The present study suggests that the measurement of dietary biomarkers, such as skin carotenoid levels and urinary Na/K ratio, is useful for screening people with a potential risk of metabolic syndrome and motivating them to improve their dietary habits, even among overweight and obese people living in Ulaanbaatar, Mongolia. Moreover, the combination of the monitoring dietary biomarkers and providing vegetable juice was suggested to be helpful in improving dietary biomarkers and metabolic syndrome components such as waist circumference. This study is expected to serve as a reference for the implementation of public health measures in Mongolia.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13063-024-08712-7.

Additional file 1. Measurements of the metabolic syndrome components and dietary biomarkers before and after the intervention in each group

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Authors' contributions
Conceptualization and methodology, E.T., Y.U., H.S., B.J. (Bayasgalan Jambaldorj), B.J. (Batjargal Jamiyan); data curation, Y.U.; formal analysis, E.T.; investigation, B.J. (Bayasgalan Jambaldorj), O.D., T.B. (Tuvshinbayar Bayaraa), T.B. (Tuul Bayarmagnai), N.K.; writing—original draft preparation, E.T.; writing—review and editing, Y.U., H.S.; visualization, E.T.; supervision, H.S., N.D., U.S., S.B.; project administration, E.T., Y.U. B.J. (Bayasgalan Jambaldorj); funding acquisition, Y.U., H.S. All authors have read and agreed to the published version of the manuscript.

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Data availability
The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Ministry of Health Medical Ethics Review Committee Resolution of Mongolia (Approval No. 283) and the ethics board of KAGOME CO., LTD (Approval No. 2020-R05).

Consent for publication
Written informed consents were obtained from all subjects involved in the study.

Competing interests
E.T., Y.U., and H.S. are employees of KAGOME CO., LTD. The other authors declare that they have no competing interests.

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