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Effect of tailored dietary guidance for pregnant women on nutritional status: A double-cohort study

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Abstract

This double cohort study aimed to evaluate the effect of tailored dietary guidance for pregnant women on dietary intake, nutritional status, and infant birth weight. Healthy pregnant women were recruited at an antenatal clinic during two phases over 2 years. The historical controls were analyzed a year prior to the intervention group. In both groups, data were collected at 19–26 gestational weeks (baseline) and at 34–37 gestational weeks (outcome measurement). The intervention included the following: (a) assessments of maternal dietary nutritional intake using the brief self-administered diet history questionnaire, (b) individual feedback based on the assessments of maternal nutritional status, (c) tailored guidance for a healthy diet, (d) original cooking recipes, and (e) goal sharing. Mann–Whitney *U* test was used to compare the outcome data between the groups. Of the 378 eligible women, 309 women had follow-up questionnaire data. Blood samples were obtained from 202 women. Despite a lack of improvement in reported dietary intake, plasma eicosapentaenoic acid ($p = .002$), docosahexaenoic acid ($p < .001$), arachidonic acid ($p < .001$), and dihomo-gamma-linolenic acid ($p < .001$) concentrations as well as maternal weight gain ($p = .019$) were significantly higher in the intervention group. However, serum folate ($p = .031$) concentration was significantly lower in the intervention group, and there were no significant differences between the groups in 25-hydroxy vitamin D levels, blood count, average birth weight, and rate of low birth weight infants. Assessment-based tailored guidance individualized to maternal dietary intake might partially contribute to improved nutrition in pregnant women.

KEYWORDS

25-hydroxy vitamin D, docosahexaenoic acid, eicosapentaenoic acid, folate, low birth weight, tailored dietary guidance

1 | INTRODUCTION

Adequate nutrition during pregnancy promotes maternal and fetal health (Abu-Saad & Fraser, 2010). Conversely, insufficient antenatal nutrition leads to maternal complications, such as pregnancy-induced hypertension, and adverse birth outcomes that increase neonatal morbidity and mortality among infants, such as intrauterine growth restriction, preterm birth, and low birth weight (LBW) (Wu et al., 2012; Belkacemi et al., 2010). Furthermore, inappropriate maternal diet and nutrition during pregnancy might alter the fetal epigenetic profile and have long-term effects on the development of non-communicable chronic diseases in adulthood (Canani et al., 2011).

While it has been suggested that maternal nutrition has only a small impact on infant health and birth weight in industrialized

populations (Mathews et al., 1999), the issues that Japanese women face appear to be different from those in other industrialized countries. Among Japanese women of reproductive age, one in five (21.5%) women aged 20–29 years has a low body mass index (BMI) (Ministry of Health, Labour and Welfare, 2013a), similar to women in developing countries (World Health Organization, 2009). Furthermore, the rate of LBW infants is increasing in Japan, reaching approximately 10% (Ministry of Health, Labour and Welfare, 2013b).

The Japanese Ministry of Health, Labour and Welfare has specified the recommended amounts of nutrients during pregnancy in the “Dietary Reference Intakes for Japanese” guideline, which is revised every 5 years, and provided information regarding appropriate weight gain during pregnancy, according to prepregnancy BMI, in the national “Dietary guidelines for pregnant and postpartum women” (Ministry of

Health, Labour and Welfare, 2006). The current guidance provided by many health professionals focuses primarily on optimal weight gain during pregnancy to avoid risks during labor and delivery. However, adequate micronutrient intake is also necessary for health during pregnancy and to encourage fetal development.

A lack of folic acid is a representative example of insufficient nutrient intake among women of reproductive age. Folic acid is particularly important during the early stage of development, when a deficiency can lead to neural tube defects (NTDs), which are birth defects of the brain and spinal cord caused by failure of the neural tube to close. In Japan, there has been a trending increase in the prevalence of NTDs. Over the previous decade, many developed countries have successfully and substantially reduced the prevalence of NTDs using folic acid supplementation and mandatory fortification. In Japan, the Ministry of Health, Labour and Welfare recommends a well-balanced diet and daily consumption of 400 µg folic acid for women who are planning to become pregnant or in early pregnancy, but mandatory fortification has not been implemented (Ministry of Health, Labour and Welfare, 2015).

Adequate maternal levels of n-3 long-chain polyunsaturated fatty acids (LC-PUFA), especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), have beneficial effects on fetal development (Swanson et al., 2012) and women's mental health (Chong et al., 2015). Therefore, adequate dietary intakes of EPA and DHA have been recommended. A recent prospective cohort study showed associations between maternal concentrations of not only n-3 LC-PUFA but also n-6 fatty acids during early pregnancy and infant birth weight at term. It is postulated that low maternal plasma n-6 LC-PUFA dihomo-gammalinolenic acid (DGLA) concentrations have an anti-inflammatory effect, and high n-6 LC-PUFA arachidonic acid (AA) concentrations are associated with reduced fetal growth (van Eijsden et al., 2008).

In addition, antenatal maternal vitamin D deficiency is associated with a risk of preeclampsia (Bodnar et al., 2007a), small for gestational age (Leffelaar et al., 2010), gestational diabetes mellitus (Zhang et al., 2015), and preterm birth (Bodnar et al., 2010). A previous study conducted in the United States suggested that prepregnancy obesity is a risk factor for vitamin D deficiency (Bodnar et al., 2007b). In contrast, maternal hypovitaminosis D has recently been reported in Asian countries (Choi et al., 2015; Shiraishi et al., 2014), and a lower prepregnancy BMI is related with a higher risk of vitamin D deficiency during pregnancy (Pratumvinit et al., 2015).

Despite the necessity of nutritional assessment and dietary counseling during pregnancy, there are few studies of the effect of individual dietary counseling, based on nutritional assessment. The

purpose of this study was to determine the effect of an individualized dietary intervention, based on nutritional assessment, for pregnant women on nutritional status and infant birth weight.

2 | PARTICIPANTS AND METHODS

2.1 | Participants and setting

This double cohort study included healthy pregnant women aged ≥20 years at an antenatal clinic in a university hospital in Tokyo, Japan. The exclusion criteria were multiple pregnancies, diabetes, hypertension, psychiatric diseases, and inability to speak Japanese.

The recruitment occurred in two phases over 2 years. The control group was recruited between May 2010 and November 2010 and received usual care, including provision of general information by midwives about a healthy diet, exercise, and appropriate weight gain during pregnancy. The data for the historical controls were analyzed a year prior to the intervention group. The intervention group was recruited between June 2011 and June 2012 and received tailored dietary guidance by the researchers based on baseline dietary assessments in addition to usual care.

Ultrasonography was performed for all pregnant women to determine accurate gestational dating at 8–12 weeks gestation. Baseline data were collected at 19–26 weeks gestation, and the outcome variables were collected at 34–37 weeks gestation.

The Ethical Committee of the Graduate School of Medicine, the University of Tokyo, approved the study procedures and protocol. The study was registered with the University Hospital Medical Information Network Clinical Trial Registration: UMIN000008573. All participants provided informed written consent prior to the baseline assessments.

2.2 | Dietary assessment

Dietary nutritional intake was assessed at baseline and the outcome measurement. Participants answered the brief-type, self-administered diet history questionnaire (BDHQ), which is a four-page fixed-portion questionnaire that assesses habitual dietary intake over the previous month based on the reported consumption of 58 food and beverage items. The relative validity of the estimation of energy and nutrient intakes using the BDHQ was determined using semi-weighed 16-day dietary records as reference in adult Japanese populations. For energy-adjusted nutrients using the density method, the median corre-

Key messages

- The tailored maternal dietary guidance based on nutritional assessment for low-risk pregnant women significantly improved their gestational weight gain and nutritional status including plasma eicosapentaenoic acid, docosahexaenoic acid, dihomo-gammalinolenic acid, and arachidonic acid concentrations.
- The results did not indicate a significant effect of the dietary guidance during pregnancy on maternal dietary nutrient intake.
- In addition, there was no association between dietary guidance during pregnancy and infant birth weight.
- Future research should include a randomized controlled trial.

lation coefficient for women was 0.49 (0.38–0.57) using the BDHQ (Kobayashi et al., 2011, 2012).

We excluded unrealistic data for energy intake, defined as reporting <50% of the energy requirement for the lowest category of physical activity or >1.5 times the energy requirement for the moderate category of physical activity, with reference to the Dietary Reference Intakes for Japanese. The intakes of protein, fat, polyunsaturated fat, EPA, DHA, cholesterol, carbohydrate, vitamin D, α -tocopherol, folate, vitamin C, sodium, potassium, calcium, and iron were adjusted for energy intake.

2.3 | Intervention

The intervention, which was conducted during the second trimester, provided tailored dietary guidance based on the Health Belief Model (HBM; Rosenstock et al., 1988; Janz & Becker, 1984). The major theoretical constructs of HBM are perceived severity, perceived susceptibility, perceived benefits, perceived barriers, and self-efficacy. Each of the individual's perceptions can be related to health behaviors, independently or in combination (Champion & Skinner, 2008).

Using the self-reported nutrient intake from the BDHQ, we determined the nutrients for which intake was inadequate for each individual. Then, we provided information about the risks of nutritional inadequacy and benefits of dietary improvement and provided recommended recipe cards to compensate for the inadequate nutrients in the following five steps: (a) assessment of maternal dietary nutritional intake using the BDHQ; (b) individualized feedback regarding the results of the maternal dietary nutritional assessment, with reference to the "Dietary Reference Intakes for Japanese 2010" issued by the Minister of Health, Labour and Welfare; (c) tailored nutrition and dietary guidance with written educational materials including information of the health risks associated with a lack of nutrition and the health benefits related to a healthy diet; (d) provision of original quick and easy recipes that aimed to compensate for inadequate nutrients, decrease the barriers against health action, and encourage healthy cooking; and (e) discussion of the participant's goals and the feasibility of achieving these goals. We provided the intervention once per person during the study period.

2.4 | Outcome variables

The primary outcome measures were maternal dietary nutrient intake, collected using the BDHQ; serum and plasma nutrient concentrations; and blood count including hemoglobin (Hb), mean corpuscular volume, and mean corpuscular hemoglobin.

Non-fasting blood samples were collected at the same time as routine blood tests during the prenatal health checkup. The blood samples were centrifuged at 3,000 rpm for 10 min, and the separated serum and plasma samples were stored at -80°C until analysis. The samples were measured within 6 months after collection. Serum total cholesterol level was measured using an enzymatic method. Serum high-density lipoprotein and low-density lipoprotein concentrations were measured using an enzymatic direct assay. Plasma EPA, DHA, and AA levels were measured using gas chromatography. Serum folate levels were measured using a chemiluminescent enzyme immunoassay.

These biochemical markers were assayed at an external laboratory (Mitsubishi Kagaku Bio-Chemical Laboratories, Tokyo, Japan). Levels of total 25-hydroxyvitamin D (25(OH)D) were measured using a chemiluminescent immunoassay (LIAISON 25 OH Vitamin D Total Assay; Diasorin, Saluggia, Italy) at Kyowa Medex Co., Ltd., Tokyo, Japan. We used Hb and Ht data from routine examinations at the hospital.

The secondary outcomes were maternal dietary intention and self-reported supplementation, as collected from the questionnaire, and prescribed iron preparation to treat iron deficiency anemia (based on Hb levels), gestational weight gain, infant birth weight, and rate of LBW (weight at birth <2,500 g), as collected from hospital medical records. In the questionnaire, we asked about maternal dietary intention using multiple choice questions and obtained self-reported information about regular supplementation. The information regarding prescribed iron preparations to treat iron deficiency anemia, maternal Hb levels, gestational weight gain, and infant birth weight was collected from hospital medical records. Maternal weight was measured using a calibrated digital weight scale at every prenatal checkup; therefore, self-reporting bias was minimized. Gestational weight gain was calculated based on the weight difference between pre-pregnancy weight and the weight at outcome measurement.

2.5 | Sample size estimation and statistical analysis

We hypothesized that maternal circulating nutrient concentrations would most likely change after the intervention, and a total sample size of 196 women was estimated for an expected effect size of 0.25 and power of 0.8, at an α of .05. Maternal dietary nutrient intakes were also evaluated as intervention outcomes. A total sample size of 320 women was estimated for an expected effect size of 0.3 and power of 0.8, at an α of .05. These statistical power analyses were conducted using G-Power version 3.1 (Faul et al., 2007). To account for possible dropouts, we aimed to recruit 400 women for the study.

We calculated the descriptive statistics, including means and standard deviations of quantitative variables and proportions of categorical variables, for all baseline variables. Unpaired *t* test and chi-square test were used to compare the control and intervention groups at baseline. At 34–37 weeks gestation, we compared the differences in maternal dietary nutrient intake and maternal serum or plasma nutrient concentrations between the two groups using Mann–Whitney *U* test. To account for seasonal variations, serum 25(OH)D levels were assessed using autumn–winter survey data. Infant birth weight and the rate of LBW infants were compared between the two groups using unpaired *t* test and chi-square test, respectively. All differences with a two-sided *p*-value < .05 were considered statistically significant. We performed the statistical analyses using SPSS v20.0® (IBM Corp, Armonk, NY, USA).

3 | RESULTS

3.1 | Participant characteristics

Of the 378 healthy pregnant women who were eligible during the 2-year recruitment period, 192 pregnant women were recruited during the first phase, and four women were excluded (declined: $n = 1$;

missing data: $n = 3$), resulting in 188 women in the control group for whom baseline data were collected (Figure 1). Of these women in the control group, 25 women were not followed until the outcome measurement (withdrew: $n = 7$; changed hospital: $n = 10$; preterm birth: $n = 4$; abortion: $n = 1$; declined: $n = 1$; missing data: $n = 2$). The remaining 186 pregnant women were recruited during the second phase, and eight women were excluded (declined: $n = 1$; missing data: $n = 7$), resulting in 178 women in the intervention group for whom baseline data were collected. Of these women in the intervention group, 32 women were not followed until the outcome measurement (withdrew: $n = 7$; changed hospital: $n = 9$; preterm birth: $n = 6$; abortion: $n = 1$; pregnancy-induced hypertension: $n = 2$; diabetes mellitus: $n = 1$; declined: $n = 3$; missing data: $n = 3$). The questionnaire was completed at 34–37 weeks gestation by 163 women in the control group and 146 women in the intervention group. A total of 202 blood samples was collected and analyzed for 134 women in the control group and 68 women in the intervention group. Recruitment for the intervention group lasted approximately 1 year, which was twice as long as that of the control group because of an insufficient number of researchers. There was no significant difference in demographic data between the women who provided blood samples and those who did not. At baseline, the intervention and control groups were similar with respect to sociodemographic characteristics (Table 1).

3.2 | Maternal dietary intention and supplementation

Maternal dietary intention and supplementation at 34–37 gestational weeks are shown in Table 2. Compared with the women in the control group, significantly more women in the intervention group reported “Avoiding too much salt” (intervention vs. control; 54.0 vs. 41.7%, $p = .029$). There were no significant differences between the groups

for the other dietary intentions. The proportion of women supplementing with iron, calcium, EPA, DHA, or folate did not differ significantly between the groups.

3.3 | Maternal dietary intake

The maternal energy-adjusted nutrient intakes were not significantly different between the two groups at 34–37 gestational weeks, except for n -3 polyunsaturated fat (% energy) and vitamin C (mg/1,000 kcal), which were significantly lower in the intervention group than in the control group (median: 1.21 vs. 1.27% energy, $p = .034$; 68.1 vs. 74.5 mg/1,000 kcal, $p = .025$, respectively; Table 3). The change in total energy intake was significantly lower in the intervention group than in the control group (−34.0 vs. 49.7 kcal/day, $p = .049$). In contrast, the change in protein intake was significantly greater in the intervention group than in the control group (0.62 vs. 0.05% energy, $p = .030$; Table 3). Changes between the two groups in other nutrient intakes from baseline to outcome measurement were not significantly different.

3.4 | Maternal plasma or serum nutrient concentrations

The maternal nutrient concentrations were measured at 19–26 gestational weeks and 34–37 gestational weeks (Table 4). The median plasma EPA, DHA, DGLA, and AA concentrations were significantly higher in the intervention group than in the control group (median: 35.0 vs. 25.0 $\mu\text{g/ml}$, $p = .002$; 177.0 vs. 135.0 $\mu\text{g/ml}$, $p < .001$; 65.0 vs. 50.0 $\mu\text{g/ml}$, $p < .001$; 255.0 vs. 164.0 $\mu\text{g/ml}$, $p < .001$, respectively). Changes in plasma EPA, DHA, and AA concentrations from baseline to outcome measurement were also significantly greater in the intervention group than in the control group (median: 8.0 vs. 1.0 $\mu\text{g/ml}$,

FIGURE 1 Flow diagram of participants in the study

TABLE 1 Characteristics of participants at baseline

	Intervention ^a n = 146	Control n = 163	p
Age (years)	34.7 ± 4.3	34.8 ± 4.0	.741
Pre-pregnancy BMI (kg/m ²)	21.0 ± 3.2	20.4 ± 2.2	.060
Under weight: BMI < 18.5	25 (17.1%)	25 (15.3%)	.121
Normal: 18.5 ≤ BMI < 25.0	104 (71.2%)	129 (79.1%)	
Overweight: 25 ≤ BMI	17 (11.6%)	9 (5.5%)	
Parity			
Primipara	88 (60.3%)	97 (59.5%)	.833
Education			
High school and below	8 (5.5%)	13 (8.0%)	.232
College and above	138 (94.5%)	150 (92.0%)	
Annual income (Yen)			
Less than 5 million	22 (15.1%)	28 (17.2%)	.811
5–7 million	34 (23.3%)	34 (20.9%)	
More than 7 million	90 (61.6%)	101 (62.0%)	
Worker	71 (48.6%)	86 (52.8%)	.495

Note. Unpaired student's t test or chi-square test.

BMI = body mass index.

^aThe dietary intervention was provided in the second trimester.

TABLE 2 Maternal dietary intention and supplementations at outcome measurement

	Outcome measurement ^b Intervention ^a n = 146	Control n = 163	p
	n (%)		
Dietary intentions			
Having well-balanced diet	85 (58.2%)	96 (58.9%)	.904
Eating more fishes	26 (17.8%)	20 (12.3%)	.172
Eating more vegetables	87 (59.6%)	89 (54.6%)	.377
Avoiding too much salt	79 (54.0%)	68 (41.7%)	.029
Avoiding too much high-sugar foods	36 (24.7%)	40 (24.5%)	.981
Supplementations			
Prescription iron supplements for anemia	17 (11.6%)	31 (19.0%)	.071
Calcium supplements at least 4 days/week	13 (8.9%)	9 (5.5%)	.255
EPA and DHA supplements at least 4 days/week	8 (5.5%)	4 (2.5%)	.239
Folate supplements at least 4 days/week	42 (28.8%)	54 (33.1%)	.455

Note. Chi-square test.

DHA = docosahexaenoic acid; EPA = eicosapentaenoic acid.

^aThe dietary intervention was provided in the second trimester.

^bOutcomes measurement: the third trimester (34–37 gestational weeks).

$p = .006$; 35.0 vs. 15.0 $\mu\text{g/ml}$, $p < .001$; 53.0 vs. 16.0 $\mu\text{g/ml}$, $p < .001$, respectively). Although serum 25(OH)D concentrations in the autumn–winter survey sample were not significantly different between the two groups, the change in serum 25(OH)D concentrations was significantly lower in the control group than in the intervention group (-0.1 vs. -3.3 ng/ml, $p < .001$). Serum folate concentration was significantly lower in the intervention group than in the control group (6.2 vs. 7.1 ng/ml, $p = .031$) at outcome measurement. The

serum folate concentration at baseline was also significantly lower in the intervention group than in the control group (median [interquartile]; 7.4 [5.6, 11.0] vs. 10.2 [5.3, 13.9] ng/ml, $p = .001$, data not shown in Table 4). However, the changes in serum folate concentrations from baseline to the time of outcome measurement in the two groups were not significantly different (-0.8 vs. -1.8 ng/ml, $p = .060$). The other nutrients and biochemical data did not show any significant differences between the groups.

TABLE 3 Maternal dietary nutrient intake in the intervention and control groups

	Outcome measurement ^b			Changes in nutrient intake from baseline to outcome measurement ^b		
	Intervention ^a n = 146	Control n = 163	p	Intervention ^a n = 146	Control n = 163	p
	Median (interquartile range)			Median (interquartile range)		
Energy (kcal/day)	1,487.1 (1,322.4, 1,744.4)	1,491.9 (1,304.5, 1,807.4)	.711	-34.0 (-236.8, 185.5)	49.7 (-151.8, 237.5)	.049
Protein (% energy)	15.0 (13.7, 16.8)	15.0 (14.0, 16.5)	.978	0.62 (-0.87, 2.10)	0.05 (-1.16, 1.45)	.030
Fat (% energy)	29.0 (25.9, 32.4)	29.1 (26.5, 32.0)	.948	0.31 (-3.22, 3.15)	0.63 (-2.22, 3.25)	.431
Polyunsaturated fat (% energy)	6.72 (5.95, 7.53)	6.73 (5.96, 7.77)	.222	0.07 (-0.75, 0.83)	0.14 (-0.53, 0.94)	.151
n-3 polyunsaturated fat (% energy)	1.21 (1.04, 1.38)	1.27 (1.10, 1.45)	.034	0.02 (-0.19, 0.25)	0.05 (-0.12, 0.23)	.419
EPA (% energy)	0.10 (0.07, 0.15)	0.11 (0.08, 0.15)	.237	0.006 (-0.03, 0.05)	-0.003 (-0.04, 0.04)	.312
DHA (% energy)	0.18 (0.14, 0.26)	0.20 (0.15, 0.26)	.352	0.01 (-0.05, 0.08)	-0.01 (-0.06, 0.07)	.180
n-6 polyunsaturated fat (% energy)	5.49 (4.74, 6.06)	5.45 (4.80, 6.34)	.358	-0.06 (-0.66, 0.59)	0.09 (-0.45, 0.80)	.072
Cholesterols (mg/1,000 kcal)	206.2 (177.2, 251.7)	202.1 (176.3, 238.0)	.355	111.5 (-20.0, 55.3)	4.58 (-24.5, 41.5)	.278
Carbohydrate (% energy)	54.6 (50.6, 59.2)	55.4 (51.6, 58.1)	.857	-0.76 (-4.71, 2.97)	-0.69 (-4.11, 2.82)	.893
Vitamin D (μg/1,000 kcal)	5.25 (3.75, 7.82)	5.44 (3.89, 7.29)	.443	0.53 (-1.54, 1.77)	0.13 (-1.2, 1.9)	.594
α-Tocopherol (mg/1,000 kcal)	4.49 (3.96, 5.10)	4.60 (4.01, 5.16)	.461	0.04 (-0.49, 0.63)	0.08 (-0.46, 0.57)	.508
Folate (μg/1,000 kcal)	185.0 (147.7, 230.6)	197.2 (158.1, 237.6)	.181	6.05 (-34.5, 44.1)	7.47 (-27.3, 38.0)	.628
Vitamin C (mg/1,000 kcal)	68.1 (50.7, 89.3)	74.5 (59.1, 88.5)	.025	-1.20 (-20.9, 17.8)	2.22 (-11.8, 21.8)	.092
Sodium (mg/1,000 kcal)	2,120.8 (1,949.6, 2,446.5)	2,231.2 (1,958.9, 2,514.1)	.099	-47.5 (-342.6, 249.7)	-82.0 (-336.5, 168.7)	.530
Potassium (mg/1,000 kcal)	1,477.4 (1,216.3, 1,697.5)	1,486.0 (1,273.4, 1,667.9)	.710	63.2 (-194.3, 260.7)	23.1 (-171.9, 213.3)	.279
Calcium (mg/1,000 kcal)	327.2 (269.8, 386.5)	330.0 (263.7, 380.7)	.827	13.4 (-34.3, 58.5)	1.87 (-39.3, 59.1)	.502
Iron (mg/1,000 kcal)	4.27 (3.70, 4.91)	4.28 (3.81, 4.99)	.425	0.05 (-0.56, 0.67)	0.03 (-0.51, 0.57)	.593

Note. Maternal energy and nutrition intakes were estimated by the brief-type self-administered diet history questionnaire.

Mann-Whitney *U* test: analysis of differences between the groups.

DHA = docosahexaenoic acid; EPA = eicosapentaenoic acid.

^aThe dietary intervention was provided in the second trimester.

^bBaseline measurement: the second trimester (19–26 gestational weeks); outcome measurement: the third trimester (34–37 gestational weeks).

3.5 | Gestational weight gain and infant birth weight

Daily average weight gain was also higher in the intervention group than in the control group. Despite significantly higher gestational weight gain in the intervention group, average birth weight and rate of LBW infants were not significantly different between the groups (Table 5).

4 | DISCUSSION

This study demonstrated the effect of tailored dietary guidance based on nutritional assessment for low-risk pregnant women on improvements in nutritional status, including plasma EPA, DHA, DGLA, and AA concentrations. A significantly greater proportion of the intervention group reported some of the maternal dietary intentions such as “Avoiding too much salt” than the control group. However, there were no significant improvements in dietary nutrient intake and infant birth weight between the groups. Despite the limited effect, this unique

dietary intervention based on individual nutrition evaluation and guidance is the first known trial for healthy pregnant women in Japan.

Although pregnancy represents a good opportunity to improve dietary intake, most pregnant women do not improve their food and nutrient intake or lifestyle (Lundqvist et al., 2014). Typical dietary guidance is generally provided to pregnant women without an individual nutrient assessment, resulting in guidance that is not specific or idiographic. We focused on individual dietary nutrition assessment and provided individualized guidance to encourage pregnant women to improve their dietary behavior.

In the intervention group, plasma EPA, DHA, DGLA, and AA concentrations were significantly higher than in the control group. During the intervention, we provided guidance regarding “A well-balanced diet contains adequate carbohydrate, protein, and fat” and “Desirable food choices.” In particular, fish are dietary sources of desirable micronutrients such as EPA and DHA. However, neither the reported intentions to “eat more fish” nor the intakes of EPA and DHA were significantly different between the two groups. Increased plasma AA concentrations might be the result of choosing protein-rich foods;

TABLE 4 Maternal circulating nutrient concentrations, blood count in the intervention, and control groups

	Outcome measurement ^b			Changes in nutrient intake from baseline to outcome measurement ^b		
	Intervention ^a n = 68	Control n = 134	p	Intervention ^a n = 68	Control n = 134	p
	Median (interquartile range)			Median (interquartile range)		
Total cholesterol (mg/dl)	280.5 (250.0, 316.3)	292.0 (261.0, 319.8)	.229	60.0 (44.3, 80.8)	62.5 (43.0, 85.3)	.982
HDL (mg/dl)	80.5 (70.0, 90.0)	83.0 (75.0, 94.0)	.119	-0.5 (-8.0, 6.8)	-1.0 (-7.3, 6.0)	.598
LDL (mg/dl)	157.5 (133.3, 196.8)	163.0 (143.0, 192.0)	.373	70.0 (47.3, 107.5)	81.0 (54.5, 108.3)	.827
EPA (μg/ml)	35.0 (23.0, 59.0)	25.0 (16.0, 41.0)	.002	8.0 (-2.0, 28.0)	1.0 (-9.8, 13.6)	.006
DHA (μg/ml)	177.0 (143.0, 226.0)	135.0 (117.0, 164.5)	<.001	35.0 (8.0, 72.0)	15.0 (-2.8, 39.0)	<.001
DGLA (μg/ml)	65.0 (54.0, 76.0)	50.0 (39.5, 65.0)	<.001	15.0 (5.0, 20.0)	11.5 (6.0, 18.8)	.125
AA (μg/ml)	255.0 (206.0, 282.0)	164.0 (135.0, 193.0)	<.001	53.0 (28.0, 67.0)	16.0 (-4.5, 32.0)	<.001
EPA/AA	0.14 (0.10, 0.23)	0.16 (0.10, 0.24)	.521	0.01 (-0.03, 0.06)	-0.01 (-0.07, 0.06)	.176
25(OH)D (ng/ml) ^c	7.7 (5.2, 11.2)	7.6 (5.8, 11.1)	.703	-0.1 (-3.1, 2.9)	-3.3 (-5.8, -0.8)	<.001
Folate (ng/ml)	6.2 (4.1, 10.3)	7.1 (5.2, 11.7)	.031	-0.8 (-2.7, 0.3)	-1.8 (-4.9, 0.3)	.060
Hb (g/dl)	11.3 (10.8, 11.9)	11.1 (10.5, 11.6)	.167	-0.10 (-0.50, 0.58)	0.00 (-0.95, 0.60)	.619
MCV (fL)	90.2 (86.9, 93.1)	89.5 (85.9, 92.9)	.524	-1.6 (-3.9, 0.6)	-2.5 (-4.2, -0.1)	.113
MCH (pg)	28.9 (27.5, 30.2)	29.0 (27.5, 30.4)	.768	-1.7 (-2.6, -0.8)	-1.3 (-2.3, -0.4)	.051

Note. Mann-Whitney U test: analysis of differences between the groups.

AA = arachidonic acid; CI = confidence interval; DGLA = dihomo-gamma-linolenic acid; DHA = docosahexaenoic acid; EPA = eicosapentaenoic acid; Hb = hemoglobin; HDL = high-density lipoprotein; LDL = low-density lipoprotein; MCH = mean corpuscular hemoglobin; MCV = mean corpuscular volume; 25(OH)D = 25-hydroxy vitamin D.

^aThe dietary intervention was provided in the second trimester.

^bBaseline measurement: the second trimester (19–26 gestational weeks); outcome measurement: the third trimester (34–37 gestational weeks).

^cTo account for seasonal variations, serum 25(OH)D levels were assessed using autumn–winter survey data.

TABLE 5 Gestational weight gain, infant birth weight

	Intervention ^a n = 146	Control n = 163	p
Gestational weight ^b gain (kg)	8.7 ± 3.5	7.8 ± 3.2	.019
Gestational weight gain (g/day)	34.5 ± 13.8	31.0 ± 12.6	.025
Birth weight (g)	2,986.4 ± 405.1	3,030.8 ± 385.3	.333
Rate of low birth weight ^c infant (%)	12 (8.3%)	14 (9.1%)	.840

Note. Unpaired student's t test or chi-square test.

^aThe dietary intervention was provided in the second trimester.

^bMaternal weight was measured at the outcome measurement (34–37 gestational weeks).

^cLow birth weight is defined as weight at birth of less than 2,500 g.

however, the direct effect of the guidance on the participants' dietary intention and behavior could not be observed. Increased plasma DGLA might be a consequence of metabolism, with increased linoleic acid intake (van Eijdsen et al., 2008). The change in energy-adjusted protein intake was significantly higher in the intervention group. Therefore, dietary interventions might successfully influence changes in dietary protein intake.

There is some discrepancy between the maternal dietary intake and circulating nutrient levels in the present study. In particular, there was no significant difference in maternal dietary EPA and DHA intakes between the groups, while plasma EPA and DHA levels were significantly higher in the intervention group. Regarding the use of the

BDHQ, our previous validation study suggested that BDHQ has acceptable validity for assessing EPA and DHA intakes among Japanese women in the second and third trimesters (Shiraishi et al., 2015). Despite Spearman's correlation coefficients of .391 and .316 for the relationships between BDHQ-estimated, energy-adjusted EPA and DHA intakes and the corresponding plasma concentrations in the third trimester, respectively (Shiraishi et al., 2015), the strength of the relationship might be not sufficient to achieve the desired measurement accuracy.

Dietary nutrient intakes in the intervention group were relatively low compared with those in the control group, and the energy-adjusted n-3 polyunsaturated fat and vitamin C intakes were significantly lower in the intervention group at outcome measurement; the reasons for this are unknown. Despite significantly higher maternal weight gain in the intervention group than in the control group, there was no difference in energy intakes between the groups. Moreover, the decrease in energy intake from baseline to outcome measurement in the intervention group was significantly greater than that in the control group ($p = .049$). The self-reported dietary intake might have resulted in underestimation of intake in the group who received the dietary intervention.

Dietary behavior modification is difficult. The dietary intervention in the present study was based on the HBM, which is one of the most widely used health behavior theories in health research (Carpenter, 2010). HBM suggests that a person's course of action often depends on the individual's perceptions of the benefits and barriers related to a health behavior. Despite the fact that the intervention was based on individualized nutrient inadequacies and provision of information,

changes to dietary intentions were limited. For example, we discussed the risk of iron deficiency anemia based on a poor iron intake; however, a similar proportion of the intervention group reported the intention for dietary iron intake as the control group. The potential risk of a nutrient deficiency might be difficult to perceive as severe or increasing the susceptibility to health risk among healthy pregnant women.

Although the BDHQ is considered valid to measure food group (Kobayashi et al., 2011) and nutrient (Kobayashi et al., 2012) intake, portion sizes for each food item are not collected in the questionnaire. This might have affected the ability to detect significant changes in dietary intake of nutrients that were inadequate at baseline. For example, increases in portion size and minor changes in dietary intake might not have been detected.

The effect of dietary counseling during pregnancy is controversial. A previous meta-analysis of 15 trials ($n = 3,287$) reported no effect of dietary counseling on birth weight, despite a significant increase in birth weight in three of the trials (Gresham et al., 2016) that provided nutritional recommendations to low-income women during pregnancy (Briley et al., 2002), dietary guidance for nutrient intake based on national recommendations for obese women (Vinter et al., 2014), and guidance to increase dietary intake among adolescent mothers (Chan et al., 2006). However, owing to the heterogeneous nature of the participants and interventions in previous trials, it is difficult to identify the most effective intervention.

There are several limitations that should be considered when interpreting the present findings. First, this pragmatic double cohort study did not adjust for all potential confounding factors. The Great East Japan Earthquake occurred in March 2011. Although the effect of the earthquake impaired daily life for several weeks, the study period did not include the 3-month period after the earthquake; therefore, overall changes in diet in the study area in the year between the analyses of the control and intervention groups are unlikely. Second, we assessed dietary intakes using the BDHQ. The brief food frequency questionnaire (FFQ) might not be sensitive enough to change to detect a significant difference in a small sample size. In addition, more objective and accurate measurements would be less prone to reporting bias. Third, participants were recruited only at a university hospital, limiting the ability to generalize the results to other populations. The number of women in the intervention group with a blood sample was very low, even relative to that in the control group. We collected blood specimens during routine blood sampling in the prenatal checkup in the outpatient department, and we did not request additional blood samples if a blood specimen was not obtained at this time partially because it is hard to collect blood specimens in the clinical setting. Fourth, the intervention included dietary guidance to improve micronutrient intake but did not consider supplementation and fortified food products. Fifth, because the women only met with the researchers once, insufficient intervention length could have resulted in an inability to find a significant difference. Last, we assessed nutrients from non-fasting blood samples, which could be affected by diet. Therefore, future research should be conducted considering these effects, including randomized controlled trials with regular contact. Although this tailored maternal dietary guidance has great potential for future maternal health promotion, it requires time and manpower. Automatic dietary assessment using information and

communications technology might be needed to improve the feasibility of upscaling this type of dietary intervention.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

Study conception and design were performed by MH and MS. Acquisition of data was performed by MH, MS, MM, and YY. Analysis and interpretation of data were performed by MH, MS, and MM. Drafting of manuscript was performed by MH, MS, MM, and SY. Critical revision was performed by MH, MS, MM, and SY.

REFERENCES

- Abu-Saad, K., & Fraser, D. (2010). Maternal nutrition and birth outcomes. *Epidemiologic Reviews*, 32, 5–25.
- Belkacemi, L., Nelson, D. M., Desai, M., & Ross, M. G. (2010). Maternal undernutrition influences placental-fetal development. *Biology of Reproduction*, 83, 325–331.
- Bodnar, L. M., Catov, J. M., Roberts, J. M., & Simhan, H. N. (2007b). Prepregnancy obesity predicts poor vitamin D status in mothers and their neonates. *The Journal of Nutrition*, 137, 2437–2442.
- Bodnar, L. M., Catov, J. M., Simhan, H. N., Holick, M. F., Powers, R. W., & Roberts, J. M. (2007a). Maternal vitamin D deficiency increases the risk of preeclampsia. *The Journal of Clinical Endocrinology and Metabolism*, 92, 3517–3522.
- Bodnar, L. M., Catov, J. M., Zmuda, J. M., Cooper, M. E., Parrott, M. S., Roberts, J. M., ... Simhan, H. N. (2010). Maternal serum 25-hydroxyvitamin D concentrations are associated with small-for-gestational age births in white women. *The Journal of Nutrition*, 140, 999–1006.
- Briley, C., Flanagan, N. L., & Lewis, N. (2002). In-home prenatal nutrition intervention increased dietary iron intakes and reduced low birthweight in low-income African-American women. *Journal of the American Dietetic Association*, 102, 984–987.
- Canani, R. B., Costanzo, M. D., Leone, L., Bedogni, G., Brambilla, P., Cianfarani, S., ... Agostoni, C. (2011). Epigenetic mechanisms elicited by nutrition in early life. *Nutrition Research Reviews*, 24, 198–205.
- Carpenter, C. J. (2010). A meta-analysis of the effectiveness of health belief model variables in predicting behavior. *Health Communication*, 25, 661–669.
- Champion, V. L., & Skinner, C. S. (2008). The health belief model. In K. Glanz, B. K. Rimer, & K. Viswanath (Eds.), *In: Health behavior and health education. Theory, research, and practice* (4th ed.). (pp. 45–65). San Francisco, CA: John Wiley and Sons, Inc.

- Chan, G. M., McElligott, K., McNaught, T., & Gill, G. (2006). Effects of dietary calcium intervention on adolescent mothers and newborns: A randomized controlled trial. *Obstetrics & Gynecology*, 108, 565–571.
- Choi, R., Kim, S., Yoo, H., Cho, Y. Y., Kim, S. W., Chung, J. H., et al. (2015). High prevalence of vitamin D deficiency in pregnant Korean women: The first trimester and the winter season as risk factors for vitamin D deficiency. *Nutrition*, 7, 3427–3448.
- Chong, M. F., Ong, Y. L., Calder, P. C., Colega, M., Wong, J. X., Tan, C. S., et al. (2015). Long-chain polyunsaturated fatty acid status during pregnancy and maternal mental health in pregnancy and the postpartum period: Results from the GUSTO study. *The Journal of Clinical Psychiatry*, 76, e848–e856.
- Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–191.
- Gresham, E., Bisquera, A., Byles, J. E., & Hure, A. J. (2016). Effects of dietary interventions on pregnancy outcomes: A systematic review and meta-analysis. *Maternal & Child Nutrition*, 12, 5–23.
- Janz, N. K., & Becker, M. H. (1984). The health belief model: A decade later. *Health Education Quarterly*, 11, 1–47.
- Kobayashi, S., Honda, S., Murakami, K., Sasaki, S., Okubo, H., Hirota, N., et al. (2012). Both comprehensive and brief self-administered diet history questionnaires satisfactorily rank nutrient intakes in Japanese adults. *Journal of Epidemiology*, 22, 151–159.
- Kobayashi, S., Murakami, K., Sasaki, S., Okubo, H., Hirota, N., Notsu, A., et al. (2011). Comparison of relative validity of food group intakes estimated by comprehensive and brief-type self-administered diet history questionnaires against 16 d dietary records in Japanese adults. *Public Health Nutrition*, 14, 1200–1211.
- Leffelaar, E. R., Vrijkotte, T. G., & van Eijdsen, M. (2010). Maternal early pregnancy vitamin D status in relation to fetal and neonatal growth: Results of the multi-ethnic Amsterdam born children and their development cohort. *The British Journal of Nutrition*, 104, 108–117.
- Lundqvist, A., Johansson, I., Wennberg, A., Hultdin, J., Högberg, U., Hamberg, K., & Sandström, H. (2014). Reported dietary intake in early pregnant compared to non-pregnant women—a cross-sectional study. *BMC Pregnancy and Childbirth*, 14, 373.
- Mathews, F., Yudkin, P., & Neil, A. (1999). Influence of maternal nutrition on outcome of pregnancy: Prospective cohort study. *BMJ*, 319, 339–343.
- Ministry of Health, Labour and Welfare. (2006). Dietary guidelines for pregnant and postpartum women. <http://www.mhlw.go.jp/houdou/2006/02/h0201-3a.html> (Accessed 10 November 2016).
- Ministry of Health, Labour and Welfare. (2013a). Summary of National Health and Nutrition Survey. <http://www.mhlw.go.jp/file/04-Houdouhappyou-10904750-Kenkoukyoku-Gantaisakukenkouyoushin-ka/0000106403.pdf> (Accessed 10 November 2016).
- Ministry of Health, Labour and Welfare. (2013b). Statistical survey of vital statistics 2013. <http://www.mhlw.go.jp/toukei/list/dl/81-1a2.pdf> (Accessed 10 November 2016).
- Ministry of Health, Labour and Welfare. (2015). Overview of dietary reference intakes for Japanese (2015): DRIs for folic acid <http://www.mhlw.go.jp/file/06-Seisakujouhou-10900000-Kenkoukyoku/Overview.pdf> (Accessed 10 November 2016).
- Pratumnit, B., Wongkrajang, P., Wataganara, T., Hanyongyuth, S., Nimmannit, A., Chatsiricharoenkul, S., ... Reesukumal, K. (2015). Maternal vitamin D status and its related factors in pregnant women in Bangkok, Thailand. *PloS One*, 10, e0131126.
- Rosenstock, I. M., Strecher, V. J., & Becker, M. H. (1988). Social learning theory and the health belief model. *Health Education Quarterly*, 15, 175–183.
- Shiraishi, M., Haruna, M., Matsuzaki, M., & Murayama, R. (2014). Demographic and lifestyle factors associated with vitamin D status in pregnant Japanese women. *Journal of Nutritional Science and Vitaminology*, 60, 420–428.
- Shiraishi, M., Haruna, M., Matsuzaki, M., Murayama, R., & Sasaki, S. (2015). The biomarker-based validity of a brief-type diet history questionnaire for estimating eicosapentaenoic acid and docosahexaenoic acid intakes in pregnant Japanese women. *Asia Pacific Journal of Clinical Nutrition*, 24, 316–322.
- Swanson, D., Block, R., & Mousa, S. A. (2012). Omega-3 fatty acids EPA and DHA: Health benefits throughout life. *Advances in Nutrition*, 3, 1–7.
- van Eijdsen, M., Hornstra, G., van der Wal, M. F., Vrijkotte, T. G., & Bonsel, G. J. (2008). Maternal n-3, n-6, and trans fatty acid profile early in pregnancy and term birth weight: A prospective cohort study. *The American Journal of Clinical Nutrition*, 87, 887–895.
- Vinter, C. A., Jensen, D. M., Ovesen, P., Beck-Nielsen, H., Tanvig, M., Lamont, R. F., & Jørgensen, J. S. (2014). Postpartum weight retention and breastfeeding among obese women from the randomized controlled lifestyle in pregnancy (LiP) trial. *Acta Obstetrica et Gynecologica Scandinavica*, 93, 794–801.
- World Health Organization. (2009). Country comparison—BMI Females % underweight (<18.5), Most recent. <http://apps.who.int/bmi/index.jsp> (Accessed 10 November 2016).
- Wu, G., Imhoff-Kunsch, B., & Girard, A. W. (2012). Biological mechanisms for nutritional regulation of maternal health and fetal development. *Paediatric and Perinatal Epidemiology*, 26, 4–26.
- Zhang, M. X., Pan, G. T., Guo, J. F., Li, B. Y., Qin, L. Q., & Zhang, Z. L. (2015). Vitamin D deficiency increases the risk of gestational diabetes mellitus: A meta-analysis of observational studies. *Nutrition*, 7, 8366–8375.

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