ORIGINAL

Validation of a dietary balance score in middle-aged and older community-dwelling Japanese

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Abstract : This study assessed the validity of dietary balance scores (DBSs) by investigating the association between DBSs and nutrient adequacy (NA) in two Japanese populations. The participants were 65 community-dwelling Japanese from Tokushima Prefecture and 2,330 community-dwelling Japanese from Aichi Prefecture. Based on food frequency questionnaires or 3-day dietary records, we obtained 18 food groups. The NA score integrates nine beneficial nutrients and two nutrients that should be limited. We calculated four different DBSs: DBS1 consisted of five food groups (score range : 0–20), DBS2 consisted of nine food groups (score range : 0–36), DBS3 consisted of eight food groups (score range : 0–32), and DBS4 consisted of 10 food groups (score range : 0–40). Both the Spearman rank correlation coefficient with NA and the area under the receiver operating characteristic curve (AUC-ROC) for the nine beneficial nutrients were then estimated to test the performance of each DBS in predicting nutrient intake. The results showed that DBS1 and DBS4 were positively correlated with NA, while the AUC-ROC showed that DBS4 could moderately discriminate individuals with adequate intake levels of all nine nutrients. These findings suggest DBSs (especially DBS4) are useful in assessing dietary balance in middle-aged and older community-dwelling Japanese. J. Med. Invest. 70 : 377-387, August, 2023

Keywords **:** *dietary balance, nutritional balance, middle-aged and older community-dwelling Japanese*

INTRODUCTION

Populations are aging rapidly worldwide (1, 2). In Japan, people aged ≥65 years account for 28.9% of the total population, and this percentage is estimated to increase to 38.4% by 2065 (3). Environmental factors, including dietary intake, are thought to play an important role in the longevity of Japanese. The Dietary Reference Intakes (DRI) for Japanese (2020) is a comprehensive guideline for diet and nutrition that aims to extend healthy life expectancy by preventing malnutrition and frailty in Japanese people (4). In the new DRI for Japanese (2020), the nutrient requirements for middle-aged and older people are defined according to new age groups (50–64 years, 65–74 years, and ≥75 years), and the importance of dietary intake is highlighted.

Several assessment scales, including the Mediterranean Diet Index (5), Healthy Eating Index (6), Japanese Diet Index (7), and Quantitative Index for Dietary Diversity (8), have been used to evaluate the quality of dietary intake. However, calculating these scores over a long period in a survey targeting older people is difficult because data on dietary intake from dietary records and food frequency surveys that contain many food items are required. The dietary variety score (DVS) developed by Kumagai *et al*. (9) is a score obtained from a short-form questionnaire about the frequencies of intake per week of 10 food items, and is therefore easy to use as an assessment tool for dietary diversity in older populations. It has been reported that higher DVS values are not only associated with lower risks of higher-level functional capacity decline (10), falls (11), and sarcopenia (12), but also moderately correlated with higher intakes of various nutrients (13) and quantitative diversity (14). However, although this score indicates the variety of food intake, whether dietary intakes that meet the DRI for major nutrients in Japanese can be evaluated by this score remains unclear. Consequently, a simple and easy-to-use score to assess whether the nutrient intake of middle-aged and older Japanese people meets the DRI has yet to be established.

In the present study, we developed a dietary balance score (DBS) with the aim of determining the association between DBS and satisfaction of nutrients based on the DRI in community-dwelling older adults. We used information on the frequency and/or amount of food consumption to establish different DBSs. The satisfaction of DRI was defined by a nutrient adequacy (NA) score integrated with nine beneficial nutrients and two nutrients that should be limited according to the Japanese DRI. First, we examined the internal validity of the DBSs by investigating their correlations with NA scores in a community-dwelling older population. Next, we evaluated the external validity of the DBSs by assessing their associations with NA scores in another community-dwelling population that included both middle-aged and older individuals.

Abbreviations :
3DR, 3-day dietary record ; AUC-ROC, area under the receiver operating characteristic curve ; BMI, body mass index ; DBS, dietary balance score ; DRI, Dietary Reference Intakes ; DVS, dietary variety score ; FFQ, food frequency questionnaire ; MMSE, Mini-Mental State Examination ; NA, nutrient adequacy ; NILS-LSA, National Institute for Longevity Sciences-Longitudinal Study of Aging ; SD, standard deviation.

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MATERIALS AND METHODS

Study subjects

This study involved two different populations of middle-aged and older community-dwelling Japanese. The first population comprised 65 community-dwelling volunteers aged 60–79 years who participated in a survey conducted in Tokushima Prefecture in 2015. Of these 65 participants, we excluded those with any missing data from 3-day dietary records (3DRs) (n = 6), leaving 59 (4 men and 55 women) for the analysis. Written informed consent was obtained from all participants. The study protocol was approved by the institutional review board of Tokushima University Hospital (ethics approval No. : 2556).

The second population comprised 2,330 randomly selected Japanese community-dwelling men and women aged 40–79 years who participated in the 7th wave survey (2010–2012) of the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA). We also excluded those with any missing data from 3DRs (n = 185), leaving 2,145 (1,069 men and 1,076 women) for the analysis. Details of the NILS-LSA study have been reported elsewhere (15). Written informed consent was obtained from all participants. The study protocol was reviewed and approved by the Human Research Ethics Committee of the National Center for Geriatrics and Gerontology, Japan (Approval No. : 899-6).

Dietary assessments

The dietary intake of two study participants was assessed using a 3DR and dietary weight records for 3 consecutive days (2 weekdays and 1 weekend day) (16). The raw food materials were weighed separately on a scale (UH-3303 2-kg digital home scale ; A&D Company, Ltd., Tokyo, Japan) before being cooked, or the portion size was estimated. We asked the participants to photograph their plates before and after eating by using a disposable camera (27 shots ; Fuji Film, Tokyo, Japan), a digital camera, or the camera function of their mobile phone. These photos were then used by dietitians to fill in any missing data. When necessary, the subjects were called to resolve any discrepancies or obtain further information. Then, the daily average intakes and daily nutrient and energy intakes of 18 food groups (cereals ; potatoes and starches ; sugars and sweeteners ; pulses ; nuts and seeds ; vegetables [dark-green and deep-yellow vegetables ; and other vegetables] ; fruits ; mushrooms ; algae ; fish, mollusks, and crustaceans ; meat ; eggs ; milk and milk products ; fats and oils ; confectionaries ; beverages ; seasonings and spices ; and prepared foods) were calculated according to the 2015 Standard Food Composition Tables in Japan (17).

In addition, we obtained information on the frequency of consumption of the following 10 food groups among the subjects in Tokushima Prefecture using a food frequency questionnaire (FFQ) : fish, mollusks, and crustaceans ; meat ; eggs ; milk and milk products ; pulses ; dark-green and deep-yellow vegetables ; algae ; potatoes and starches ; fruits ; and fats and oils. The participants answered the frequency of consumption of the 10 food groups per week, with frequency options including "almost every day", "once every 2 days", "once or twice a week", and "almost never".

Nutrient adequacy score

To assess the participants' nutritional balance based on the DRI, we modified the NRF9.3 index (a nutrient density indicator composed of 12 nutrients) (18-21) as an NA score. The NRF9.3 index consists of nine beneficial nutrients (protein, potassium, calcium, magnesium, iron, vitamin A, vitamin E, vitamin C, and fiber) and three nutrients that should be limited (saturated fatty acids, sodium, and sugar). As no reference value for sugar has been established in the DRI for Japanese 2020 (4), we excluded sugar from the index and developed an NA score containing 11 nutrients (nine beneficial nutrients plus saturated fatty acids and sodium). The NA ratio of each nutrient was calculated using the following equation : NA ratio = [(daily nutrient intake value) / (age- and sex-specific reference value)] × 100 (%). Then, each NA ratio was further standardized by the age- and sex-specific recommended daily energy intakes (except for saturated fat). Both the daily reference value for each nutrient and the daily recommended energy intake were based on the DRIs for Japanese 2020 (Supplemental table 1). Therefore, the NA score was obtained as follows : NA score = $\Sigma 9$ beneficial NA ratios – $\Sigma 2$ limit NA ratios. A higher NA score means better overall nutrient intake.

Nutrient contributions of the 18 food groups

Among older adults in Tokushima Prefecture, we calculated the contribution of each food group to the daily DRI for 11 nutrients included in the NA scores. Using 3DRs, we calculated the mean daily intake of protein, potassium, calcium, magnesium, iron, vitamin A, vitamin E, vitamin C, fiber, saturated fatty acids, and sodium for each participant in Tokushima Prefecture for 3 days, as well as the mean daily intake of each of the above nutrients contained in each of the 18 food groups, thereby obtaining the contribution of each food group to each nutrient.

Dietary balance score

We developed four different DBSs (DBS1 to DBS4) (Supplemental table 2). Based on the nutrient contributions of 18 food groups, DBS1 and DBS2 consisted of food groups (except cereals) that contributed more than 15% and 10% of daily dietary intake for the 11 nutrients in the NA scores, respectively. DBS3 consisted of food groups (except cereals and fats and oils) that contributed more than 10% of daily dietary intake for the 11 nutrients. DBS4 consisted of food groups summarized by the Standard Tables of Food Composition in Japan 2015 (17) (except cereals, sugar and sweeteners, potatoes and starches, seasonings and spices, fats and oils, and beverages). Sugar and sweeteners, potatoes and starches, seasonings and spices, fats and oils, and beverages were excluded from the DBS calculations because the intake of these food groups is not recommended, and/or because such intake contributes little to nutrients such as vitamins and minerals (22, 23). Cereals were excluded from all DBS calculations because only small variation was seen in the frequency of cereal consumption among all participants (all participants in Tokushima Prefecture consumed cereals three times a day).

Two scoring patterns were used to calculate DBSs according to the dietary assessment method. Pattern 1 was set based on the quartiles of daily consumption of the food groups derived from the 3DRs : "Quantile 4 (the highest quartile group)" as 4 points, "Quantile 3" as 2 points, "Quantile 2" as 1 point, and "Quantile 1 (the lowest quartile group)" as 0 points. Pattern 2 was set based on the frequency of food groups obtained by the FFQs : 4 points for "almost every day", 2 points for "once every 2 days", 1 point for "once or twice a week" and 0 points for "almost never". When scoring food groups for which no information on consumption frequency was available (i.e., other vegetables and mushrooms), the scoring rules of Pattern 1 were used. These points (0 to 4) were set in order to simplify the calculation in consideration of the frequency of data based on the method used in a previous study (14).

DBS1 was defined by five food groups (fish, mollusks, and crustaceans ; milk and milk products ; dark-green and deep-yellow vegetables ; other vegetables ; and meat) and ranged from 0 to 20 points. DBS2 was defined by nine food groups (fish, mollusks, and crustaceans ; milk and milk products ; dark-green and deep-yellow vegetables ; other vegetables ; meat ; pulses ; eggs ; fruits ; and fats and oils) and ranged from 0 to 36 points. DBS3 was defined by eight food groups (fish, mollusks, and crustaceans ; milk and milk products ; dark-green and deep-yellow vegetables ; other vegetables ; meat ; pulses ; and eggs and fruits) and ranged from 0 to 32 points. DBS4 was defined by 10 food groups (fish, mollusks, and crustaceans ; milk and milk products ; dark-green and deep-yellow vegetables ; other vegetables ; meat ; pulses ; eggs ; fruits ; mushrooms ; and algae) and ranged from 0 to 40 points.

Other measurements

Other measurements were assessed among older adults in Tokushima Prefecture using the following methods. The height of each participant was measured to the nearest 0.1 cm with each participant standing upright without shoes, and body weight was measured to the nearest 0.1 kg with each subject wearing lightweight clothing. Body mass index (BMI) was calculated as weight (kg)/height $(m)^2$. Cognitive function was assessed by the Mini-Mental State Examination (MMSE) only in those aged ≥60 years. The MMSE was conducted during face-to-face interviews with graduate students who had received intensive training. Data regarding education level (categorical : ≤9 years, 9–12 years, or >12 years), annual household income (categorical : ≤1.49 million yen, 1.50–4.49 million yen, or ≥4.50 million yen), current and previous histories of hypertension, dyslipidemia, diabetes, heart disease, and stroke (binary : yes or no), current physical activity (binary : yes or no), drinking habit (categorical : current, former, or never) and smoking habit (categorical : current, former, or never) were collected using a self-administered questionnaire.

The same measurements, except for current physical activity and alcohol intake, were also assessed in the NILS-LSA using similar methods. Current physical activity (metabolic equivalent of task [METs]-min/year) was assessed using the METs (a multiple of the resting metabolic rate) score, which was obtained through participant interviews with trained interviewers using a semi-quantitative method to assess the participants' level of habitual physical activity during leisure time and on the job, as well as their sleeping hours (24). Alcohol intake (g/day) was assessed using the 3DRs (16).

Statistical analysis

Continuous variables are expressed as the mean ± standard deviation (SD), and categorical variables as numbers and proportions (%). First, the association between each DBS and NA score was investigated by Spearman's rank correlation coefficient test. Next, the area under the receiver operating characteristic curve (AUC-ROC) and 95% confidence interval were used to test the accuracy of each DBS in distinguishing between individuals with sufficient (met the DRI criteria) and insufficient intakes of all nine beneficial nutrients. The AUC-ROCs were also used to determine the accuracy of each DBS in discriminating individuals whose intake levels of all nine nutrients exceeded the DRI criteria. The AUC-ROCs ranged from 0.5 to 1.0, with 0.5 indicating no discrimination and 1.0 indicating perfect discrimination. The discriminatory accuracy of each DBS was thus considered "low" if the AUC-ROC was ≥0.5 and <0.7, "moderate" if ≥0.7 and <0.9, and "high" if ≥0.9.

All statistical tests were based on two-sided probabilities and performed using SPSS version 28.0 Japanese for Windows (IBM Japan, Tokyo, Japan) and/or SAS version 9.3 (SAS Institute, Cary, NC, USA). All p values <0.05 were considered statistically significant.

RESULTS

Characteristics of the participants

Table 1 shows the characteristics of the participants in Tokushima Prefecture. The mean ± SD age and BMI of the participants were 67.6 ± 4.7 years and 24.0 ± 3.9 kg/m^2, respectively. The proportion of participants with more than 9 years of education was 93.3%, and the mean ± SD MMSE score was 28.1 ± 1.9. There were no current smokers.

Supplemental table 3 shows the characteristics of the participants in the NILS-LSA. The mean ± SD age and BMI of the participants were 61.1 ± 12.5 years and 22.7 ± 3.2 kg/m^2, respectively. The proportion of participants with 9 years of education was 83.9%, and the mean ± SD MMSE score was 27.8 ± 1.9. The proportion of current smokers was 11.3%.

Table 1. Characteristics of the participants from Tokushima Prefecture

	Total participants (n = 59)
Age (years)†	67.6 ± 4.7
Men‡	4 (6.8)
Body mass index (kg/m^2)†	24.0 ± 3.9
Current physical activity (+)†	36 (61.0)
Mini-Mental State Examination score†	28.1 ± 1.9
Education‡	
≤9 years	4 (6.8)
9–12 years	28 (47.5)
>12 years	27 (45.8)
Annual household income‡	
≤1.49 million yen	29 (49.2)
1.50–4.49 million yen	19 (32.2)
≥4.50 million yen	11 (18.6)
Smoking habit‡	
Current	0 (0.0)
Former/never	59 (100.0)
Drinking habit‡	
Current	17 (28.8)
Former/never	42 (71.2)
Medical history‡	
Hypertension (+)	18 (30.5)
Dyslipidemia (+)	13 (22.0)
Diabetes (+)	3 (5.1)
Heart disease (+)	0 (0.0)
Stroke (+)	0 (0.0)

† Mean ± SD ; ‡ Number (%)
‖ Abbreviations : SD, standard deviation.

Contribution rates of food groups

Table 2 shows the contribution rates of food groups for the intake of protein, potassium, calcium, magnesium, iron, vitamin A, vitamin E, vitamin C, fiber, saturated fatty acids, and sodium (>10%) among older adults in Tokushima Prefecture. The highest protein intake was from fish and shellfish (19.1%), followed by cereals (16.6%) and meat (13.5%). The highest potassium intake was from other vegetables (14.4%), followed by dark-green and deep-yellow vegetables (13.5%). The highest calcium intake was from milk and milk products (23.6%), followed by pulses (13.5%). The highest magnesium (12.7%) and iron (14.0%) intakes were from pulses. The highest vitamin A, C, and E intakes were from dark-green and deep-yellow vegetables. The highest vitamin A intake was from dark-green and deep-yellow vegetables (42.5%), followed by eggs (11.4%). The highest vitamin E intake was from dark-green and deep-yellow vegetables (24.0%), followed by fats and oils (11.2%) and fish, mollusks, and crustaceans (10.3%). The highest vitamin C intake was from dark-green and deep-yellow vegetables (29.5%), followed by other vegetables (23.5%) and fruits (14.3%). The food groups with a high contribution rate for dietary fiber were other vegetables (22.1%), dark-green and deep-yellow vegetables (17.4%), and cereals (16.1%). Meat contributed the most to saturated fatty acids (22.5%), followed by milk and milk products (19.5%). The food group with the highest contribution rate for sodium was seasonings and spices (53.7%).

Based on these results, we defined the DBSs based on food groups with high contribution rates for the nutrients among older adults in Tokushima Prefecture (Supplemental table 2).

Correlations between dietary balance and nutrient adequacy scores

Table 3 shows the correlations between each DBS based on frequency of intake and NA scores among older adults in Tokushima Prefecture.

First, we confirmed the correlation between each DBS calculated using the consumption frequency of food groups and NA scores. Using Spearman's rank correlation coefficient test, statistically significant correlations were found between DBS1, DBS4, and NA scores : $r = 0.312$ ($p = 0.016$) for DBS1 and $r = 0.280$ ($p = 0.032$) for DBS4.

Table 3. Correlations between dietary balance score and nutrient adequacy scores in older adults from Tokushima Prefecture†, ‡

	r	(	95% CI			)	*p*
Based on the FFQ							
DBS1	0.312	(	0.053	–	0.532	)	0.016
DBS2	0.196	(	–0.071	–	0.436	)	0.138
DBS3	0.238	(	–0.027	–	0.471	)	0.070
DBS4	0.280	(	0.018	–	0.506	)	0.032
Based on 3DRs				–			
DBS1	0.512	(	0.288	–	0.683	)	<0.001
DBS2	0.492	(	0.263	–	0.669	)	<0.001
DBS3	0.529	(	0.308	–	0.695	)	<0.001
DBS4	0.468	(	0.234	–	0.651	)	<0.001

† Correlation coefficients among older adults in Tokushima Prefecture.
‡ Correlations between each dietary balance score and nutrient adequacy score were estimated using Spearman's rank correlation coefficient test.
‖ Abbreviations : CI, confidence interval ; DBS, dietary balance score ; DR, dietary record ; FFQ, food frequency questionnaire.

Table 2. Food groups that contribute to each nutrient intake based on 3-day dietary records in older adults from Tokushima Prefecture†, ‡

	Nutrients to encourage (9 items)									Nutrients to limit (2 items)	
Food groups	Protein	Potassium	Calcium	Magnesium	Iron	Vitamin A	Vitamin E	Vitamin C	Fiber	Saturated fatty acids	Sodium
Cereals	16.6	5.0	5.4	11.8	9.6	0.0	3.7	0.0	16.1	5.6	7.1
Potatoes and starches	0.7	4.4	1.2	2.2	2.0	0.0	1.8	6.3	4.2	0.1	0.0
Sugars and sweeteners	0.1	0.1	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Pulses	9.2	5.8	13.5	12.7	14.0	0.0	5.3	0.0	8.2	7.1	0.6
Nuts and seeds	0.6	0.5	1.9	1.8	1.4	0.0	0.8	0.2	1.4	1.2	0.0
Dark-green and deep-yellow vegetables	2.3	13.5	6.2	7.5	7.2	42.5	24.0	29.5	17.4	0.2	0.4
Other vegetables	3.9	14.4	9.9	10.9	9.6	5.9	7.4	23.5	22.1	0.6	3.9
Fruits	1.3	8.1	1.9	5.5	3.4	5.9	5.9	14.3	7.7	0.2	2.4
Mushrooms	0.5	1.2	0.0	0.5	0.7	0.0	0.0	0.5	2.9	0.0	0.0
Algae	0.4	1.7	2.1	2.8	2.0	2.3	0.3	0.7	3.1	0.0	2.1
Fish, mollusks, and crustaceans	19.1	8.1	9.6	9.7	8.4	5.3	10.3	0.6	0.0	8.4	9.4
Meat	13.5	5.5	0.6	4.0	5.8	2.4	2.8	3.4	0.0	22.5	3.1
Eggs	6.6	1.9	3.8	1.5	8.2	11.4	5.1	0.0	0.0	7.5	1.9
Milk and milk products	7.1	6.8	23.6	5.3	0.5	9.3	2.6	1.1	0.0	19.5	2.7
Fats and oils	0.1	0.0	0.0	0.0	0.0	1.1	11.2	0.0	0.0	9.2	0.3
Confectionaries	2.6	1.6	2.7	1.9	3.0	1.8	2.6	0.3	3.0	4.8	1.7
Beverages	1.3	6.4	3.8	5.5	5.7	1.8	1.6	9.6	1.5	0.2	0.1
Seasonings and spices	3.9	5.3	3.8	7.1	8.1	0.6	5.4	0.2	3.1	3.1	53.7
Prepared foods	0.9	0.7	0.6	0.0	0.9	0.5	0.1	0.3	0.0	0.4	1.1

† Food groups are shown based on the Standard Tables of Food Composition in Japan.
‡ Contribution rates of food groups (%).

Second, we confirmed the correlation between each DBS calculated using quartiles of daily food group consumption volumes and NA scores. Using Spearman's rank correlation coefficient test, statistically significant moderate correlations were found between all DBSs and NA scores : $r = 0.512$ ($p < 0.001$) for DBS1, $r = 0.492$ ($p < 0.001$) for DBS2, $r = 0.529$ ($p < 0.001$) for DBS3 and $r = 0.468$ ($p < 0.001$) for DBS4.

Next, to assess the external validity of the DBSs, we confirmed the correlations between DBSs calculated using quartiles of daily food group consumption volumes and NA scores according to gender and age groups in the NILS-LSA (Supplemental table 4). All DBSs had similar and moderate correlations with both NA scores using Spearman's rank correlation coefficient test. Additionally, the results of all correlations for the participants in the NILS-LSA were similar to those for the participants in Tokushima using the 3DRs.

Area under the receiver operating characteristic curve for dietary balance score

Figures 1 and 2 and Table 4 show the AUC-ROC for each DBS for discriminated individuals with sufficient intake (met the DRI criteria) of all nine beneficial nutrients among older adults in Tokushima Prefecture.

Using the consumption frequency of food groups (Figure 1 and Table 4), DBS4 had the highest ability to discriminate nutrient sufficiency. The results of the AUC-ROCs for the DBSs were : AUC-ROC = 0.730 for DBS1, 0.699 for DBS2, 0.728 for DBS3, and 0.742 for DBS4. Using 3DRs (Figure 2 and Table 4), DBS3 had the highest ability to discriminate nutrient sufficiency ; however, all DBSs had moderate accuracy to discriminate nutrient sufficiency : AUC-ROC = 0.788 for DBS1, 0.753 for DBS2, 0.815 for DBS3, and 0.763 for DBS4.

Next, to assess the external validity of the DBSs, we confirmed the AUC-ROCs for each DBS for discriminated individuals with sufficient intake (met the DRI criteria) of all nine beneficial nutrients in the NILS-LSA by gender (Supplemental figures 1 and 2). Although the results for all AUC-ROCs were similar, DBS2 had the highest ability to discriminate nutrient sufficiency in both men (AUC-ROC = 0.860 for DBS1, 0.865 for DBS2, 0.826 for DBS3, and 0.820 for DBS4) and women (AUC-ROC = 0.891 for DBS1, 0.892 for DBS2, 0.874 for DBS3, and 0.864 for DBS4).

Table 4. Area under the receiver operating characteristic curve for the dietary balance score in older adults from Tokushima Prefecture†

	AUC-ROC	(	95% CI			)	SE
Based on the FFQ							
DBS1	0.730	(	0.581	—	0.879	)	0.076
DBS2	0.699	(	0.557	—	0.840	)	0.072
DBS3	0.728	(	0.592	—	0.864	)	0.069
DBS4	0.742	(	0.614	—	0.871	)	0.065
Based on 3DRs							
DBS1	0.788	(	0.666	—	0.910	)	0.062
DBS2	0.753	(	0.628	—	0.878	)	0.064
DBS3	0.815	(	0.701	—	0.929	)	0.058
DBS4	0.763	(	0.636	—	0.891	)	0.065

† AUC-ROCs and 95% confidence intervals were used to evaluate the accuracy of each formula for DBSs for discriminating individuals whose intake levels of all nine nutrients exceed the levels in the Japanese Dietary Reference Intake criteria.
‡ Abbreviations : AUC-ROC, area under the receiver operating characteristic curve ; CI, confidence interval ; DBS, dietary balance score ; DR, dietary record ; FFQ, food frequency questionnaire ; SE, standard error.

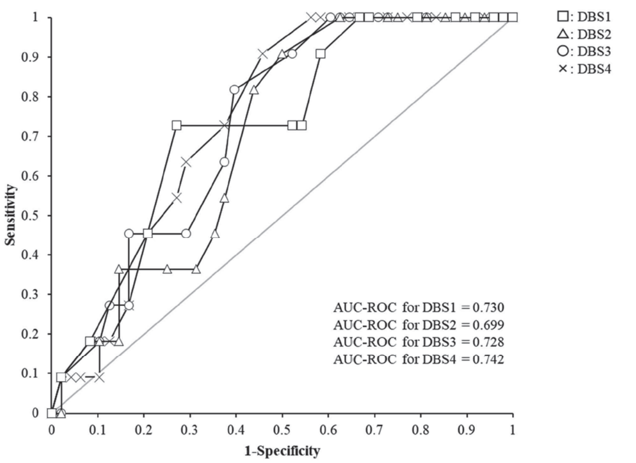

Figure 1. AUC-ROCs showing whether four DBSs based on FFQ-discriminated individuals with sufficient intake (met the DRI criteria) of all nine beneficial nutrients among older adults in Tokushima Prefecture. □, △, ○, and × show the AUC-ROCs of DBS1, 2, 3, and 4, respectively. Although the results for all AUC-ROCs were similar, DBS4 had the highest ability to discriminate nutrient sufficiency, and its ability to discriminate nutrients showed moderate accuracy.

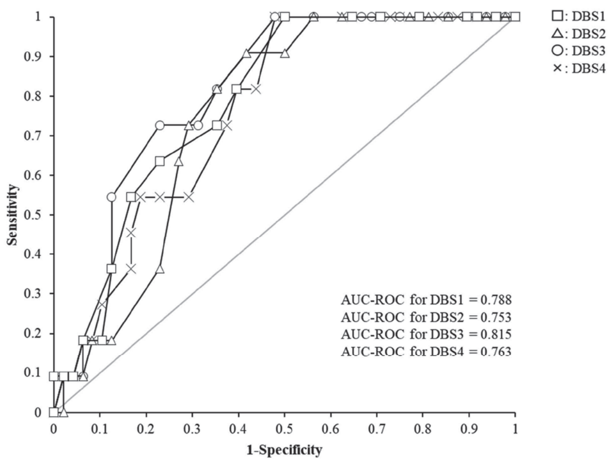

Figure 2. AUC-ROCs showing whether four DBSs based on 3DR-discriminated individuals with sufficient intake (met the DRI criteria) of all nine beneficial nutrients among older adults in Tokushima Prefecture. □, △, ○, and × show the AUC-ROCs of DBS1, 2, 3, and 4, respectively. Although the results for all AUC-ROCs were similar, DBS3 had the highest ability to discriminate nutrient sufficiency, and its ability to discriminate nutrients showed moderate accuracy.

DISCUSSION

In this study, we developed and assessed the internal validity of DBSs using food group consumption based on FFQs and 3DRs among older community-dwelling Japanese in Tokushima Prefecture. We then assessed the external validity of DBSs by comparing the association between DBSs and NA scores according to gender and age groups among other community-dwelling Japanese in the NILS-LSA. When the FFQ-based food group consumption data obtained among older adults in Tokushima Prefecture were used for analysis, DBS1 and DBS4 were statistically significantly correlated with NA scores. Analysis of the same data showed that although the results were similar for all AUC-ROCs, DBS4 had the highest discriminatory power for NA and moderate discriminatory power. Whereas, when the 3DR-based food group consumption data from two different Japanese populations were used for analysis, all DBSs were statistically significantly correlated with NA scores and had similar and moderate discriminatory power for nutrient adequacy.

Among older adults in Tokushima Prefecture, all DBSs based on 3DRs were statistically significantly correlated with NA scores and showed better discriminatory power for nutrient adequacy compared with all DBSs based on FFQs. In participants in the NILS-LSA, similar results using DBSs based on 3DRs were obtained, which suggests adequate internal and external validity. Because dietary intake as assessed by FFQs means ranking the amount of dietary intake in a given study population, it cannot assess the actual amount of dietary intake. Conversely, because 3DRs, which directly measure the amount of food intake, minimize reliance on a subject's memory (25), they are considered to be the closest to the true value among the current dietary assessment methods (26). Therefore, the results using all DBSs based on 3DRs may have exhibited stronger correlations between each DBS and NA score and better discriminatory power for nutrient adequacy than those using all DBSs based on FFQs. In addition, two scoring patterns were used in this study to calculate DBSs according to the dietary assessment method (3DRs or FFQs). The differences in scoring patterns according to the dietary assessment method might also have resulted in differences in the correlations between DBSs and NA scores.

Our results from the FFQ-based food group consumption data obtained from among older adults in Tokushima Prefecture revealed that DBS4 had a significant correlation with the NA score and the highest discriminatory power for nutrient adequacy. It is important to evaluate NA with more food groups because older adults consume nutrients from a larger variety of food groups, such as fruits, fish, beans, and vegetables compared with middle-aged adults (27). On the other hand, because the ability to understand and memorize new things declines with age (28, 29), the simplest possible dietary survey method is preferable. Therefore, DBS4 based on a simple FFQ composed of 10 food groups, which showed the highest discriminatory power for NA among older adults in Tokushima Prefecture, might be the most useful from among the four FFQ-based DBSs. However, caution is required when using the FFQ-based DBS4 to assess NA. Because dietary intake information obtained from FFQs depends on self-reports, it is highly likely to be different from the actual amount. Previous studies have reported that the possibility of errors in estimating food consumption may differ depending on food groups (30). Especially among older adults, this difference may occur more easily between self-reports and dietary records in the case of food groups that are difficult to recognize when consumed. In fact, significant correlations were found between FFQ- and 3DR-based consumption of milk and milk products and dark-green and deep-yellow vegetables, which correspond to the five food groups (milk and milk products, $r = 0.72$, $p < 0.001$; dark-green and deep-yellow vegetables, $r = 0.30$, $p = 0.022$; data not shown), whereas these correlations were small for eggs and pulses (eggs, $r = -0.023$, $p = 0.861$; pulses, $r = 0.007$, $p = 0.958$; data not shown).

The results of the AUC-ROCs using FFQ-based DBSs among older adults in Tokushima Prefecture revealed that DBS4 (consisting of 10 food groups) had the highest ability to discriminate NA. To utilize the FFQ-based simple DBS4 in the future, we estimated the optimal cutoff value of DBS4 according to the Youden index. We found that the optimal cutoff value of DBS4 was 26 points (data not shown). We then compared NA scores between two groups (subjects with <26 and ≥26 points) using this cutoff value among older adults in Tokushima Prefecture. As a result, the NA score was significantly higher ($p = 0.045$) in older subjects with ≥26 points (n = 26 ; mean ± SD NA score = 915.3 ± 249.2 points) than in older subjects with <26 points (n = 33 ; 792.1 ± 211.9 points ; data not shown). In addition, we similarly compared NA scores between two groups using this cutoff value among older adults in the NILS-LSA. We also found a similar significant difference between the two groups. In men in the NILS-LSA, the mean ± SD NA score was 967.3 ± 238.9 points in subjects with ≥26 points (n = 101), and 742.7 ± 228.5 points in those with <26 points (n = 968) ($p < 0.0001$, data not shown). In women in the NILS-LSA, the mean ± SD NA score was 955.1 ± 232.1 points in subjects ≥26 points (n = 102), and 758.5 ± 235.3 points in those with <26 points (n = 974) ($p < 0.0001$, data not shown). A higher NA score indicates good overall dietary quality. Thus, the optimal cutoff value of DBS4 based on the FFQ (26 points) could be useful for judging nutritional adequacy.

Our study has several limitations. First, the sample size of Tokushima participants was small (n = 59). Second, almost all Tokushima participants (n = 55, 93.2%) were healthy older women. As the number of male participants was very small (n = 4, 6.8%), it was not possible to confirm the presence of any gender difference in the correlation coefficient. However, the correlation coefficient between the DBS based on 3DRs and NA scores in the NILS-LSA was estimated to be higher in men than in women. Therefore, the correlation coefficient between the DBS based on the FFQ and NA scores will need to be confirmed in both sexes in the future. Although our results can be applied to healthy older women, it might not be possible to generalize our results to older people with impaired physical functions, such as those admitted to hospitals. Third, the proportion of overweight subjects in this study (33.9%) was higher than the proportion of underweight older adults in Tokushima Prefecture. When Spearman's correlation coefficients between DBS1 and NA scores were calculated by stratifying the subjects according to body type (BMI <25 kg/m^2 or BMI ≥25 kg/m^2), almost the same correlation was shown, regardless of body type, although there were no significant differences between non-overweight subjects ($r = 0.306$, $p = 0.058$) and overweight subjects ($r = 0.268$, $p = 0.254$) (data not shown). As our study population consisted of women who were physically and cognitively healthy, the participants might have provided accurate answers to the FFQ. However, as overweight individuals are known to be likely to underreport dietary intake (31-33), it is necessary to consider these points fully when interpreting our results. Fourth, for some food groups, such as other vegetables, dietary intake based on the 3DRs was divided into four groups in quartiles and scored because we could not obtain information on the frequency of intake. Therefore, because of possible misclassification between actual frequency responses and classification based on the 3DRs, it is necessary to consider these points fully when interpreting our results. Finally, a previous study showed that the ratios of intra- to interindividual variance tended to be smaller for macronutrients and larger for minerals and vitamins (34). In the present study, while all of the DBSs were evaluated by intake frequency in 1 week (7 days), nutrient intake was evaluated by 3DRs. Because a large number of subjects and a long survey period would be required to consider the daily variance in micronutrient intake, the use of a 3DR as an assessment tool might not be sufficient. In addition, regarding food groups such as vegetables and fruits, it has been reported that intake may vary depending on the season of the survey (35). Both the dietary surveys conducted in Tokushima Prefecture and NILS-LSA did not have a specific survey period (i.e., each participant could be surveyed during any season of the year). As the frequency or quantity of seasonal food groups, such as vegetables and fruits, was used in calculating the DBS, the estimated correlation between DBS and NA scores and the ability to discriminate nutrient sufficiency could be higher if a long-term dietary survey considering the season of the survey were carried out.

In conclusion, our results indicate the possibility of moderate relationships between DBSs (especially DBS4) and NA scores and their possible usefulness in assessing dietary balance in middle-aged and older community-dwelling Japanese. Although we assessed the validity of DBSs using the Food Composition Tables 2015 and DRI 2020 in two different Japanese populations in the present study, further studies are needed to improve the validity of revised DBSs according to the revised Food Composition Tables and DRI in the future.

CONFLICT OF INTEREST

All authors state that they have no conflicts of interest.

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CONTRIBUTIONS

MN designed the research and was the principal investigator ; YT, SO, YI, and MN conducted the survey ; TN and MN analyzed the data ; MN drafted the manuscript ; AN, RO, and TS supported the analyses and drafting of the manuscript ; TS provided study oversight ; all authors interpreted the data, provided critical input, and read and approved the final manuscript. MN had primary responsibility for the final content.

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Supplemental table 1. Japanese Dietary Reference Intake values for the calculation of the overall nutrient adequacy score†

Nutrients	RDA‡, ¶							
	Men				Women			
	40–49 years	50–64 years	65–74 years	≥75 years	40–49 years	50–64 years	65–74 years	≥75 years
Energy (kcal)	2700	2600	2400	2100	2050	1950	1850	1650
Nutrients to encourage (9 items)								
Protein (g)	65	65	60	60	50	50	50	50
Potassium (mg)	2500	2500	2500	2500	2000	2000	2000	2000
Calcium (mg)	750	750	750	700	650	650	650	600
Magnesium (mg)	370	370	350	320	290	290	280	260
Iron (mg)	7.5	7.5	7.5	7.0	6.5	6.5	6.0	6.0
Vitamin A (μgRAE)	900	900	850	800	700	700	700	650
Vitamin E (mg)	6.0	7.0	7.0	6.5	5.5	6.0	6.5	6.5
Vitamin C (mg)	100	100	100	100	100	100	100	100
Fiber (g)	21	21	20	20	18	18	17	17
Nutrients to limit (2 items)								
Saturated fatty acids (%) ‖	≤7	≤7	≤7	≤7	≤7	≤7	≤7	≤7
Sodium (mg) §	< 3000	< 3000	< 3000	< 3000	< 2600	< 2600	< 2600	< 2600

† Guided by the Dietary Reference Intakes for Japanese, 2020
‡ As nutrients for which RDA values have not been published, we adopted the Tentative Dietary Goal value (fiber, saturated fat, sodium) or Adequate Intake value (potassium, vitamin E).
‖ % energy intake
§ Daily reference values for sodium intake are < 7.5 g for men and < 6.5 g for women.
Thus, we converted salt to sodium : sodium (mg) = daily reference value for salt intake (g) × [600 (mg) / 1.5 (g)]
¶ Abbreviations : RDA, recommended dietary allowance.

Supplemental table 2. Number of food groups that composed the four formulas and range of the four formulas for the dietary balance score †, ‡, ¶, ††

	Food groups used in the scoring formula	No. of food groups	Score range
DBS1 †	Fish, mollusks, and crustaceans, milk and milk products, dark-green and deep-yellow vegetables, other vegetables, meat	5	0–20
DBS2 ‡	Fish, mollusks, and crustaceans, milk and milk products, dark-green and deep-yellow vegetables, other vegetables, meat, pulses, eggs, fruits, fats and oils	9	0–36
DBS3‖	Fish, mollusks, and crustaceans, milk and milk products, dark-green and deep-yellow vegetables, other vegetables, meat, pulses, eggs, fruits	8	0–32
DBS4 §	Fish, mollusks, and crustaceans, milk and milk products, dark-green and deep-yellow vegetables, other vegetables, meat, pulses, eggs, fruits, mushrooms, algae	10	0–40

† DBS1 : The score consisted of food groups (except cereals) that contributed more than 15% of daily dietary intake for the 11 nutrients in the NA scores.
‡ DBS2 : The score consisted of food groups (except cereals) that contributed more than 10% of daily dietary intake for the 11 nutrients in the NA scores.
‖ DBS3 : The score consisted of food groups (except cereals and fats and oils) that contributed more than 10% of daily dietary intake for the 11 nutrients.
§ DBS4 : The score consisted of food groups summarized by the Standard Tables of Food Composition in Japan (2015), except cereals, sugars and sweeteners, potatoes and starches, seasonings and spices, fats and oils, and beverages.
¶ Scoring pattern 1 : Pattern 1 was set based on the quartiles of daily consumption of the food groups derived from the 3DRs : "Quantile 4 (the highest quartile group)" as 4 points, "Quantile 3" as 2 points, "Quantile 2" as 1 point, and "Quantile 1 (the lowest quartile group)" as 0 points.
†† Scoring pattern 2 : Pattern 2 was set based on the frequency of food groups obtained by FFQs : 4 points for "almost every day", 2 points for "once every 2 days", 1 point for "once or twice a week", and 0 points for "almost never". When scoring food groups for which no information on consumption frequency was available (i.e., other vegetables and mushrooms), the scoring rules of Pattern 1 were used.
‡‡ Abbreviations : DBS, dietary balance score ; FFQ, food frequency questionnaire ; NA, nutrient adequacy.

Supplemental table 3. Characteristics of the participants in the NILS-LSA

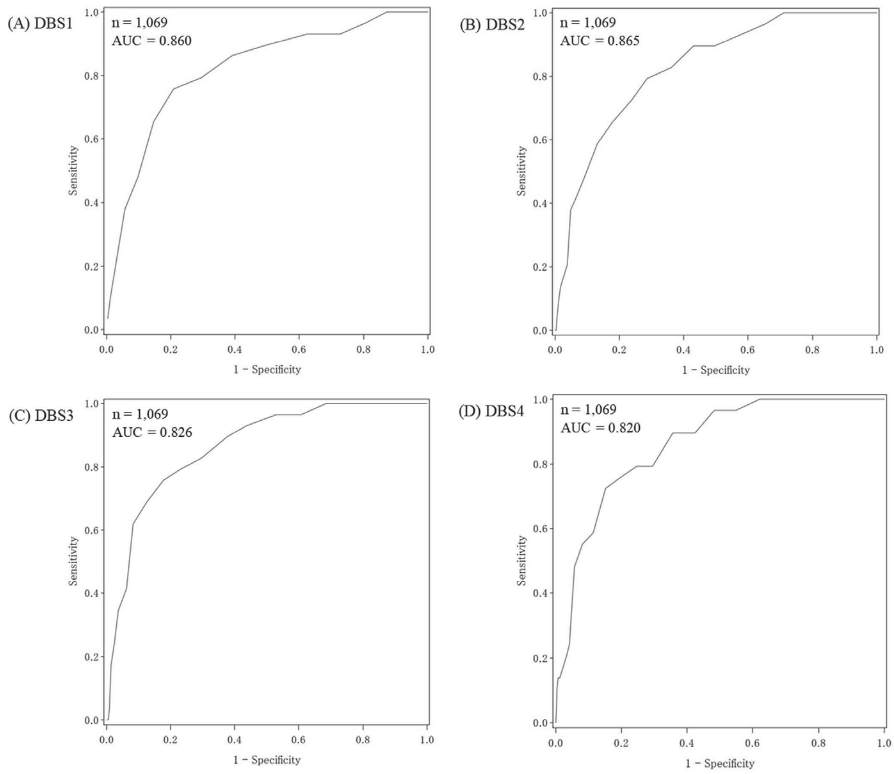
	Total participants (n = 2,145)	Men (n = 1,069)	Women (n = 1,076)
Age (years)†	61.1 ± 12.5	61.1 ± 12.3	61.1 ± 12.7
Body mass index (kg/m²) †	22.7 ± 3.2	23.1 ± 2.8	22.3 ± 3.4
Current physical activity (METs-min/year)†, §	701821.6 ± 64914.5	687253.6 ± 71934.0	716335.2 ± 53276.1
Mini-Mental State Examination score†, §	27.8 ± 1.9	27.6 ± 2.0	28.0 ± 1.9
Education‡			
≤9 years	344 (16.0)	140 (6.5)	204 (9.5)
9–12 years	846 (39.4)	384 (17.9)	462 (21.5)
>12 years	955 (44.5)	545 (25.4)	410 (19.1)
Annual household income‡, §			
≤1.49 million yen	71 (3.3)	23 (1.1)	48 (2.2)
1.50–4.49 million yen	696 (32.4)	328 (15.3)	368 (17.2)
≥4.50 million yen	1,337 (62.3)	707 (33.0)	630 (29.4)
Smoking habit‡			
Current	242 (11.3)	205 (9.6)	37 (1.7)
Former/never	1,903 (88.7)	864 (40.3)	1,039 (48.4)
Alcohol intake (g/day)†	9.9 ± 17.2	16.3 ± 20.8	3.6 ± 8.8
Medical history‡			
Hypertension (+)	642 (29.9)	350 (16.3)	292 (13.6)
Dyslipidemia (+)	453 (21.1)	207 (9.7)	246 (11.5)
Diabetes (+)	153 (7.1)	91 (4.2)	62 (2.9)
Heart disease (+)	98 (4.6)	62 (2.9)	36 (1.7)
Stroke (+)	75 (3.5)	43 (2.0)	32 (1.5)

† Mean ± SD ; ‡ Number (%)
‖ Abbreviations : METs, metabolic equivalents ; NILS-LSA, National Institute for Longevity Sciences-Longitudinal Study of Aging ; SD, standard deviation.
§ Current physical activity, n = 2,138 (1,067 men, 1,071 women) ; Mini-Mental State Examination score, n = 1,151 (583 men, 568 women) ; Annual household income, n = 2,104 (1,058 men, 1,046 women)

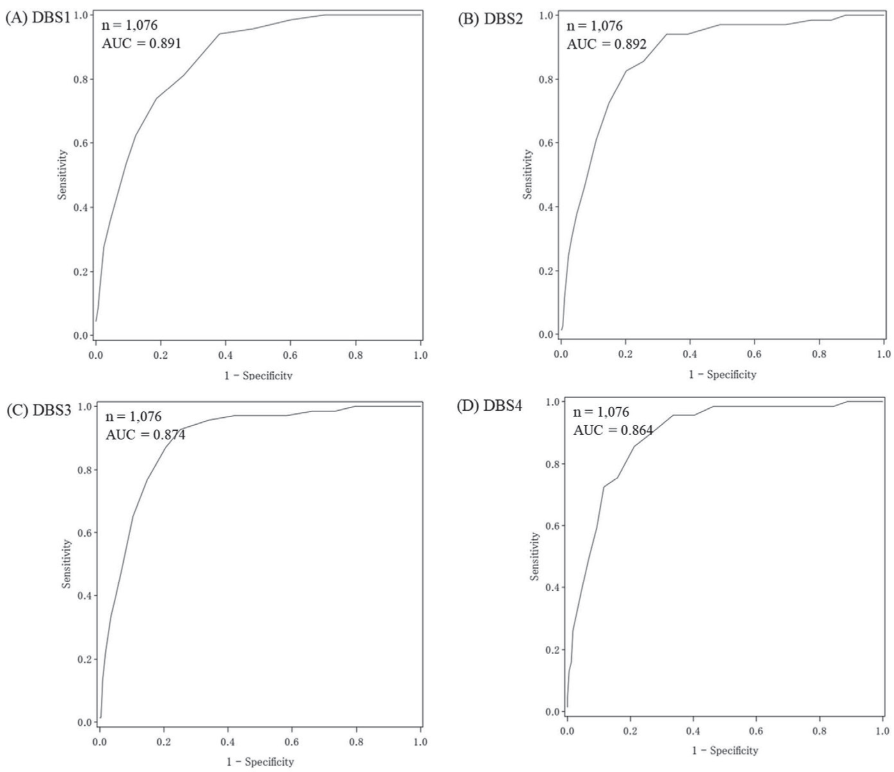
Supplemental table 4. Correlation between each dietary balance score based on 3-day dietary records and the nutrient adequacy score among older community-dwelling Japanese in the NILS-LSA by gender and age groups†, ‡

	Men			Women		
	r	(95% CI)	*p*	*r*	(95% CI)	*p*
All (n = 1,069 men, n = 1,076 women)						
DBS1	0.489	(0.442 – 0.534)	< 0.001	0.388	(0.336 – 0.438)	< 0.001
DBS2	0.476	(0.428 – 0.521)	< 0.001	0.382	(0.330 – 0.432)	< 0.001
DBS3	0.547	(0.503 – 0.588)	< 0.001	0.452	(0.403 – 0.498)	< 0.001
DBS4	0.547	(0.503 – 0.588)	< 0.001	0.472	(0.425 – 0.517)	< 0.001
40–64 years (n = 637 men, n = 635 women)						
DBS1	0.505	(0.445 – 0.561)	< 0.001	0.414	(0.348 – 0.477)	< 0.001
DBS2	0.486	(0.424 – 0.543)	< 0.001	0.427	(0.361 – 0.489)	< 0.001
DBS3	0.549	(0.493 – 0.601)	< 0.001	0.496	(0.435 – 0.553)	< 0.001
DBS4	0.550	(0.493 – 0.602)	< 0.001	0.505	(0.445 – 0.561)	<0.001
≥65 years (n = 432 men, n = 441 women)						
DBS1	0.482	(0.407 – 0.552)	< 0.001	0.378	(0.296 – 0.456)	0.001
DBS2	0.469	(0.392 – 0.540)	< 0.001	0.343	(0.258 – 0.423)	< 0.001
DBS3	0.554	(0.485 – 0.616)	< 0.001	0.422	(0.342 – 0.496)	< 0.001
DBS4	0.553	(0.484 – 0.615)	< 0.001	0.449	(0.371 – 0.520)	< 0.001

† Correlation coefficients in the NILS-LSA.
‡ The correlation between each dietary balance and nutrient adequacy score was estimated using Spearman's rank correlation coefficient test.
‖ Abbreviations : CI, confidence interval ; DBS, dietary balance score ; NILS-LSA, National Institute for Longevity Sciences-Longitudinal Study of Aging.



Supplemental figure 1. AUC-ROCs showing whether four DBSs based on 3DR-discriminated individuals with sufficient intake (met the DRI criteria) of all nine beneficial nutrients among men in the NILS-LSA. A) AUC-ROC of DBS1, B) AUC-ROC of DBS2, C) AUC-ROC of DBS3, and D) AUC-ROC of DBS4. Although the results for all AUC-ROCs were similar, DBS2 had the highest ability to discriminate nutrient sufficiency, and its ability to discriminate nutrients showed moderate accuracy.



Supplemental figure 2. AUC-ROCs showing whether four DBSs based on 3DR-discriminated individuals with sufficient intake (met the DRI criteria) of all nine beneficial nutrients among women in the NILS-LSA. A) AUC-ROC of DBS1, B) AUC-ROC of DBS2, C) AUC-ROC of DBS3, and D) AUC-ROC of DBS4. Although the results for all AUC-ROCs were similar, DBS2 had the highest ability to discriminate nutrient sufficiency, and its ability to discriminate nutrients showed moderate accuracy.