Original Article

Validity of a self-administered diet history questionnaire for estimating vitamin D intakes of Japanese pregnant women

Mie Shiraishi*, Megumi Haruna*, Masayo Matsuzaki*, Ryoko Murayama*, Sachiko Kitanaka[†] and Satoshi Sasaki[‡]

*Department of Midwifery and Women's Health, Division of Health Sciences and Nursing, Graduate School of Medicine, The University of Tokyo, Bunkyo-ku, Tokyo, Japan, [†]Department of Pediatrics, Graduate School of Medicine, The University of Tokyo, Bunkyo-ku, Tokyo, Japan, and [‡]Department of Social and Preventive Epidemiology, School of Public Health, The University of Tokyo, Bunkyo-ku, Tokyo, Japan

Abstract

Maternal vitamin D status is important for fetal development and the prevention of pregnancy complications. Mothers require both sufficient intakes and skin production of this vitamin. We investigated the validity and test–retest reliability of a self-administered diet history questionnaire (DHQ) to establish a method of assessing vitamin D intakes of Japanese pregnant women, using a serum marker. A total of 245 healthy pregnant women in the second trimester, who were not taking vitamin D supplements, were recruited at a university hospital in Tokyo between June 2010 and July 2011. Serum 25-hydroxyvitamin D [25(OH)D] concentrations were measured as an indicator of vitamin D status. To assess the test–retest reliability of the DHQ, 58 pregnant women completed it twice within a 4–5-week interval. Significant positive correlations between intakes and serum concentrations of vitamin D were found ($r = 0.266$ for daily intakes and $r = 0.249$ for energy-adjusted intakes). In the winter investigation in which the serum 25(OH)D concentrations were less likely to be affected by sunlight exposure, the correlation coefficients were 0.304 for both daily and energy-adjusted intakes. After excluding participants with pregnancy-associated nausea, the coefficients increased. The intraclass correlation coefficient between vitamin D intakes estimated from the two-time DHQ was 0.638. The DHQ provides an acceptable validity and reliability of the vitamin D intake of Japanese pregnant women. However, the data of women with nausea should be interpreted with caution. We believe that the DHQ is a useful questionnaire to grasp and improve vitamin D intakes during pregnancy.

Keywords: diet history questionnaire, pregnancy, serum marker, validation, vitamin D.

Correspondence: Ms Mie Shiraishi, Department of Midwifery and Women's Health, Division of Health Sciences and Nursing, Graduate School of Medicine, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. E-mail: mi-shi@umin.ac.jp

Introduction

Vitamin D has long been known to help reduce the risk of many diseases, including osteoporosis, cancer, diabetes and cardiovascular disease (Grant & Boucher 2011). In addition, it has become clear recently that vitamin D may contribute to the prevention of pregnancy complications, such as pre-eclampsia, and has been known to promote fetal skeletal development (Lewis *et al.* 2010). Pregnant

women are recommended to maintain blood concentrations of vitamin D [25-hydroxyvitamin D, 25(OH)D] above 30 ng mL⁻¹, according to general clinical guidelines (Holick *et al.* 2011). 25(OH)D is a long-term stable form of 1,25-dihydroxy-vitamin D, which is the active form of vitamin D. Therefore, circulating 25(OH)D concentrations are considered as the best marker for the evaluation of vitamin D deficiency (Rosen 2011). A recent study showed that the mean 25(OH)D concentrations in Japanese pregnant

women was only 14.5 ng mL⁻¹ (Shibata *et al.* 2011), in spite of no change or only mildly decrease in 25(OH)D concentration during pregnancy (Kovacs 2008). However, measuring circulating 25(OH)D concentrations is difficult in a large-scale study because of their high cost and heavy burden on participants. The 25(OH)D concentration depends on both dietary vitamin D intake (D2/D3) and vitamin D3 production in the skin through exposure to the sun (Standing Committee on the Scientific Evaluation of Dietary Intakes FaNBIoM 1997). Vitamin D2 is found in fungi; vitamin D3 is found in fish, eggs and meat. Foods containing vitamin D2 or D3 have been shown to positively contribute to circulating 25(OH)D concentrations in the Japanese population (Nakamura *et al.* 2000a; Nanri *et al.* 2011). Therefore, an accurate assessment method of vitamin D intake would be helpful in estimating its circulating concentrations and evaluating the risk of perinatal adverse outcomes in expecting mothers.

The 'gold standard' for estimating dietary intakes is the dietary record method. However, implementation of this method is also difficult due to its high cost and heavy burden on participants (Thompson & Subar 2008). Therefore, an easy-to-implement dietary assessment tool such as a self-report questionnaire is required to estimate dietary intakes. Unfortunately, no validated dietary assessment questionnaire that estimates the vitamin D intakes of pregnant women exists in Japan.

However, a self-administered diet history questionnaire (DHQ) has been validated, although only in Japanese non-pregnant populations (Sasaki *et al.* 1998a,b, 2000). The DHQ had relatively high correlation coefficients with a reference method compared

with other Japanese dietary assessment questionnaires (Wakai 2009), and it has an established distribution system. In addition, the validity of the DHQ has already been proven regarding vitamin B12, folate, vitamin C and β -carotene during pregnancy (Shiraishi *et al.* 2012, 2013). A validation study of the DHQ for pregnant women would be the shortest and best way to establish a convenient assessment tool for vitamin D intakes.

Thus, we evaluated the relative validity and reliability of the DHQ for estimating vitamin D intakes in Japanese pregnant women. To verify its validity, we compared the reported dietary vitamin D intakes to their corresponding serum concentrations; to verify test-retest reliability, we compared the intakes estimated from two administrations of the DHQ in a 4–5-week interval.

Materials and methods

Study participants

Healthy Japanese women with singleton pregnancies were recruited at their routine antenatal medical check-ups during their second trimester. The exclusion criteria included diabetes, hypertension, intake of vitamin D supplements, age less than 20 years and poor reading ability for Japanese. The present study was conducted at a university hospital in Tokyo, Japan (35.4°N, 139.4°E) between June 2010 and July 2011. Serum 25(OH)D concentrations fluctuate seasonally; therefore, we conducted the research during the course of one year to reduce the possibility of seasonal bias. All women underwent ultrasonography at 8–12 weeks' gestation to allow for accurate dating of

Key messages

- Vitamin D status in pregnancy plays a role in fetal development and the prevention of pre-eclampsia. Establishment of accurate and easy-to-implement assessment methods of vitamin D intakes during pregnancy is needed.
- The study results show that a self-administered diet history questionnaire (DHQ) can estimate vitamin D intakes of Japanese pregnant women acceptably. However, the estimated intakes should be interpreted cautiously among pregnant women with nausea.
- The DHQ is the only dietary assessment questionnaire to estimate vitamin D intakes during pregnancy in Japan. It would be useful in interventional and epidemiological studies that deal with maternal vitamin D intakes.

the gestation. Each participant was given detailed information about the study protocol, and then gave written informed consent. The study procedures and protocols were approved by the ethics committee of the Graduate School of Medicine, The University of Tokyo.

Each participant answered the questionnaire while waiting for her antenatal medical check-up at 19–23 weeks' gestation. Participants who did not have sufficient time during the check-up filled out their questionnaires after returning home and then submitted them by mail. We drew non-fasting blood samples at the routine blood tests of the antenatal medical check-ups to reduce participant burden.

To verify the test–retest reliability of the DHQ, we recruited pregnant women at 15–19 weeks' gestation between February and April 2011. They answered the DHQ twice during their second trimester; the first was completed at recruitment and the second was carried out 4–5 weeks later.

Diet history questionnaire (DHQ)

The DHQ is a 22-page structured questionnaire designed to assess dietary intakes from the previous month for the Japanese adult population (Sasaki *et al.* 1998a,b, 2000). Its questions cover eating frequency, food portion size, general dietary behaviour and major cooking methods. Food items and portion sizes were derived from the primary data of the National Nutrition Survey of Japan and various Japanese recipe books for Japanese dishes (Sasaki *et al.* 1998a). Eight responses for eating frequency are listed, ranging from 'more than twice per day' to 'almost never'. Five responses for portion size are listed, ranging from 'less than half of a general portion size' to 'more than 1.5 times a general portion size'. The nutrient intakes were calculated based on Japanese standard food composition tables (Ministry of Education *et al.* 2005). The density method was used to obtain energy-adjusted intakes in order to reduce the potential impact of misreporting dietary intakes (Willett *et al.* 1997). We calculated nutrient density as the ratio of nutrient content to total energy content. In non-pregnant young women, the Spearman's rank correlation coefficient between energy-adjusted

intakes estimated from the DHQ and serum concentrations of vitamin D has been reported to be 0.20 (Ohta *et al.* 2009).

We excluded the data from participants who reported an extremely unrealistic energy intake, that is, less than half the energy requirement for the lowest physical activity category or more than 1.5 times the energy requirement for the moderate physical activity category according to the Dietary Reference Intakes for Japanese (Sasaki *et al.* 2003; Ministry of Health, Labour and Welfare of Japan 2010a).

Preparation and analysis of blood biomarker

Within 8 h of collection, blood samples were centrifuged for 10 min at 3000 rpm to separate the serum and then were stored at -80°C until measurement. The serum 25(OH)D concentrations were measured using chemiluminescent immunoassay (LIAISON 25-hydroxy Vitamin D Total Assay, Diasorin, Salugia, Italy). This assay monitors both D2 and D3. Both the intra- and inter-assay coefficients of variation of 25(OH)D concentrations were less than 8%. The linear dynamic range was $4.0\text{--}150.0\text{ ng mL}^{-1}$. The assay was conducted by Kyowa Medex Co., Ltd (Tokyo, Japan). The values measured using the LIAISON assay were reported to be 13.5% lower than those measured using a liquid chromatography-tandem mass spectrometry method, which has been as widely used as the LIAISON assay (Moon *et al.* 2012).

General questionnaires

Information on demographic variables, such as age, gestational age and education level, was collected via a self-administered questionnaire. We calculated pre-pregnancy body mass index (BMI) from participants' self-reported pre-pregnancy weight and height. Participant weight was classified according to World Health Organization criteria: underweight ($\text{BMI} < 18.5\text{ kg m}^{-2}$), normal weight ($18.5 \leq \text{BMI} < 25.0\text{ kg m}^{-2}$) and overweight or obese ($\text{BMI} \geq 25.0\text{ kg m}^{-2}$). Participants were also asked whether they had pregnancy-associated nausea. We asked the participants about their duration of sunlight

exposure and use of skin protection from sunburn during the preceding 1-month period because these variables affect vitamin D production in the skin. Duration of sunlight exposure was collected separately for weekdays and weekends. We calculated the mean duration of daily sunlight exposure as [(minutes of sunlight exposure on weekdays $\times$ 5 + minutes of sunlight exposure on weekends $\times$ 2)/7]. Use of skin protection from sunburn was defined by the use of a parasol or sunscreen. The participants were asked about their frequency of use, and the choices were as follows: not used at all, sometimes used or always used. The women who answered 'sometimes used' or 'always used' to the question about skin protection were classified as 'user of skin protection from sunburn'. We defined the season of investigation as summer (April–September) and winter (October–March).

Statistical analyses

The differences between the characteristics in the two groups were compared using chi-square tests or Student's *t*-tests. The duration of sunlight exposure and the vitamin status were analysed after a log-transformation of the variables to achieve normal distributions. Pearson's correlation coefficients were used to investigate whether there were associations between intakes and serum concentrations of vitamin D. In addition, partial correlation analysis was conducted to investigate the correlation coefficient between the variables, adjusted for the duration of sunlight exposure and the use of skin protection from sunburn. Cross-classification was used to test the relative agreement between intake and serum concentration of vitamin D. All pregnant women were classified into quintiles according to their intakes and serum concentrations of vitamin D. Concordance in quintile ranking was assessed as a percentage classification in the same and adjacent quintiles. Discordance was defined as a percentage classification in opposite quintiles (quintile 1 vs. quintile 5).

The mean intakes estimated from the two-time DHQ were compared using a paired *t*-test, after the log-transformation of the variables. In addition, we calculated the intraclass correlation coefficients

(ICCs) of estimated intakes from the two-time DHQ. All pregnant women were classified into quintiles according to the vitamin D intakes estimated from the two-time DHQ. Concordance and discordance in quintile ranking was assessed in the same way as in the validation study. In addition, the Bland–Altman plots were used to illustrate the difference between the two-time DHQ against the mean intakes of the two-time DHQ (Bland & Altman 1999). The upper and lower lines represented the upper and lower 95% limits of agreement (mean difference $\pm$ 1.96 SD).

All statistical analyses were conducted using Statistical Package for Social Sciences for Windows, version 15.0 (SPSS Japan Inc., Tokyo, Japan). The tests were two-sided and *P*-values less than 0.05 were considered statistically significant.

Results

Validation study

A total of 321 pregnant women were recruited. Of these women, 299 (93.1%) gave written informed consent. Fifty-four were excluded from the analysis for the following reasons: 39 took vitamin D supplements, 14 had missing data and 1 reported an unrealistically low energy intake. Thus, data from 245 (76.3%) healthy pregnant women were analysed.

Participant characteristics are shown in Table 1. The mean (SD) age was 34.5 (4.0), and 152 (62.0%) were primigravida. Seventy (28.6%) reported having pregnancy-associated nausea. One hundred and thirty-two (53.9%) participants were examined in summer; their rate of skin protection from sunburn was significantly higher in summer than in winter (90.2% vs. 79.6%, respectively). No difference in the mean duration of daily sunlight exposure was found between the participants in the summer and winter investigation (112.3 min day⁻¹ vs. 112.8 min day⁻¹, respectively). Table 2 indicates the mean vitamin D intakes estimated from the DHQ and serum 25(OH)D concentrations. The mean (SD) intakes of energy and vitamin D were 1805 (409) kcal day⁻¹ and 6.3 (3.2) μ g day⁻¹, respectively. The overall proportions of vitamin D ingested from fish/seafood, eggs and fungi were 72.5%, 8.9% and 5.4%, respectively, in

Table 1. Characteristics of participants

	Validation study		Reproducibility study (<i>n</i> = 58)
	All participants (<i>n</i> = 245)	Participants without nausea (<i>n</i> = 175)	Mean $\pm$ SD or <i>n</i> (%)
Age (years)	34.5 $\pm$ 4.0	34.5 $\pm$ 4.1	33.8 $\pm$ 4.2
Gestational age (weeks)	20.3 $\pm$ 1.1	20.4 $\pm$ 1.1	
Gestational age at first survey (weeks)			16.9 $\pm$ 1.5
Gestational age at second survey (weeks)			21.0 $\pm$ 1.3
Parity: Primigravida [<i>n</i> (%)]	152 (62.0)	114 (65.1)	38 (65.5)
Currently married [<i>n</i> (%)]	244 (99.6)	174 (99.4)	58 (100.0)
Education [<i>n</i> (%)]			
High school	23 (9.4)	17 (9.7)	3 (5.2)
Junior or technical college	100 (40.8)	68 (38.9)	24 (41.4)
College or university	122 (49.8)	90 (51.4)	31 (53.4)
Height (cm)	159.1 $\pm$ 5.5	159.2 $\pm$ 5.3	159.1 $\pm$ 5.4
Pre-pregnancy body mass index (kg m ⁻²)	20.5 $\pm$ 2.4	20.5 $\pm$ 2.4	20.2 $\pm$ 3.0
Working [<i>n</i> (%)]	117 (47.8)	94 (53.7)	22 (38.3)
Regular smoker during pregnancy [<i>n</i> (%)]	3 (1.2)	3 (1.7)	1 (1.7)
Having pregnancy-associated nausea [<i>n</i> (%)]	70 (28.6)		10 (17.2)
Duration of sunlight exposure* (min day ⁻¹)	112.6 $\pm$ 88.6	112.1 $\pm$ 81.5	
Use of skin protection from sunburn† [<i>n</i> (%)]	209 (85.3)	151 (86.3)	
Season of investigation [summer (from April to September): <i>n</i> (%)]	132 (53.9)	95 (54.3)	

*Duration of sunlight exposure was asked weekday and weekend separately. We calculated mean duration of daily sunlight exposure as [(minutes of sunlight exposure on weekdays $\times$ 5 + minutes of sunlight exposure on weekends $\times$ 2)/7]. †Use of skin protection from sunburn was assessed as use of parasol or sunscreen.

Table 2. Nutrient intakes estimated from the self-administered diet history questionnaire (DHQ) and serum concentrations

	All participants (<i>n</i> = 245)			Participants without nausea* (<i>n</i> = 175)		
	Mean $\pm$ SD	Min.	Max.	Mean $\pm$ SD	Min.	Max.
Nutrient intakes						
Energy (kcal)	1805 $\pm$ 409	1009	3016	1801 $\pm$ 399	1056	3016
Vitamin D (μ g day ⁻¹)	6.3 $\pm$ 3.2	0.9	20.0	6.3 $\pm$ 3.2	0.9	19.8
(μ g/1000 kcal)	3.5 $\pm$ 1.6	0.6	10.7	3.5 $\pm$ 1.6	0.6	10.6
Serum concentrations						
25(OH)D (ng mL ⁻¹)	9.6 $\pm$ 4.7	4.0	27.2	9.6 $\pm$ 4.9	4.0	27.2

25(OH)D, 25-hydroxyvitamin D. *Participants who reported having pregnancy-associated nausea (*n* = 70) were excluded.

the summer investigation and 68.9%, 9.1% and 4.9%, respectively, in the winter investigation. There were no significant differences in the consumption of these vitamin D-rich foods between the participants in the summer and winter investigations. Further, no significant differences were found in mean vitamin D intake

between participants with and without nausea (6.4 μ g day⁻¹ vs. 6.3 μ g day⁻¹, respectively) between the participants in the summer and winter investigation (6.2 μ g day⁻¹ vs. 6.6 μ g day⁻¹, respectively). The participants in the summer investigation had significantly higher serum 25(OH)D concentrations than

those in the winter investigation (10.2 ng mL^{-1} vs. 8.8 ng mL^{-1} , respectively, $P = 0.029$). There was no significant difference in mean 25(OH)D concentration between the users and non-users of sun protection (9.6 ng mL^{-1} vs. 9.2 ng mL^{-1} , respectively, $P = 0.556$). Similar results were observed irrespective of the season. The mean (SD) serum 25(OH)D concentration of the pregnant women, who were ultimately excluded from analyses due to taking vitamin D supplements, was $11.9 (4.4) \text{ ng mL}^{-1}$.

Among the participants in both the summer and the winter investigations, vitamin D intake was significantly positively correlated with corresponding serum concentration ($r = 0.258$ and $r = 0.213$ for daily and energy-adjusted intake in the summer investigation, respectively; $r = 0.304$ for both daily and energy-adjusted intake in the winter investigation; Table 3). Although partial correlation analysis was performed with adjustment for duration of sunlight exposure and use of skin protection from sunburn, the correlation coefficients did not differ significantly from the results of Pearson's correlation coefficients. When the participants with pregnancy-associated nausea were excluded, the Pearson's correlation coefficients increased. According to our classification of quintiles based on intakes and serum concentrations, more than 60% of participants were classified in the same or an adjacent quintile (Table 4).

Reliability study

A total of 64 pregnant women completed the first DHQ at 15–19 weeks' gestation. Six pregnant women were excluded from the analysis for the following reasons: three dropped out, two reported unrealistically low energy intakes due to nausea and one had missing data. Therefore, data from 58 women were analysed to assess the test–retest reliability of the DHQ. The characteristics of the participants in the reliability and validation studies did not noticeably differ (Table 1).

The overall proportions of vitamin D ingested from fish/seafood, eggs and fungi were 68.3%, 10.8% and 5.0%, respectively, in the first administration and 70.8%, 9.3% and 4.5%, respectively, in the second administration. No differences in consumption of

Table 3. Pearson's correlation coefficients between dietary intakes and corresponding serum concentrations

	25(OH)D (ng mL^{-1})									
	All participants ($n = 245$)		Participants without nausea* ($n = 175$)		Summer investigation			Winter investigation		
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	Participants ($n = 132$)		<i>r</i>	Participants ($n = 113$)		<i>r</i>
					Participants without nausea* ($n = 95$)	<i>P</i>		Participants without nausea* ($n = 80$)	<i>P</i>	
Dietary intake										
Vitamin D										
($\mu\text{g day}^{-1}$)	0.266	<0.001	0.311	<0.001	0.258	0.003	0.272	0.008	0.001	0.371
($\mu\text{g}/1000 \text{ kcal}$)	0.249	<0.001	0.282	<0.001	0.213	0.014	0.227	0.027	0.001	0.353

25(OH)D, 25-hydroxyvitamin D. These analyses were conducted after a log-transformation of all variables. *Participants who reported having pregnancy-associated nausea were excluded.

Table 4. Concordance and discordance in quintile ranking based on intakes and serum concentrations of vitamin D

	All participants (<i>n</i> = 245)				Participants without nausea* (<i>n</i> = 175)				Summer investigation				Winter investigation			
	Concordance [†] (%)		Discordance [‡] (%)		Concordance [†] (%)		Discordance [‡] (%)		Participants (<i>n</i> = 132)		Discordance [‡] (%)		Participants (<i>n</i> = 113)		Discordance [‡] (%)	
Dietary intake																
Vitamin D ($\mu\text{g}/1000 \text{ kcal}$)	61.6	5.3	62.9	6.1	62.9	5.7	63.4	6.3	60.7	6.1	60.7	6.8	62.8	4.4	63.8	5.0
	62.9	6.1											65.5	5.3	66.3	5.0

*Participants who reported having pregnancy-associated nausea (*n* = 70) were excluded. [†]All pregnant women were classified into quintiles according to the intakes and the serum concentrations for each nutrient. Concordance in quintile ranking was assessed as the percentage classification in the same and adjacent quintiles based on the intakes and the serum concentrations. [‡]Discordance in quintile ranking was assessed as the percentage classification in the opposite quintiles based on the intakes and the serum concentrations.

Fig. 1. Bland–Altman plots comparing vitamin D intakes estimated from the two-time diet history questionnaire (DHQ).

these vitamin D-rich foods were found between the two administrations. The ICC of the two-time DHQ was 0.638 and no significant difference was found between the mean intakes of the two-time DHQ. According to the cross-classification based on vitamin D intakes from the two-time DHQ, 82.8% of the pregnant women were classified in the same or adjacent quintiles (Table 5). The Bland–Altman plots of vitamin D intake from the two-time DHQ showed that most participants' values were within the limits of agreement (Fig. 1). However, three women showed differences between the intakes estimated from the two-time DHQ beyond the limits of agreement. These three women reported nausea in the first DHQ administration, and their energy and vitamin D intakes were 1900–2600 kcal day⁻¹ and 11.2–18.9 $\mu\text{g day}^{-1}$, respectively. Their intakes in the second DHQ decreased.

Discussion

This is the first study to provide evidence supporting the validity and test–retest reliability of a DHQ for estimating the vitamin D intakes of Japanese pregnant women.

Among the participants in the winter investigation, the Pearson's correlation coefficients between intakes and serum concentrations of vitamin D were greater than 0.30. In dietary questionnaire validation studies,

Table 5. Mean intakes estimated from the two-time DHQ and the intraclass correlation coefficients ($n = 58$)

	First DHQ Mean $\pm$ SD	Second DHQ Mean $\pm$ SD	Mean difference (95% CI)	P^*	First DHQ vs. second DHQ ICC (95% CI)	Concordance [‡] (% classified into the same and adjacent quintile)	Discordance [§] (% classified into the opposite quintile)
Energy (kcal day ⁻¹)	1727 $\pm$ 407	1771 $\pm$ 399	44 (–51–139)	0.362	0.599 (0.406 to 0.741)	70.7	1.7
Vitamin D ($\mu\text{g day}^{-1}$) [†]	5.6 $\pm$ 3.6	5.8 $\pm$ 2.9	0.3 (–0.2–0.9)	0.262	0.638 (0.458 to 0.768)	82.8	0

DHQ, a self-administered diet history questionnaire; CI, confidence interval; ICC, intraclass correlation coefficient. ^{*}Paired t -test. [†]The analyses were conducted after log-transformation of the variables. [‡]All pregnant women were classified into quintiles according to energy and vitamin D intakes estimated from the two-time DHQ. Concordance in quintile ranking was assessed as the percentage classification in the same and adjacent quintiles based on the two-time DHQ. [§]Discordance in quintile ranking was assessed as the percentage classification in the opposite quintiles based on the two-time DHQ.

correlation coefficients of more than 0.50 are considered strong; those of 0.30–0.50, acceptable, and those less than 0.30, weak (Ortiz-Andrellucchi *et al.* 2009). According to these criteria, the DHQ can adequately estimate vitamin D intake when applied to the winter data. On the other hand, the correlation coefficient for the summer was slightly lower than acceptable criteria. However, these results could be due to seasonal changes in sunlight exposure (Nakamura *et al.* 2000b). The amount of vitamin D production in the skin is likely to be larger in summer than in winter because of the correspondingly larger amount of ultraviolet radiation per unit time of sunlight exposure in summer. Therefore, serum 25(OH)D concentrations are susceptible to modulation by seasonal variation in endogenous vitamin D production. Actually, our participants' serum 25(OH)D concentrations were higher in summer than in winter, although dietary vitamin D intake did not differ between the two seasons. The lower correlation coefficient in the summer investigation seems to be due to the greater effect of endogenous vitamin D production, not due to low validity of the DHQ. In cross-classification, 63–66% of participants in the winter investigation were classified into the same or adjacent quintiles according to the intakes and serum concentrations, which was similar to that reported in a previous study (Brantsaeter *et al.* 2008). Considering the attenuated results by the effects of vitamin D production in the skin, our results in the winter investigation provided an acceptable validity of DHQ for ranking Japanese pregnant women on the basis of vitamin D intake.

The correlation during pregnancy is often weakened by pregnancy-associated nausea (Brantsaeter *et al.* 2008; Shiraishi *et al.* 2012). This could be partly due to the nutrient loss that accompanies vomiting and the dietary changes depending on the degree of nausea. In the present study, the correlation coefficient between vitamin D intake and serum concentration was lower when participants with nausea were included, although the effect size was not large. On the basis of the results in winter, we suggest that the DHQ can estimate daily and energy-adjusted vitamin D intake regardless of the presence vs. absence of pregnancy-associated nausea. However, the estimated intake of vitamin D may be interpreted with more caution in pregnant women with nausea.

The ICC of vitamin D, 0.638, was in the range of good correlation (0.50–0.70), as defined by Cade *et al.* (2004). In light of the changes in dietary intakes, as gestation progresses, we considered this an acceptable value, although the ICC in our study was not very high. In addition, the present study showed both no difference in the mean intakes between two-time DHQ and the high concordance in the quintile ranking. From these results, we suggest that the DHQ has an acceptable reliability. On the other hand, the Bland–Altman plots showed three data points outside the limits of agreement between the two-time DHQ. The three women reported having nausea symptoms in the first DHQ administration, although they had a far higher vitamin D intake in the first administration than in the second administration. We speculated from the difference between their intakes of the

two-time DHQ that they had eaten more to prevent nausea triggered by hunger, as opposed to limiting food intake due to nausea. The dietary questionnaire results may not be reliable for some pregnant women with nausea because of changes in the degree of nausea within a brief period. In the present study, however, 95% of participants' values were within the limits of agreement. Thus, we believe that the reliability of the DHQ is acceptable.

Two women were excluded from the analyses of the reliability study because their energy intakes in the first DHQ administration were extremely unrealistic. They had nausea symptoms in the period covered by the first DHQ administration. Nausea seems to affect the reported energy intakes through under-recognition of intakes or true low intakes (Winkvist *et al.* 2002). Therefore, the reported unrealistic low energy intake would not be due to an invalidity of the DHQ.

Our participants' serum 25(OH)D concentrations were far lower than the recommended minimum of 30 ng mL⁻¹ (Holick *et al.* 2011). Serum 25(OH)D concentrations during pregnancy are generally equal to or slightly lower than that in the non-pregnancy period (Kovacs 2008). Although levels of vitamin D binding globulin increase during pregnancy, this is not considered to cause changes in serum 25(OH)D concentrations (Bruinse & van den Berg 1995). Low serum 25(OH)D concentrations found even in the present study's summer investigation could be due to low vitamin D intake, deliberate reduction in sunlight exposure or the high prevalence of sunscreen use. Although the participants' mean vitamin D intake was only slightly lower than the adequate level for Japanese pregnant women (7 µg day⁻¹; Ministry of Health, Labour and Welfare of Japan 2009), this amount is considerably lower than recommended dietary allowance of other countries (15 µg day⁻¹; Health Canada 2010; The National Academies Press 2011). Such insufficient vitamin D intake during pregnancy may be generally found in Japanese pregnant women: the vitamin D intake of our participants is considered to be equivalent to that in other parts of Japan due to the mitigation of regional differences by improved distribution systems (Watanabe *et al.* 2001; Nakamura *et al.* 2002). Meanwhile, our participants'

mean duration of sunlight exposure was equivalent to that of young women in Tokyo (1.2 h day⁻¹ in winter, Ohta *et al.* 2009). Most of our participants used measures to prevent sunburn regardless of season, which would prevent vitamin D from being produced in the skin. This behaviour could be caused by societal knowledge regarding the effects of ultraviolet radiation on health hazards, such as skin cancer and skin damage (Ministry of the Environment 2008). The high rate of sunscreen use during both summer and winter might have alleviated the seasonal differences in vitamin D production in the skin. However, the amount of vitamin D produced in the skin was presumed to be barely adequate in the present study, which could explain the low serum 25(OH)D concentrations observed in our participants. Health care providers need to not only recommend increased vitamin D intake but also inform pregnant women of the significance of adequate sunlight exposure for the attainment of optimal 25(OH)D concentrations. As a screening tool for vitamin D intake among Japanese pregnant women, the DHQ can help to estimate the risk of low-vitamin D status.

The present study had a few limitations. First, the characteristics of the participants might be biased because the research location was a university hospital in an urban area. In addition, the mean age of participants was older than that in national reports (34.5 years vs. 31.2 years) (Ministry of Health, Labour and Welfare of Japan 2010b). However, the vitamin D intakes of our participants were similar to those in another study (Miyake *et al.* 2012). Thus, we propose that the validity of the DHQ regarding vitamin D would be applicable to Japanese pregnant women in general. Secondly, the measurement values of the LIAISON 25-hydroxy vitamin D total assay might be a little lower compared with those of other vitamin D measurement methods, although strong correlations between the methods have been established (Moon *et al.* 2012). Thirdly, we did not obtain detailed information regarding increased vitamin D intake from the consumption of fortified food because only a few food products are fortified with vitamin D in Japan. This might have reduced the correlation coefficients between estimated intake by the DHQ and serum 25(OH)D concentrations, but does not affect the

main conclusions of the present study. Fourthly, we did not measure actual endogenous vitamin D production. Depending on the production quantity, the relationship between vitamin D intake and the corresponding biomarker would be attenuated, especially in the summer investigation. Finally, the 4–5-week interval period used in the reliability study might have been longer than the period in which dietary changes due to nausea were likely to occur.

Despite these limitations, the present study managed to establish an effective assessment method of estimating the vitamin D intakes of Japanese pregnant women. However, the intakes of pregnant women with nausea should be interpreted with more caution. The mean vitamin D intake in our study was less than established adequate vitamin D intake (Ministry of Health, Labour and Welfare of Japan 2010a). We believe that the DHQ will be useful to determine whether the vitamin D intake is lower than the recommended amount and to create awareness among pregnant women about the need for improving vitamin D intake on the basis of that estimated from the DHQ. In addition, the DHQ would help in interventional and epidemiological studies regarding vitamin D intakes during pregnancy.

Acknowledgements

We are deeply grateful to the participants and the hospital staff for their cooperation.

Source of funding

This work was supported by Institute for Food and Health Science, Yazuya Co Ltd, 2009 and Fumiko Yamaji Professional Nursing Education, 2011.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Contributions

All authors conceived of and designed the study. MS, MH and MM carried out the data collection. MS

performed the statistical analyses. All authors contributed to the interpretation of the findings. MS drafted the manuscript. All authors revised the manuscript for intellectual content, and read and approved the final manuscript.

References

- Bland J.M. & Altman D.G. (1999) Measuring agreement in method comparison studies. *Statistical Methods in Medical Research* **8**, 135–160.
- Brantsaeter A.L., Haugen M., Alexander J. & Meltzer H.M. (2008) Validity of a new food frequency questionnaire for pregnant women in the Norwegian Mother and Child Cohort Study (MoBa). *Maternal and Child Nutrition* **4**, 28–43.
- Bruinse H.W. & van den Berg H. (1995) Changes of some vitamin levels during and after normal pregnancy. *European Journal of Obstetrics, Gynecology, and Reproductive Biology* **61**, 31–37.
- Cade J.E., Burley V.J., Warm D.L., Thompson R.L. & Margetts B.M. (2004) Food-frequency questionnaires: a review of their design, validation and utilisation. *Nutrition Research Reviews* **17**, 5–22.
- Grant W.B. & Boucher B.J. (2011) Requirements for vitamin D across the life span. *Biological Research for Nursing* **13**, 120–133.
- Health Canada (2010) *Vitamin D and Calcium: Updated Dietary Reference Intakes*. Available at: <http://www.hc-sc.gc.ca/fn-an/nutrition/vitamin/vita-d-eng.php> (Accessed 6 May 2013).
- Holick M.F., Binkley N.C., Bischoff-Ferrari H.A., Gordon C.M., Hanley D.A., Heaney R.P. *et al.* (2011) Endocrine Society. Evaluation, treatment, and prevention of vitamin D deficiency: an Endocrine Society clinical practice guideline. *The Journal of Clinical Endocrinology and Metabolism* **96**, 1911–1930.
- Kovacs C.S. (2008) Vitamin D in pregnancy and lactation: maternal, fetal, and neonatal outcomes from human and animal studies. *The American Journal of Clinical Nutrition* **88**, 520S–528S.
- Lewis S., Lucas R.M., Halliday J. & Ponsonby A.L. (2010) Vitamin D deficiency and pregnancy: from preconception to birth. *Molecular Nutrition and Food Research* **54**, 1092–1102.
- Ministry of Education, Culture, Sports, Science and Technology (2005) *Standard Tables of Food Composition in Japan*, 5th rev enlarged edn, Printing Bureau of the Ministry of Finance: Tokyo.
- Ministry of Health, Labour and Welfare of Japan (2009) *Dietary Reference Intakes for Japanese People*. Available at: <http://www.mhlw.go.jp/shingi/2009/05/s0529-4.html> (Accessed 6 May 2013).

- Ministry of Health, Labour and Welfare of Japan (2010a) *The National Health and Nutrition Survey in Japan*. Dai-ichi Shuppan: Tokyo.
- Ministry of Health, Labour and Welfare of Japan (2010b) *Population Survey Report 2010*. Available at: <http://www.mhlw.go.jp/toukei/saikin/hw/jinkou/suii10/dl/s02.pdf> (Accessed 6 May 2013).
- Ministry of the Environment (2008) *Health Care Manual for UV*. Available at: http://www.env.go.jp/chemi/uv/uv_manual.html (Accessed 6 May 2013).
- Miyake Y., Tanaka K., Okubo H., Sasaki S. & Arakawa M. (2012) Dairy food, calcium and vitamin D intake and prevalence of allergic disorders in pregnant Japanese women. *The International Journal of Tuberculosis and Lung Disease* **16**, 255–261.
- Moon H.W., Cho J.H., Hur M., Song J., Oh G.Y., Park C.M. *et al.* (2012) Comparison of four current 25-hydroxyvitamin D assays. *Clinical Biochemistry* **45**, 326–330.
- Nakamura K., Nashimoto M., Hori Y. & Yamamoto M. (2000a) Serum 25-hydroxyvitamin D concentrations and related dietary factors in peri- and postmenopausal Japanese women. *The American Journal of Clinical Nutrition* **71**, 1161–1165.
- Nakamura K., Nashimoto M. & Yamamoto M. (2000b) Summer/winter differences in the serum 25-hydroxyvitamin D3 and parathyroid hormone levels of Japanese women. *International Journal of Biometeorology* **44**, 186–189.
- Nakamura K., Nashimoto M., Okuda Y., Ota T. & Yamamoto M. (2002) Fish as a major source of vitamin D in the Japanese diet. *Nutrition* **18**, 415–416.
- Nanri A., Foo L.H., Nakamura K., Hori A., Poudel-Tandukar K., Matsushita Y. *et al.* (2011) Serum 25-hydroxyvitamin D concentrations and season-specific correlates in Japanese adults. *Journal of Epidemiology* **21**, 346–353.
- Ohta H., Kuroda T., Onoe Y., Orito S., Ohara M., Kume M. *et al.* (2009) The impact of lifestyle factors on serum 25-hydroxyvitamin D levels: a cross-sectional study in Japanese women aged 19–25 years. *Journal of Bone and Mineral Metabolism* **27**, 682–688.
- Ortiz-Andrellucchi A., Henríquez-Sánchez P., Sánchez-Villegas A., Peña-Quintana L., Mendez M. & Serra-Majem L. (2009) Dietary assessment methods for micronutrient intake in infants, children and adolescents: a systematic review. *The British Journal of Nutrition* **102**, S87–S117.
- Rosen C.J. (2011) Clinical practice. Vitamin D insufficiency. *The New England Journal of Medicine* **364**, 248–254.
- Sasaki S., Yanagibori R. & Amano K. (1998a) Validity of a self-administered diet history questionnaire for assessment of sodium and potassium: comparison with single 24-hour urinary excretion. *Japanese Circulation Journal* **62**, 431–435.
- Sasaki S., Yanagibori R. & Amano K. (1998b) Self-administered diet history questionnaire developed for health education: a relative validation of the test-version by comparison with 3-day diet record in women. *Journal of Epidemiology* **8**, 203–215.
- Sasaki S., Ushio F., Amano K., Morihara M., Todoriki O., Uehara Y. *et al.* (2000) Serum biomarker-based validation of a self-administered diet history questionnaire for Japanese subjects. *Journal of Nutritional Science and Vitaminology* **46**, 285–296.
- Sasaki S., Katagiri A., Tsuji T., Shimoda T. & Amano K. (2003) Self-reported rate of eating correlates with body mass index in 18-y-old Japanese women. *International Journal of Obesity and Related Metabolic Disorders* **27**, 1405–1410.
- Shibata M., Suzuki A., Sekiya T., Sekiguchi S., Asano S., Udagawa Y. *et al.* (2011) High prevalence of hypovitaminosis D in pregnant Japanese women with threatened premature delivery. *Journal of Bone and Mineral Metabolism* **29**, 615–620.
- Shiraishi M., Haruna M., Matsuzaki M., Murayama R., Sasaki S. & Murashima S. (2012) Validity and reproducibility of folate and vitamin B(12) intakes estimated from a self-administered diet history questionnaire in Japanese pregnant women. *Nutrition Journal* **11**, 15.
- Shiraishi M., Haruna M., Matsuzaki M., Murayama R. & Sasaki S. (2013) Validity of a diet history questionnaire estimating β -carotene, vitamin C, and α -tocopherol intakes in Japanese pregnant women. *International Journal of Food Sciences and Nutrition*. (in press).
- Standing Committee on the Scientific Evaluation of Dietary Intakes FaNBioM (1997) Vitamin D. In *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D and Fluoride* (eds V. Young & C. Garza), pp 250–287. National Academy Press: Washington, DC.
- The National Academies Press (2011) *Dietary Reference Intakes for Calcium and Vitamin D*. Available at: http://www.nap.edu/openbook.php?record_id=13050&page=363 (Accessed 6 May 2013).
- Thompson F.E. & Subar A.F. (2008) Dietary assessment methodology. In: *Nutrition in the Prevention and Treatment of Disease* (eds A.M. Coulston & C.J. Boushey), 2nd edn, pp 3–39. Academic Press: Philadelphia.
- Wakai K. (2009) A review of food frequency questionnaires developed and validated in Japan. *Journal of Epidemiology* **19**, 1–11.
- Watanabe T., Suzuki A. & Tanaka E. (2001) Estimated intake of vitamin D in Japanese – a difference by the area and secular change. *Chiba College of Health Science* **20**, 23–30.

Willett W.C., Howe G.R. & Kushi L.H. (1997) Adjustment for total energy intake in epidemiologic studies. *The American Journal of Clinical Nutrition* **65**, 1220S–1231S.

Winkvist A., Persson V. & Hartini T.N. (2002) Underreporting of energy intake is less common among pregnant women in Indonesia. *Public Health Nutrition* **5**, 523–529.