Original Article

Potassium Excretion in Healthy Japanese Women Was Increased by a Dietary Intervention Utilizing Home-Parcel Delivery of Okinawan Vegetables

Mallet K.-N. TUEKPE[1)], Hidemi TODORIKI[1)], Satoshi SASAKI[2)],
Kui-Cheng ZHENG[1)], and Makoto ARIIZUMI[1)]

Potassium, which is abundant in vegetables, is inversely related to blood pressure. Although the situation has changed somewhat in recent years, the Okinawan diet has generally included a large amount of vegetables, and until recently Okinawans had the lowest rates of mortality due to stroke and coronary heart disease in Japan. Based on the hypothesis that these low mortality rates are partly attributable to increased potassium intake resulting from the high vegetable consumption, this study examined whether increasing the consumption of typical yellow-green Okinawan vegetables increases potassium intake. The purpose of this investigation was to determine whether increased consumption of these vegetables should be one of the dietary modifications recommended in public health promotion programs for Okinawans. The study employed 56 healthy, normotensive, free-living Japanese women aged 18–38 years living in Okinawa. They were randomized to a dietary intervention group (n=27) or a control group (n=29). Members of the dietary intervention group received an average weight of 371.4 g/day of a combination of the following vegetables twice weekly through an express home parcel deliver service for a period of 14 days: Goya (*Momordica charantia*), green papaya (*Carica papaya*), Handama (*Gynura bicolor*), Karashina (*Brassica juncea*), Njana (*Crepidiastrum lanceolatium*), Fuchiba (*Artemisia vulgaris*) and Fudanso (*Beta vulgaris*); and they consumed an average of 144.9 g/day, resulting in a 20.5% increase in their urinary potassium excretion over the baseline (p=0.045). The members of the control group were asked to avoid these vegetables, and the change in potassium excretion in this group was not significant (p=0.595). Urinary sodium and magnesium excretions, systolic and diastolic blood pressures, folic acid, triglycerides and serum high density lipoprotein cholesterol, low density lipoprotein cholesterol and total cholesterols changed non-significantly in both groups. Also, post-intervention urinary potassium excretion correlated positively with vegetable consumption in both the dietary intervention (p<0.0001) and control (p=0.008) groups and with Okinawan vegetable intake in the dietary intervention group (p=0.0004). (*Hypertens Res* 2006; 29: 389–396)

***Key Words*: Okinawa, vegetable intake, urinary potassium excretion, randomized controlled dietary intervention**

From the [1)]Department of Environmental and Preventive Medicine, Faculty of Medicine, University of the Ryukyus, Okinawa, Japan; and [2)]Project of Scientific Evaluation of Dietary Reference Intakes, National Institute of Health and Nutrition, Tokyo, Japan.
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Address for Reprints: Hidemi Todoriki, Ph.D., Department of Environmental and Preventive Medicine, Faculty of Medicine, University of the Ryukyus, 207 Uehara, Nishihara-cho, Okinawa 903–0215, Japan. E-mail: todoriki@med.u-ryukyu.ac.jp
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Introduction

Although recent data shows that the prevalence of hypertension, stroke and myocardial infarction in Okinawa are currently not much different from those in the rest of Japan (*1*), until recently Okinawans had the lowest rate of mortality due to stroke and coronary heart disease in Japan (*2–4*). The reasons for this are not entirely clear, but the dietary habits of Okinawans have been suggested to be a major factor (*5*). Although these dietary habits are changing (*6*), Okinawans used to consume large amounts of vegetables (*7*, *8*).

Vegetables are a rich source of dietary potassium (*9*). Potassium inhibits platelet aggregation and arterial thrombosis, increases vasomotricity and natriuresis (*10–13*), reduces high blood pressure and helps prevent heart attacks (*10*, *14*, *15*). It also reduces both systolic and diastolic blood pressures in normotensives and hypertensives (*14*, *15*).

Although pharmacological methods are currently the main treatment option for hypertension (*16*), non-pharmacological treatments have also been proposed (*17*). Increasing the intake of vegetables could be a less expensive non-pharmacological treatment not only for lowering high blood pressure in hypertensives but also for promoting cardiovascular health.

This study examined whether increasing the consumption of the yellow-green Okinawan vegetables typically used in Okinawan dishes increases potassium intake. The purpose was to determine whether dietary modifications involving increased consumption of typical yellow-green Okinawan vegetables could be proposed for public health promotion programs for Okinawans.

In addition, this study employed the relatively new concept of dietary intervention *via* home-parcel delivery, in which the vegetables used in the intervention were delivered directly to the homes of the subjects.

Methods

Subjects

The subjects were healthy free-living female volunteers living in Okinawa. They were recruited through posters and by personal contacts. All subjects were between 18 and 38 years of age, and none of them was undergoing treatment for any disease at the time of the study. Fifty-six volunteers consented to participate, and 53 successfully completed the study. Twenty-five of these 53 subjects were randomized to the dietary intervention group, and 29 to the control group.

Study Design, Vegetable Intake and Dietary Assessment

The study was carried out in March–April of 2005. It was designed as a randomized controlled trial employing dietary intervention. The aims, objectives, and intervention method were carefully explained to all the subjects, and all of them were informed that they were at liberty to withdraw from the study at any time without providing an explanation. After providing their informed written consent, subjects were randomized to the dietary intervention or control group. A list of the yellow-green Okinawan vegetables being used in the study was given to all the subjects. Additionally, the dietary intervention group was provided with instructions on how to cook the Okinawan vegetables. The dietary intervention group was strongly urged to consume a combination of these vegetables as part of their diet, while the controls were asked to refrain from consuming them as much as possible.

The dietary intervention lasted 14 days. Intervention days were specifically tailored for each subject so as not to coincide with their menstruation. During the intervention period about 1.3 kg of a combination of five typical yellow-green Okinawan vegetables were delivered twice a week to the homes of the intervention group by an express home parcel delivery service. The combination consisted of four primary vegetables: about 400 g Goya (*Momordica charantia*), about 600 g green papaya (*Carica papaya*), 100 g Handama (*Gynura bicolor*) and 100 g Karashina (*Brassica juncea*); and 100 g of one of three others: Njana (*Crepidiastrum lanceolatium*), Fuchiba (*Artemisia vulgaris*) or Fudanso (*Beta vulgaris*). The 2.6 kg/week supply of vegetables was based on the national recommended intake of 350 g/day and the results of a 1 year preliminary nutritional survey carried out by us in Ginowan City, Okinawa.

All subjects in both groups were provided with digital scales which they used to weigh and record all vegetables, fruits and juices they consumed during the intervention period. Any of these foods consumed outside the home were also recorded and their weights estimated later using a picture booklet designed for this purpose (*18*). The potassium content of vegetables was calculated from Standard Tables of Food Composition in Japan (*19*). The Medical Ethics Committee of the University of the Ryukyus approved the study protocol.

Blood Pressure and Anthropological Data

Pre- and post-intervention blood pressures were measured in both groups using an automatic digital sphygmomanometer (HEM-762; Omron Corp., Tokyo, Japan) after subjects had rested for at least 5 min. These blood pressure values were measured three times in the right arm with subjects in a seated position. If any of the measurements differed by more than 5 mmHg from the others, it was repeated. The mean value was then calculated for each subject. Anthropological data was also collected at the start and end of the dietary intervention period from all subjects in both intervention and control groups.

Blood Sampling

Fasting blood samples (10 ml) were collected the day before

Table 1. Pre-Intervention and Post-Intervention Changes in Variables

Variables	Pre-intervention (mean±SD)		Pre-intervention between group comparison† (*p*-value)	Post-intervention changes* (mean (*p*-value))		Between group post-intervention change comparison† (*p*-value)
	Intervention group (*n*=19)	Control group (*n*=20)		Intervention group (*n*=19)	Control group (*n*=20)	
Age (years)	24.4±3.8	25.7±4.8	0.396	—	—	—
Body height (cm)	156.4±4.4	158.1±5.2	0.278	—	—	—
Body weight (kg)	49.3±4.8	52.7±6.9	0.082	−0.3 (0.140)	−0.3 (0.068)	0.687
Body mass index (kg/m²)	20.1±1.4	21.1±3.1	0.667	−0.1 (0.136)	−0.1 (0.073)	0.857
Systolic blood pressure (mmHg)	109.3±8.9	112.3±10.0	0.365	0.3 (0.832)	−2.6 (0.198)	0.396
Diastole blood pressure (mmHg)	69.1±6.4	69.2±6.5	0.964	−0.5 (0.689)	0.5 (0.634)	0.536
Serum HDL cholesterol (mg/dl)	71.2±19.7	70.4±17.8	0.813	−2.1 (0.304)	−1.6 (0.409)	0.850
Serum LDL cholesterol (mg/dl)	91.9±26.7	96.8±20.0	0.396	−3.9 (0.481)	−0.4 (0.899)	0.607
Serum triglycerides (mg/dl)	56.4±11.1	61.0±28.3	0.771	1.2 (0.879)	−1.1 (0.940)	0.742
Serum total cholesterol (mg/dl)	177.1±37.2	181.6±33.0	0.607	−8.5 (0.114)	−3.3 (0.588)	0.434
Serum folic acid (ng/ml)	5.5±2.2	4.9±1.7	0.204	0.5 (0.095)	0.4 (0.313)	0.857
24-h urinary sodium (mg/day)	2,911.4±1,051.6	2,977.8±1,148.8	0.852	−208.9 (0.495)	67.3 (0.772)	0.465
24-h urinary potassium (mg/day)	1,600.9±474.0	1,630.4±451.6	0.843	363.5 (0.045)	−68.6 (0.595)	0.047
24-h urinary magnesium (mg/day)	78.1±21.1	77.0±21.5	0.872	1.4 (0.800)	−4.1 (0.338)	0.420
24-h urinary sodium-potassium ratio	1.9±0.8	1.8±0.7	0.811	−0.4 (0.039)	0.1 (0.394)	0.031

*Difference between pre-intervention and post-intervention values. Student's paired sample *t*-test was used to compare normally distributed variables and Wilcoxon matched pairs test was used for those that could not be made normal by logarithm transformation. †Student's independent sample *t*-test was used to compare normally distributed variables and Mann-Whitney *U* test was used for those that could not be made normal by logarithm transformation. HDL, high density lipoprotein; LDL, low density lipoprotein.

intervention started and the day after intervention ended in all subjects of both groups. The samples were centrifuged immediately after collection and the serum was transferred into stock tubes and stored at −80°C until measurement.

Urine Collection

Plastic, opaque brown urine-collection containers containing 0.1 g pre-weighed boric acid were given to all subjects of both groups after carefully instructing them on how to collect 24-h urine samples. The importance of collecting complete samples was emphasized. Urine samples were collected the day before intervention started and the day after intervention ended. The plastic containers with the urine samples were kept in black bags at room temperature during the collection period. Subjects brought the urine samples to a pre-arranged submission point. The weight, specific gravity and volume of each sample were immediately determined after submission, and approximately 50 ml of each sample was collected into stock tubes and stored at −20°C until measurement.

Analysis of Samples

Analyses of both urine and blood samples were carried out at the SRL Laboratory in Tokyo, Japan. The laboratory personnel were blinded to the subjects and the coding system used to label the samples.

Outcome Measures

The outcome measures were urine electrolytes and serum folic acid, triglycerides and high density lipoprotein (HDL)

Table 2. Average Vegetable, Fruit and Potassium Intake (g/Day)

	Intervention group (n=19) (mean±SD)	Control group (n=20) (mean±SD)	Between group difference†	p-value
Vegetables				
Average daily intake*	251.3±78.4	153.7±74.5	97.6	<0.001
Average daily Okinawan vegetable intake	144.9±66.9	4.7±5.8	140.2	<0.001
Average daily intake of other vegetables	106.4±51.3	149.0±72.0	42.6	0.041
Fruit				
Average daily intake	33.5±28.5	44.6±44.1	11.1	0.550
Potassium				
Average daily intake from all vegetables	0.9±0.3	0.5±0.2	0.5	0.000
Average daily intake from fruits	0.07±0.1	0.12±0.1	0.04	0.415
Average daily intake from Okinawan vegetables	0.6±0.3	0.02±0.03	0.6	0.000
Average daily intake from other vegetables	0.3±0.2	0.4±0.2	0.2	0.023
Potassium intake per 100 g vegetables				
Okinawan vegetables	0.4±0.08	0.4±0.28	0.07	0.293
Other vegetables	0.3±0.06	0.3±0.04	0.01	0.429

*Includes Okinawan vegetables. †Student's independent sample t-test was used to compare differences between the two groups.

Table 3. Correlation between Urinary Sodium, Potassium and Change in Blood Pressure Post-Intervention

	r* (p-value)			
	Intervention group		Control group	
	Potassium	Sodium	Potassium	Sodium
Change in systolic pressure	−0.09 (0.711)	−0.08 (0.745)	0.16 (0.511)	0.19 (0.412)
Change in diastolic pressure	−0.12 (0.624)	−0.03 (0.903)	−0.08 (0.748)	−0.16 (0.493)

*Pearson's correlation coefficient.

cholesterol, low density lipoprotein (LDL) cholesterol and total cholesterols. Since a positive correlation exists between potassium intake and its excretion in urine (*20*, *21*), urinary potassium excretion was set up as the primary endpoint.

Statistical Analysis

For the purposes of this report, subjects with incomplete data (only one urine or blood sample; n=6), and subjects with a creatinine (mg)/body weight (kg) ratio less than 10.8 or greater than 25.2 (*22*) (n=6) were excluded from the statistical analysis. Since current smokers excrete lower urinary potassium than non-smokers (*23*) and since serum potassium level is strongly associated with cigarette smoking (*24*), smokers (n=2) were also excluded. The results for the 39 subjects (intervention group, n=19; control group, n=20) who met the above criteria are reported here.

SAS statistical software (version 8.0; SAS Institute Inc., Cary, USA) was used for the analyses. For normally distributed variables, Student's paired sample t-test was used to analyze changes within each group and Student's independent sample t-test was used to assess differences between the groups. Wilcoxon matched pair and Mann-Whitney U tests, respectively, were used for variables that could not be normalized even after logarithmic transformation. Pearson correlation procedures were used to explore relationships between vegetable intake (total and Okinawan) and post-intervention urinary sodium and potassium excretions. Also, relationships between post-intervention changes in systolic and diastolic pressures and changes in urinary sodium and potassium excretions were explored. Since fruits are also a major source of potassium, adjustments were made for fruit intake.

Unless otherwise stated, all p-values are two-tailed and only differences with $p<0.05$ were considered significant.

Results

Table 1 shows pre- and post-intervention characteristics of the subjects. There were no statistically significant differences between the intervention and control groups pre-intervention. The mean age for the intervention group was 24.4 years, *vs*. 25.7 years for the control group. The difference in mean body mass index (BMI) was not significant (p=0.667). Sodium and potassium excretion in the 24-h urine samples were also not significantly different between the two groups (p=0.852 and p=0.843, respectively). There was a non-significant mean weight loss of 0.3 kg in each group at the end of intervention. The post-intervention changes and differences

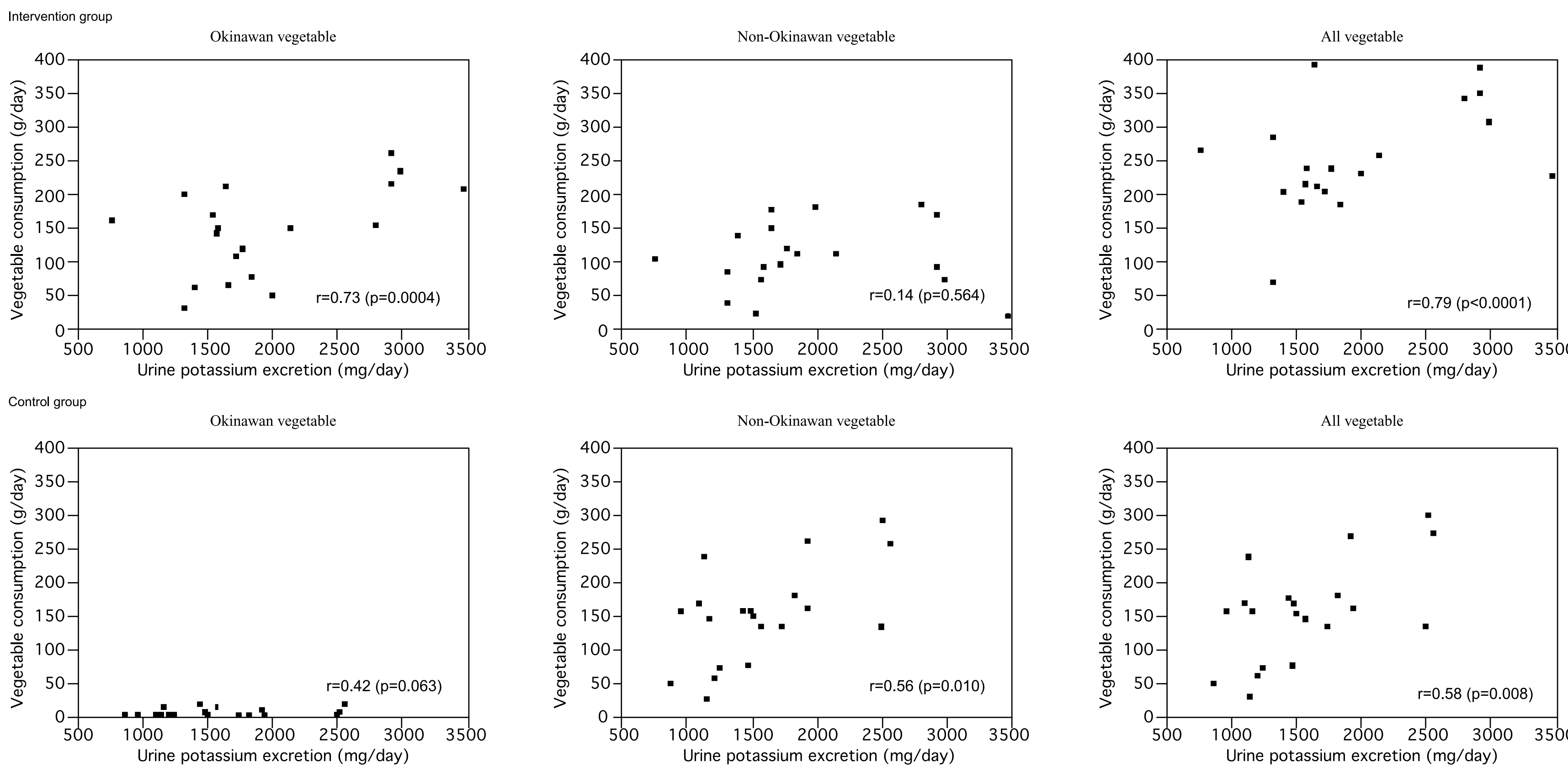

Fig. 1. *Scatter plot of mean daily Okinawan, non-Okinawan and all vegetable consumption and urine potassium excretion in the intervention and control groups.* r *is Pearson's correlation coefficient.*

in the mean urinary sodium and magnesium excretions, serum HDL cholesterol, LDL cholesterol and total cholesterols, folic acid and triglycerides of both groups were also not significant. However, the post-intervention potassium excretion was significantly different from the pre-intervention excretion in the intervention group (p=0.045) but not in the control group (p=0.595). While it increased by 363.5 mg in the intervention group, it decreased in the control group by 68.6 mg. The sodium-potassium ratio also changed significantly in the intervention group and between the two groups post-intervention (p=0.039 and p=0.031, respectively). When all 53 subjects who successfully completed the study were included in the statistical analyses no significant post-intervention change in urinary potassium excretion of the control group (p=0.656) was observed (data not shown). However, the intervention group showed an increase, although this increase did not reach the level of statistical significance (p=0.063).

An average of 371.4 g/day Okinawan vegetables was supplied to the dietary intervention group during the intervention period. However, they consumed only an average of 144.9 g/day (Table 2). The control group, who were not supplied with Okinawan vegetables during the intervention period, consumed an average of 4.7 g/day of Okinawan vegetables. The differences between the two groups in both average daily all vegetable and Okinawan vegetable intakes were statistically significant (p<0.001 for each). During the intervention period, the control group consumed a higher amount of fruits than the dietary intervention group (44.6 g/day and 33.5 g/day, respectively), but the difference was not statistically significant (p=0.550). Based on the Standard Tables of Food Composition in Japan (*19*), the potassium intakes from fruits and vegetables in the present study are shown in Table 2. For every 100 g, Okinawan vegetables provided 0.382 g and 0.386 g of potassium, while other vegetables provided 0.273 g and 0.276 g in the dietary intervention and control groups, respectively. Okinawan vegetables therefore provided about 40% more potassium than other vegetables. There was no significant difference between the two groups in the potassium intake from fruits (p=0.415).

Table 3 shows that there were no significant correlations between changes in blood pressure and changes in urinary sodium and potassium excretions in either group. Adjustments for age and BMI did not materially change the observed results.

Figure 1 is a scatter plot of vegetable intake *vs*. potassium excretion. The correlation between Okinawan vegetable consumption and urinary potassium excretion in the dietary intervention group was stronger than the correlation between the intake of other vegetables and urinary potassium excretion in the control group (r=0.73, p=0.0004 and r=0.56, p=0.010, respectively), although the amount of Okinawan vegetable intake in the intervention group (144.9 g) was similar to the intake of other vegetables in the control group (149.0 g) (Table 2). Also, Fig. 1 shows significant correlations between average daily all vegetable intake and urinary potassium excretion in both the intervention and control groups (p<0.0001 and p=0.008, respectively).

Discussion

This study found that increasing the intake of typical yellow-green Okinawan vegetables significantly increased urinary potassium excretion; a reflection of both the higher intake and the higher bioavailability of potassium. The significant difference in intake of Okinawan vegetables (p<0.001) between the intervention and control groups indicates that the dietary intervention was successful. Although many studies have been carried out on Okinawans and their diet, to our knowledge there has been no randomized controlled study investigating the effects of increased consumption of typical yellow-green Okinawan vegetables in free-living healthy subjects. In addition, this was the first study in which a dietary intervention was accomplished by home-parcel delivery of vegetables.

The 251.3 g daily vegetable consumption by the intervention group (of which 144.9 g were the yellow-green Okinawan vegetables used in this study), is comparable to the 233 g daily vegetable consumption (82 g of which are yellow-green) by Japanese in the 20–29 years age group (*6*), the same age group to which most of our subjects belong. The yellow-green Okinawan vegetables formed 57.7% and 3.1% of the total vegetables consumed by the intervention and control groups, respectively, with the intervention group consuming a mean of 97.6 g/day (38.8%) more vegetables than the control group. This resulted in a 20.5% increase in urinary potassium excretion (p=0.045) over the baseline in the intervention group. It has been reported that a daily intake of 0.6–0.8 kg of fruits and vegetables is required to ensure a daily potassium supply of 2.5–3.5 g (*25*).

All subjects in this study were normotensive and their blood pressure was not significantly reduced post-intervention. This finding is in agreement with another study which found that neither potassium chloride nor potassium citrate (the form of potassium found in vegetables) significantly changed blood pressure in normotensives (*26*). Although there was a significant post-intervention change in urinary potassium excretion in the intervention group, it was not strong enough to cause a significant reduction in their blood pressure. In any case, increased potassium intake reduces blood pressure to a lesser extent in normotensives as compared to hypertensives (*14*).

There were several potential limitations in this study. First, we relied on the subjects to correctly weigh and record their entire vegetable intake and to submit their complete 24-h urine samples. In addition, if the total daily amount of vegetables consumed in the intervention and control groups had been made equal, this would have made it easier to evaluate the specific effect of Okinawan vegetables on potassium excretion. These limitations are related to the many difficulties associated with dietary interventions in free-living subjects. At the same time, this is also one of the strengths of this study, since the dietary habits of free-living subjects closely resemble those of the general population.

One of the values of this study is that it is the first to employ home-parcel delivery of vegetables as a dietary intervention method. This intervention method is very convenient for intervention studies in free-living subjects, and is expected to prove useful in future dietary studies. Also, this study has shown for the first time that the potassium content of the yellow-green Okinawan vegetables used here is higher than that of other vegetables.

A larger study involving both normo- and hypertensives with a longer intervention period and a higher vegetable consumption is currently underway to further investigate the effects of increasing consumption of typical yellow-green Okinawan vegetables on blood pressure.

In conclusion, the present study has shown that increasing the consumption of yellow-green Okinawan vegetables typically used in Okinawan dishes significantly increased urinary potassium, a reflection of increased intake. Public health diet modification programs aimed at promoting higher intakes of dietary potassium in Okinawans (for example, for the purpose of reducing high blood pressure) might consider recommending increases in the intake of typical yellow-green Okinawan vegetables. In view of the fact that hypertension in particular and cardiovascular diseases in general are major contributors to the global disease burden in both developed and developing countries (*27*), the inclusion of non-pharmacological methods (such as increased vegetable consumption) in the clinical therapy as well as preventive programs for these diseases would greatly reduce the cost of health care globally. Also, the positive correlation found between urinary potassium excretion and average daily vegetable intake indicates that urinary potassium excretion could probably be a useful biomarker for vegetable intake.

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