Physiological and nutritional intake characteristics of pregnant women according to their recommended gestational weight gain in relation to the birth weight of their full-term infants

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ABSTRACT

The purpose of the present study was to elucidate the relationship between the physiological characteristics and nutritional intake of pregnant women and the birth weight of their full-term infants. The women had been recommended a certain gestational weight gain according to their body mass index (BMI) classification. We surveyed 477 pregnant women who provided their consent to participate in the study at three hospitals and one clinic in Okinawa. We performed prenatal check-ups during the second and third trimesters and measured the women's body weight and ordered blood tests and assessed their nutritional intake status using a brief-type self-administered diet history questionnaire (BDHQ). We obtained the pre-pregnancy BMIs of the women using the World Health Organization (WHO) criteria, and classified the amount of gestational weight gain over the entire pregnancy as either "below," "within," or "above" the recommended weight gain as indicated by the Ministry of Health, Labour and Welfare. The fetal birth weights were divided into four percentile groups (≦10th percentile, 10-50th percentile, 50-90th percentile, and ≧90th percentile) using the "Gestational age-specific standards for birth size (Revised edition)" created by the Japan Pediatric Society in 2010. We analyzed the associations between the four groups of fetal birth weight and the recommended actual gestational weight gains by the women. An analysis of covariance was performed between the birth weight percentile groups and the nutritional intake, with each recommended gestational weight gain classification, age, and pre-pregnancy BMI as covariates. As a result, with regard to the ratio of consumed energy and energy-producing nutrients, in the second trimester the ratio of carbohydrate energy was significantly lower for women gaining less than the recommended weight (10-50th percentile) than for those in the 50-90th percentile group; and significantly higher for those gaining the recommended weight (≦10th percentile). The ratio of protein and fat energy was significantly higher for the group in the 10-50th percentile than for that in the 50-90th percentile. In the third trimester, no significant differences were observed. In the second trimester, increasing staple foods in underweight mothers increased the energy intake from carbohydrates, leading to fetal growth; however, projections suggested that overconsumption of energy from carbohydrates by mothers with normal weights according to the recommendations could lead to fetal birth weights that were small-for-gestational-age. *Ryukyu Med. J., 37 (1~4) 61~72, 2018*

Key words: fetal birth weight, gestational weight gain, nutrient intake

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INTRODUCTION

Many epidemiological and clinical studies have been conducted demonstrating the concept of the "developmental origins of health and disease (DOHaD)" according to Barker's hypothesis[1-3]. The DOHaD theory explains well the phenomenon in which decreased birth weight is caused by deterioration of the nutritional environment in the uterus. According to the model, exposure to malnutrition or overnutrition during fertilization, the embryonic or fetal stages, or during infancy leads to the generation of factors underlying lifestyle-related diseases, and subsequent lifestyle stresses trigger the onset of lifestyle-related diseases[3]. In addition, a recent study reported that small-for-gestational-age (SGA) infants was associated with adult psychological disorders as well. Children born full term but weighing less than 5.5lb (2,495g) had increased psychological distress in later life, and that a 1SD decrease in birth weight for gestational age was associated with increased psychological distress in adulthood[4]. In Japan, the mean birth weight of infants in single births over the past 30 years (1979-2010) has significantly decreased, and even though full-term infants, the rate of low-birth-weight (LBW) infants is increasing[5]. Using vital statistics data, Yoshida et al. listed birth weights against various factors including sex, single/multiple birth, maternal age, post-term/full-term/preterm delivery, gestational age, and birth order; and then examined factors that influence low birth weight. They found that a shorter gestational duration can explain reductions of 0.04kg in birth weights, but cannot account for all of the average 0.2kg reduction that has occurred during the past 30 years[6]. In other developed countries, advancements in medical technology and improved physical fitness has led to a gradual and continued increase in birth weight, yet by contrast, considering the DOHaD theory, the low birth weights in Japan carry the risk of lifestyle-related diseases developing later in life.

Increasing numbers of SGA infants and LBW infants have been attributed to the low mean birth weight[5]. Earlier studies have found that maternal factors underlying SGA and LBW include low pre-pregnancy BMI, smoking during pregnancy, and poor gestational weight gain[7-9]. In Japan, over the past 50 years, BMIs for women in their 20s and 30s (so-called women of reproductive age) have drastically decreased, whereas the rates of underweight women have increased. However, BMI for women of other generations is in an upward trend, and an extremely unique nutritional state is now seen in developed countries with increases in underweight and obese women of reproductive age[10]. The "Healthy Parents and Children 21" promotion council of the Japanese Ministry of Health, Labour and Welfare prepared recommendations for weight gain throughout pregnancy according to the mother's BMI classification[11]. Subsequent studies have confirmed that irrespective of the pre-pregnancy BMI, appropriate weight gains during pregnancy effectively decrease the risk of SGA births[12-14].

On the other hand, some nutrients are vital to fetal growth. Low serum concentrations of zinc, iron, and calcium in the first, second, and third trimesters in the pregnant women affect the birth weight of their baby[15]. Furthermore, vitamin D in the first trimester helps to maintain fetal growth and bone development[16], and maternal serum levels of vitamin D at delivery are significantly low in the LBW group[17]. According to a survey conducted in South Korea, which is geographically close to Japan, consumption of dietary fiber, phosphorus, iron, vitamin B6, and folic acid in the second trimester was significantly lower in a LBW group ($<$3.1kg) than in a high birth weight group ($>$3.6kg)[18]. However, the folic acid content of red blood cells has also been shown to have a positive correlation with birth weight during late pregnancy and at delivery[19]. Meanwhile, according to a cohort study in Europe, the consumption of seafood during pregnancy decreases the risk of preterm delivery and increases weight gain[20, 21]. Furthermore, another study reported high omega-6 fatty acid levels in maternal total red blood cells at the time of delivery but low omega-3 fatty acid levels in the same cells in a LBW group[22]. In Japan, underweight pregnant women showing little weight gain usually have low intake of n-3 fatty acids, sodium, and zinc in the first trimester[23], whereas pregnant women who were underweight before pregnancy have low intake of protein, iron, magnesium, and folic acid in the second trimester[24].

As noted above, regarding the nutritional status of pregnant women, many surveys examine serum concentrations, whereas few surveys examine intake from actual food. Furthermore, although it has been pointed out that low gestational weight gain is a cause of SGA and LBW, gestational weight gain, and actual consumed nutrients have not been investigated in any longitudinal studies, including those in the second and third trimesters. The purpose of the present study was therefore to find associations between the maternal hemoglobin and hematocrit levels, the nutritional intake of food and the birth weight of full-term infants, according to the recommended gestational weight gain for each BMI classification.

METHODS

1. Subjects

Among the pregnant women seen for routine prenatal health check-ups at three hospitals (southern district, central district, and northern central district), and one clinic (southern district) in Okinawa, we included in our study those scheduled for delivery between August 2010 and March 2011.

Of 964 candidates, we included 477 pregnant women who provided their consent to participate in the study after receiving an explanation of the study content. We had to exclude 35 women because of hospital transfers, 13 for preterm delivery, three for carrying multiple fetuses, six for pregnancy-induced hypertension, six for gestational diabetes mellitus, one for concurrent mental disease, two for consent withdrawal, 72 for unsatisfactory survey completion, and 36 for obesity with a pre-pregnancy BMI of ≧25kg/m^2 (individual support is recommended in the event of pre-pregnancy obesity.[11]) In the end, 303 women were included in our analysis.

2. Survey procedure

The subjects were explained the study significance, purpose, and content in writing in the waiting room of the outpatient services and gave their signed consent to participate. Blood tests were performed once during routine prenatal health examinations in the second trimester (24-28 weeks of pregnancy), third trimester (34-37 weeks of pregnancy), and on the day defined as the survey date.

3. Survey content

1) Maternal and infant birth data

Maternal and infant birth data were extracted retrospectively from hospital records (electronic charts). Information from the maternal records included age, height, pre-pregnancy weight, gestational weight gain, smoking status, parity, pregnancy complications, obstetric history. Physiological indices of pregnant women included blood test values in the second trimester (24-28 weeks of pregnancy) and third trimester (34-37 weeks of pregnancy). Information extracted from the infant records included birth weight, gestational age and sex.

2) The nutritional intake status of pregnant women

For the nutritional intake status of pregnant women, we used the brief-type self-administered diet history questionnaire (BDHQ). BDHQ is a four-page, structured self-administered questionnaire. BDHQ assesses dietary habits during the preceding month and consists of the following five sections: (1) intake frequency of food and nonalcoholic beverage items, (2) daily intake of rice and miso soup, (3) frequency of drinking and amount per drink of alcoholic beverages, (4) usual cooking methods, and (5) general dietary behavior. Estimates of dietary intake for 58 food and beverage items were calculated using an ad hoc computer algorithm (including weighting factors) for BDHQ[25].

Regarding the reliability and validity of BDHQ, the mean correlation coefficient for intake values obtained using BDHQ and intake values obtained from 16-day weighted dietary records was 0.46-0.49, suggesting that BDHQ is superior to other similar questionnaires and dietary assessment methods[26].

Subjects excluded from our analysis of nutritional intake status included those whose energy intake for each age group was either $<$0.5 times the estimated energy requirement for level I physical activity, or equivalent to or $>$1.5 times the estimated energy requirement for level III physical activity, in accordance with the 2015 Dietary Reference Intakes for Japanese people (Ministry of Health, Labour and Welfare). That is, pregnant women aged 18-29 years consuming $<$825kcal/day or equivalent to or $>$3,300kcal/ day, and pregnant women aged 30-49 years consuming $<$875kcal/day or equivalent to or $>$3,450kcal/ day were excluded. Furthermore, Murakami et al. found that the misreporting of dietary intake of energy, protein, potassium and sodium was differential among a group of lean young Japanese women with low-fat intake and was associated with their BMI.

Nevertheless, the differential misreporting of energy-adjusted values of protein, potassium and sodium was not associated with BMI because of a positive correlation between the reporting accuracy of energy consumption and that of the absolute values of the three nutrients[27]. Therefore, for BDHQ, energy-adjusted intake values are highly reliable[28], and we therefore used the value adjustsd per 1,000kcal of energy intake for each nutrient intake value in the present study.

4. Analytical methods

Pre-pregnancy BMI classification was performed using the WHO criteria (underweight: BMI<18.5, normal range: 18.5≦BMI<25)[29]. Gestational weight gain was classified into the three categories of the recommended levels of the Healthy Parents and Children 21 Promotional Council, Ministry of Health, Labour and Welfare, Japan: below (<9kg), within (9-12kg), and above (>12kg) for underweight (BMI<18.5kg/m^2) women; and below (<7kg), within (7-12kg), and above (>12kg) for normal range (18.5≦BMI<25.0kg/m^2) women[11]. In the present study, the gestational weight gain was defined as the difference between measured weight at the prenatal visit closest to the delivery and self-reported pre-pregnancy weight (<1 week prior to delivery).

The fetal birth weights were classified into one of four categories using the "new gestational age-specific standards for birth size (revised edition)" created by the Japan Pediatric Society[30], namely into a ≦10th percentile group (10th group), a >10th-≦50th percentile group (10-50th group), a >50th-≦90th percentile group (50-90th group), or a >90th percentile group (90th group).

The relationship between the four birth weight percentile groups and the gestational weight gain for each pre-pregnancy BMI classification was examined by one-way analysis of variance, which revealed no statistically significant differences (underweight: F=.804, P=.497, normal range: F=2.074, P=.104). The weight gain was thus classified into three groups, i.e., below, within, and above the recommended weight gain.

For each analysis, the relationship between the four birth weight percentiles and the blood tests and energy and nutrient intakes for each recommended gestational weight gain classification was examined by analysis of covariance. After that, we used the variables that showed a significant difference to perform a multiple comparison analysis using the Bonferroni test.

Statistical analyses were performed using the software SPSS Statistics Ver. 24.0 J, and a *p* value of <0.05 was considered significant.

5. Ethical considerations

The present study was performed in accordance with the Declaration of Helsinki and the "Ethical Principles for Medical Research Involving Human Subjects". The content of the survey was explained to the potential study participants in writing, and participants were also explained that participation in the study was voluntary, that they were free to withdraw from the study without any repercussions even after providing consent, and that due care would be paid to protecting their personal information and that all data would be processed statistically so as not to make individuals personally identifiable. Signed consent forms were subsequently obtained. The ethical review board for clinical research of the University of the Ryukus gave their approval for this survey to be conducted (approval number 246, July 21, 2010).

RESULTS

Table 1 shows the characteristics of the Subjects. Overall, the mean age of our participants was 31.8±5.5 years, the mean height was 156±5.5cm, the mean weight was 49.7±6.1kg, and the mean pre-pregnancy BMI was 20.4±2.0kg/m^2. The pre-pregnancy BMI classification showed that 18.8% women were underweight and that the mean gestational weight gain was 11.3±3.7kg. According to the gestational weight gain classification, 11.6% women were below, 53.1% were within, and 35.3% were above the recommended pregnancy weight gain. In addition, 12.2% women had a smoking habit before their pregnancy and 2.0% smoked during their pregnancy. Overall, 31.4% were primiparas, 74.3% of the subjects were delivered in normal delivery, and the rate of male neonates given birth to was 55.8%.

Regarding to the birth weight percentiles, the mothers of infants in the 10th group accounted for 8.6%, those in the 10-50th group for 45.2%, those in the 50-90th group for 37.0%, and those in the 90th

Table 1 **Comparisons of characteristics according to the fetal birth weight percentile**

Variable		Toal	Fetal birth weight percentile				*P*
		303 (100.0)	≦ 10th 26 (8.6)	10-50th 137 (45.2)	50-90th 112 (37.0)	90th< 28 (9.2)	
Age (years) [a]		31.8±5.5	33.4±5.0	30.9±5.8	32.1±5.1	33.2±5.4	**0.035**
Height (cm) [a]		156±5.2	153.9±5.2	155±5.3	157±4.4	159±5.2	**<0.001**
Pre-pregnancy weight (kg) [a]		49.7±6.1	48.0±6.0	48.2±5.6	51.1±5.8	53.6±6.6	**<0.001**
Pre-pregnancy BMI (kg/m^2) [a]		20.4±2.0	20.2±2.2	20.0±2.0	20.6±2.0	21.1±2.0	**0.022**
Pre-pregnanacy BMI classification [b]							
Underweight (BMI<18.5)		57(18.8)	6(23.1)	33(24.1)	15(13.4)	3(10.7)	0.104
Normal range (18.5 ≦ BMI<25.0)		246(81.2)	20(76.9)	104(75.9)	97(86.6)	25(89.3)	
Gestational weight gain (kg) [a]		11.3±3.7	10.4±3.0	11.1±3.9	11.4±3.6	12.7±3.6	0.089
Recommended gestational weight gain							
	Below	35(11.6)	6(23.1)	17(12.4)	12(10.7)	—	
	Within	161(53.1)	13(50.0)	74(54.0)	59(52.7)	15(53.6)	0.229
	Above	107(35.3)	7(26.9)	46(33.6)	41(36.6)	13(46.4)	
Pre-pregnancy smoking status [b]	Non-smoker	266(87.8)	22(84.6)	124(91.2)	98(87.5)	22(78.6)	0.340
	Smoker	37(12.2)	4(15.4)	13(8.8)	14(12.5)	6(21.4)	
Maternal smoking status [b]	Non-smoker	297(98.0)	25(96.2)	136(99.3)	111(99.1)	25(89.3)	—
	Smoker	6(2.0)	1(3.8)	1(0.7)	1(0.9)	3(10.7)	
Parity [b]	Primiparous	95(31.4)	9(34.6)	38(27.7)	40(35.7)	8(28.6)	0.562
	Multiparous	208(68.6)	17(65.4)	99(72.3)	72(64.3)	20(71.4)	
Type of Delivery [b]	Normal	225(74.3)	17(65.4)	94(68.6)	91(81.3)	23(82.1)	0.240
	Vacuum	64(21.1)	8(30.8)	34(24.8)	18(16.1)	4(14.3)	
	Caesarean Section	14(4.6)	1(3.8)	9(6.6)	3(2.7)	1(3.6)	
Infant sex [b]	Male	169(55.8)	16(61.5)	79(57.7)	59(52.7)	15(53.6)	0.792
	Female	134(44.2)	10(38.5)	58(42.3)	53(47.3)	13(46.4)	

a: Mean±SD, one-way layout analysis of variance b: n (%), chi-square test
Fetal birth weight percentile: Classification based on the "Introduction of the new gestational age-specific standards for birth size (2010)" by the Japan Pediatric Society
Pre-pregnancy BMI classification: Classification taken from the WHO criteria
Recommended gestational weight gain: below (<9kg), within (9-12kg), and above (>12kg) for underweight (BMI<18.5kg/m^2) women, and below (<7kg), within (7-12kg), above (>12kg) for normal weight (18.5 ≦ BMI<25.0kg/m^2) women.

group for 9.2%; thus, a higher rate was observed in the 10-50th group than in the 50-90th group.

Comparisons according to each birth weight percentile revealed the mean maternal age to be highest in the 10th group (P=0.035), whereas mean height and pre-pregnancy weight were lowest in the 10th group (P<0.001) and the mean pre-pregnancy BMI was lowest in the 10-50th group (P=0.022). According to the recommended gestational weight gain classification, for subjects with weight gain below the recommended amount, the birth weight percentile of their infants was most commonly in the 10th group at 23.1%, and for subjects with weight gain above the recommended amount, their infants were most commonly in the 90th group, accounting for 46.4%.

For the mean hemoglobin and hematocrit levels in the second and third trimesters, we found no statistically significant differences among the four birth weight percentiles (Table 2).

To examine the relationship of the birth weight percentiles with consumed energy and the rate of energy-producing nutrient intake according to each recommended gestational weight gain classification, we performed an analysis of covariance, with age and pre-pregnancy BMI as covariates (Table 3). We observed no statistical significant difference between the consumed energy in both the second and third trimesters and the birth weight percentiles. On the other hand, the rate of energy from protein in the second trimester was significantly higher in the 10-50th group than it was in the 50-90th group in the "below" category (P=0.043). Furthermore, the rate of energy from carbohydrates was significantly lower in the 10-50th group than in the 50-90th group in the "below" category (P=0.012), whereas the rate of energy from carbohydrates was high in the 10th group in the "within" category (P=0.044). The rate of energy from lipids was significantly higher in the 10-50th group than in the 50-90th group in the "below"

Table 2 **Blood test values according to the recommended gestational weight gain and fetal birth weight percentile**

Mean±SD

Variable	Recommended gestational weight gain	2nd trimester: Fetal birth weight percentile ≦ 10 n=23	10-50th n=134	50-90th n=110	90< n=28	*P*	3rd trimester: Fetal birth weight percentile ≦ 10th n=26	10-50th n=132	50-90th n=109	90th< n=28	*P*
Hb (g/dL)	Below	10.7±0.2	11.2±0.7	11.0±1.2	–	0.481	11.3±0.7	11.2±0.6	10.8±1.2	–	0.722
	Within	10.8±0.6	10.9±0.9	10.8±1.0	10.6±1.0	0.163	11.4±1.0	11.2±1.0	11.3±1.0	11.1±0.7	0.650
	Above	11.0±0.9	11.0±0.9	11.0±1.0	10.9±0.9	0.901	11.3±0.8	11.5±0.9	11.3±0.9	11.2±0.8	0.278
Hct (%)	Below	31.8±0.2	33.1±2.1	31.9±3.1	–	0.347	33.9±1.9	33.7±1.7	32.3±3.5	–	0.504
	Within	32.3±1.7	32.2±2.6	32.1±2.7	31.5±2.4	0.307	34.4±2.7	33.4±2.6	34.0±2.7	33.7±1.8	0.552
	Above	32.4±2.4	32.6±2.3	32.5±2.5	31.9±2.9	0.746	33.4±2.4	34.3±2.3	33.7±2.4	33.0±2.4	0.199

Analysis of covarianc
Covariance: age, pre-pregnancy BMI
Fetal birth weight percentile: Classification based on the "Introduction of the new gestational age-specific standards for birth size (2010)" by the Japan Pediatric Society
Recommended gestational weight gain: below (<9kg), within (9-12kg), and above (>12kg) for underweight (BMI<18.5kg/m^2) women, and below (<7kg), within (7-12kg), above (>12kg) for nomal weight (18.5 ≦ BMI<25.0kg/m^2) women.

Table 3 **Energy and energy-providing nutrient intake for the recommended gestational weight gain according to fetal birth weight percentile**

Mean±SD

Variable	Recom-mended gestational weight gain	2nd trimester: Fetal birth weight percentile ≦ 10th [a] n=15	10-50th [b] n=86	50-90th [c] n=71	90th< [d] n=20	*P*	Multiple comparison	3rd trimester: Fetal birth weight percentile ≦ 10th n=15	10-50th n=99	50-90th n=89	90th< n=25	*P*
Energy (kcal)	Below	–	1619.7±299.4	1796.7±552.9	–	0.331		1421.3±263.0	1618.1±415.7	1456.6±246.2	–	0.366
	Within	1598.5 ± 425.8	1515.7±365.6	1433.6±318.8	1387.6±333.0	0.335		1407.9±242.6	1471.7±317.7	1571.0±399.1	1426.5±317.2	0.343
	Above	1288.8 ± 168.2	1575.2±411.5	1661.8±459.6	1580.8±629.3	0.315		1481.0±382.7	1526.3±366.7	1578.5±374.5	1392.8±495.1	0.451
Protein (% of energy)	Below	–	14.1±1.3	12.6±1.4	–	**0.043**	c<b	15.3±5.6	14.0±1.9	13.1±2.0	–	0.307
	Within	13.2 ± 1.7	14.4±2.4	13.9±1.9	15.7±1.7	0.066		14.0±0.6	14.6±2.2	14.0±1.6	15.0±2.0	0.291
	Above	14.1 ± 1.0	13.3±1.9	14.1±1.9	14.1±3.4	0.611		12.0±1.1	13.5±2.1	14.2±2.1	13.9±1.7	0.253
Carbohydrate (% of energy)	Below	–	55.3±4.0	61.6±3.2	–	**0.012**	b<c	53.5±8.3	56.9±4.9	60.0±5.2	–	0.122
	Within	59.5 ± 7.4	56.3±6.0	57.3±5.4	52.3±5.1	**0.044**	d<a,c	56.4±4.3	56.3±5.5	56.2±5.3	55.8±3.8	0.980
	Above	58.4 ± 2.1	57.0±6.3	55.6±6.3	58.4±8.2	0.726		60.0±4.0	56.7±5.9	56.1±7.7	59.3±3.7	0.356
Fat (% of energy)	Below	–	29.3±3.4	24.4±3.2	–	**0.037**	c<b	30.2±3.8	28.1±3.4	25.7±3.8	–	0.114
	Within	26.0 ± 6.2	28.2±4.5	27.8±4.3	31.0±4.3	0.091		28.0±4.3	27.9±4.6	28.5±4.5	28.2±3.0	0.930
	Above	25.9 ± 2.8	28.3±5.0	29.2±5.8	26.7±5.6	0.665		26.9±5.0	28.7±4.8	28.8±6.2	25.7±3.4	0.277

The "below" group with a the birth weight percentile of ≦ 10 comprised 1 individual, and was therefore excluded from the analysis.
Analysis of covariance: Multiple comparison with Bonferroni test
Covariance: age, pre-pregnancy BMI
Fetal birth weight percentile: Classification based on the "Introduction of the new gestational age-specific standards for birth size (2010)" by the Japan Pediatric Society
Recommended gestational weight gain: below (<9kg), within (9-12kg), and above (>12kg) for underweight (BMI<18.5kg/m^2) women, and below (<7kg), within (7-12kg), above (>12kg) for normal weight (18.5 ≦ BMI<25.0kg/m^2) women.

category (P=0.037). In the third trimester, we found no significant differences between the rate of energy from all energy-producing nutrients and the birth rate percentiles.

An analysis of covariance was performed to examine the relationship between nutrient intake corrected per 1,000kcal and birth weight percentiles according to each recommended gestational weight gain classification (Table 4). To this end, age and pre-pregnancy BMI were included as covariates. In the second trimester, the vitamin B_6 intake was significantly higher in the 10-50th group than in the 50-90th group in the "below" category (P=0.047), and intake of zinc was also significantly higher in the 10-50th group than in the 50-90th group in the "below" category (P=0.010). In the third trimester, the intake of vitamin D was significantly higher in the 10-50th group than in the 50-90th group in the "within" category (P=0.010).

DISCUSSION

According to WHO reports anemia is associated

Table 4 **Energy and nutritional intake for the recommended gestational weight gain according to fetal birth weight percentile**

Mean±SD

Variable	Recommended gestational weight gain	2nd trimester: Fetal birth weight percentile ≦ 10th [a] n=15	10-50th [b] n=86	50-90th [c] n=71	90th< [d] n=20	*P*	Multiple comparison	3rd trimester: Fetal birth weight percentile ≦ 10th [a] n=15	10-50th [b] n=99	50-90th [c] n=89	90th< [d] n=25	*P*	Multiple comparison
n-3 polyunsaturated fat (mg/1,000kcal)	Below	—	1.1±0.2	1.0±0.2	—	0.415		1.5±0.7	1.2±0.3	0.9±0.2	—	0.088	
	Within	1.1 ± 0.3	1.2±0.3	1.2±0.3	1.4±0.3	0.255		1.2±0.1	1.2±0.3	1.2±0.3	1.2±0.2	0.656	
	Above	1.1 ± 0.2	1.1±0.3	1.2±0.4	1.0±0.3	0.232		1.0±0.1	1.2±0.3	1.2±0.3	1.0±0.1	0.100	
n-6 polyunsaturated fat (mg/1,000kcal)	Below	—	5.9±0.7	5.0±1.0	—	0.170		6.2±0.8	5.6±0.9	5.4±1.1	—	0.451	
	Within	5.4 ± 1.3	5.8±1.2	5.6±1.0	6.3±1.1	0.271		5.7±0.8	5.6±1.1	5.7±0.9	6.0±0.6	0.890	
	Above	5.4 ± 1.4	5.6±1.1	5.9±2.0	5.0±1.2	0.630		5.6±0.9	5.7±1.1	5.8±1.3	5.2±0.7	0.317	
Vitamin D (μg/1,000kcal)	Below	—	4.2±1.4	4.6±2.8	—	0.902		7.0±7.4	4.9±2.6	3.4±1.7	—	0.216	
	Within	3.6 ± 1.3	5.7±3.6	5.2±2.5	5.4±1.6	0.235		5.9±1.4	6.1±3.6	4.2±1.8	5.0±2.1	**0.010**	c<b
	Above	4.1 ± 1.1	3.7±1.6	4.9±2.9	3.9±1.7	0.354		2.0±0.6	4.2±1.9	5.0±2.5	4.1±1.3	0.062	
Vitamin B6 (mg/1,000kcal)	Below	—	0.6±0.1	0.5±0.1	—	**0.047**	c<b	0.7±0.4	0.6±0.1	0.6±0.1	—	0.259	
	Within	0.6 ± 0.1	0.6±0.2	0.6±0.2	0.7±0.1	0.399		0.6±0.1	0.6±0.1	0.6±0.1	0.7±0.1	0.311	
	Above	0.6 ± 0.1	0.6±0.1	0.6±0.1	0.6±0.3	0.540		0.5±0.1	0.6±0.1	0.6±0.1	0.6±0.1	0.175	
Vitamin B12 (mg/1,000kcal)	Below	—	3.2±1.1	3.1±1.4	—	0.420		4.8±4.2	3.4±1.6	2.4±0.8	—	0.153	
	Within	3.0 ± 0.9	3.8±2	3.3±1.3	4.3±1.0	0.186		3.9±1.1	4.0±2.0	3.4±1.4	3.9±1.5	0.325	
	Above	2.9 ± 1.0	2.8±1.0	3.7±2.0	2.8±0.9	0.255		1.4±0.4	3.2±1.3	3.8±1.8	2.8±0.8	0.014	
Folate (mg/1,000kcal)	Below	-	174.7±44.7	172.0±46.6	—	0.969		170.8±69.6	196.6±63.9	171.1±25.3	—	0.286	
	Within	161.6 ± 31.8	184.6±57.6	183.9±61.5	172.7±35.0	0.652		151.3±39.7	170.1±48.4	181.3±61.5	187.4±41.3	0.374	
	Above	222.4 ± 72.6	156.0±54.6	168.3±60.1	195.4±87.5	0.361		147.7±36.5	180.0±66.4	197.4±53.1	183.2±59.1	0.403	
Vitamin C (mg/1,000kcal)	Below	—	57.1±18.4	57.5±21.4	—	0.630		54.3±25.3	66.4±26.5	60.9±20.7	—	0.651	
	Within	58.4 ± 18.1	63.5±22.6	62.9±25.9	50.3±15.5	0.429		52.4±22.0	59.6±20.7	60.1±24.2	67.3±23.0	0.581	
	Above	72.6 ± 20.4	51.8±20.3	59.6±25.8	67.0±40.7	0.607		50.0±12.5	62.7±29.2	69.3±27.5	63.3±27.5	0.298	
Calcium (mg/1,000kcal)	Below	-	270.0±80.3	255.5±67.7	—	0.594		255.8±65.7	286.8±74.4	276.9±63.5	—	0.657	
	Within	249.6 ± 82.2	288.0±95.8	270.7±76.0	275.9±63.2	0.584		246.4±53.2	285.4±91.2	285.1±67.9	321.8±67.5	0.235	
	Above	301.0 ± 58.2	257.3±68.4	272.9±82.6	323.4±110.0	0.322		224.7±48.2	281.9±84.6	289.2±92.3	281.8±87.2	0.515	
Iron (mg/1,000kcal)	Below	—	4.1±0.6	4.0±0.6	-	0.897		4.1±1.3	4.3±0.8	4.1±0.7	—	0.483	
	Within	3.8 ± 0.6	4.2±0.9	4.2±0.9	4.3±0.8	0.506		3.9±0.5	4.1±0.8	4.2±0.9	4.3±0.8	0.819	
	Above	4.5 ± 0.9	3.8±0.9	4.0±0.8	4.3±1.2	0.566		3.5±0.5	4.1±0.9	4.4±0.9	4.1±0.9	0.093	
Zinc (mg/1,000kcal)	Below	—	4.6±0.4	4.0±0.4	—	**0.010**	c<b	4.4±0.7	4.5±0.5	4.2±0.5	—	0.371	
	Within	4.2 ± 0.3	4.4±0.5	4.4±0.6	4.6±0.6	0.367		4.2±0.3	4.4±0.5	4.5±0.5	4.7±0.6	0.241	
	Above	4.6 ± 0.2	4.1±0.5	4.4±0.6	4.5±0.8	0.137		3.9±0.5	4.3±0.6	4.3±0.6	4.3±0.5	0.613	
Copper (μg/1,000kcal)	Below	—	0.6±0.1	0.6±0.1	—	0.934		0.6±0.1	0.6±0.1	0.6±0.1	—	0.852	
	Within	0.6 ± 0.1	0.6±0.1	0.6±0.1	0.6±0.09	0.925		0.6±0.1	0.6±0.1	0.6±0.1	0.7±0.1	0.358	
	Above	0.6 ± 0.0	0.6±0.1	0.6±0.1	0.61±0.15	0.817		0.6±0.2	0.6±0.1	0.6±0.1	0.6±0.1	0.358	

The "below" group with a the birth weight percentile of ≦ 10 comprised 1 individual, and was therefore excluded from the analysis.
Analysis of covariance: Multiple comparison with Bonferroni test
Covariance: age, pre-pregnancy BMI
Fetal birth weight percentile: Classification based on the "Introduction of the new gestational age-specific standards for birth size (2010)" by the Japan Pediatric Society
Recommended gestational weight gain: below (<9kg), within (9-12kg), and above (>12kg) for underweight (BMI<18.5kg/m^2) women, and below (<7kg), within (7-12kg), above (>12kg) for normal weight (18.5 ≦ BMI<25.0kg/m^2) women.

with abortion, preterm delivery, LBW, and fetal growth restriction[31, 32]. Many previous studies have also reported an association between maternal hemoglobin and birth weight[33-36]. However, in the present study we found no statistically significant differences between the four birth weight percentiles and the mean hemoglobin and hematocrit levels in the second and third trimesters. In Japan, fees for health check-ups are subsidized up to 14 times during pregnancy and testing for anemia is performed in the second trimester (at 24-27 weeks of pregnancy) when expectant mothers are physiologically prone to anemia. When hemoglobin levels are found to be <11.0 in these check-ups, iron tablets are often prescribed. The same tests are performed in the third trimester (at ≧34 weeks of pregnancy) to verify whether the iron tables have improved the anemia, which suggests that no pregnancies occur with severe anemia that might affect birth weight.

An earlier study showed that age and BMI can influence the relative accuracy of energy intake among Japanese adults[37]. In the present study, age and BMI showed a significant difference with the birth weight percentile. We therefore conducted an analysis of covariance with age and pre-pregnancy BMI as covariates to examine their relationship with the birth weight percentile in each recommended gestational weight gain classification.

As a result, there were not significant differences among birth weight percentiles for the energy intake in the second and third trimesters. The Dietary Reference Intakes for Japanese people (2010), recommended by the Ministry of Health Labour and Welfare, indicate that an additional 250 kcal and 450 kcal in energy intake are needed in the second and third trimesters, respectively[38]. In the present study, the energy intake in the second and third trimesters did not meet the recommended amounts. A study by Konno et al. using BDHQ found that energy intake was less than the amount recommended by the Ministry of Health, Labour and Welfare by 180-230kcal/day in the second trimester and by 320-370kcal/day in the third trimester.[23] In another survey, by Kubota et al., energy intake was found to be <1,600kcal/day throughout pregnancy[39]. Results of the National Health and Nutrition Survey from 1995 to 1999 show no difference in energy intake between pregnant women and nonpregnant women at 1,869±498kcal/day[40]. Furthermore, in Okinawa prefecture, the energy intake of women aged 20-39 years is low at just 1,549kcal/day[41]. It may therefore be difficult to improve on pre-pregnancy dietary habits during pregnancy.

On the other hand, regarding the rate of energy-producing nutrients among pregnant women who had "below" the recommended weight gain in the second trimester, the intake of carbohydrates was significantly lower in the 10-50th group than in the 50-90th group, whereas the protein and fat intake was significantly higher. Furthermore, for pregnant women classified "within" the recommended weight gain, the rate of energy intake from carbohydrates was highest in the 10th group. On comparing the dietary reference intakes for the pregnancy trimesters, the carbohydrate intake was within the reference range, but the fat intake exceeded the reference range. Moreover, additional protein is needed in the second and third trimesters. Sekiya et al. report the most sensitive period of maternal weight gain for the birth weight and length of gestation to be the second trimester[42]. During the second trimester, increasing consumption of staple foods in pregnant women with poor weight gain improves fetal growth because of the increase in energy intake from carbohydrates and selection of foods that are low in fat and high in protein. Furthermore, if the pregnant woman's weight gain is as recommended, then consuming near the lower limit of the reference energy consumption from carbohydrates may effectively decrease their risk of a SGA birth. In Japan, for pregnant women who are underweight and for those with normal pre-pregnancy weights, the recommended weight gain per week from the second trimester through to the third trimester is 0.3-0.5kg/week. As a result, a subsequent survey regarding the effects of physicians' guidance on weight gain listed no recommendations for increasing weight and the rate of weight gain was consequently decreased by half in prenatal health checks following this guidance on weight gain and snacking[43]. British guidelines note the importance of measuring maternal weight and height at the initial prenatal checkup and discourage weighing on a daily basis when there is no benefit to it44). A pre-pregnancy BMI of <25kg/m^2 is also reported to be desirable to prevent Japanese women from developing pregnancy induced hypertension[45]. Furthermore, in the case of pre-pregnancy obesity, weight management throughout the trimesters is important. However, pregnant women who are underweight or within the normal weight range pre-pregnancy and who have no complications or problems in their family history should be instructed to watch the ratio of energy-producing nutrients they consume based on their recommended weight gain.

Regarding nutrient intake adjusted to 1,000 kcal of energy, we found that in the second trimester, the intake of vitamin B6 and zinc was significantly higher in the 10-50th group than in the 50-90th group among pregnant women with "below" the recommended weight gain, whereas in the third trimester, the intake of vitamin D was significantly higher in the 10-50th group than in the 50-90th group among pregnant women classified "within" the recommended weight gain. On comparing the Dietary Reference Intakes for Japanese people (2010) in the second and third trimesters[38], adjusted to

1,000 kcal of energy intake, as recommended by the Ministry of Health, Labour and Welfare, we found that the reference amount was consume in the 50-90th group despite low intakes of vitamin B_6 and zinc in the second trimester, whereas in the 10-50th group, intakes were above the recommended amount. These nutrients are obtained from sources including meat and seafood, and thus among expectant mothers with "below" the recommended weight gain, a significantly high rate of energy intake from protein and fat was seen in the 10-50th group, which suggested that the birth weight was affected by an energy intake from fat that was higher than the reference value. Furthermore, in the third trimester, the intake of vitamin D among pregnant women classified "within" the recommended weight gain was at least twice the recommended amount in the 10-50th group, which indicates that, as in the second trimester, high fat consumption affects birth weight. According to reports, of the nutrients important to pregnancy, those associated with birth weight are iron[15, 18], vitamin B_6[18], and folic acid[18, 19] in relation to blood formation, and calcium[15], vitamin D[16, 17], zinc[15], and n-3 fatty acids[21, 22] in relation to bone formation and growth. The Okinawan diet is reportedly nutritionally characterized by a low caloric intake, high meat consumption, and low seafood consumption[46]. Furthermore, it is said that the rapid post-war shift in dietary habits was mainly because of strong influences from the food culture of mainland Japan and the United States, and from socio-economic changes. However, the traditional cooking styles of Okinawa (such as "stir-fry" and "boiling") have been maintained despite the larger changes seen in the raw materials used in cooking[47]. The vast majority of nutrients associated with birth weight can be obtained from meat products. The food culture of Okinawa includes low seafood consumption with many fried dishes, which suggests that n-3 fatty acids, which contribute to fetal growth, can be obtained from seasoning oils.

LIMITATIONS

In the present study, we excluded subjects whose energy intake had been calculated using BDHQ[A1]. According to Okubo et al., underreporting, rather than over reporting, of energy intake has been predominant in the relatively lean Japanese female population and BMI has been the most important factor affecting the reporting accuracy of energy intake[48]. In the present survey, the fact that the "below" category included only one individual with an infant birth weight below the 10th percentile indicates that many underweight pregnant women underreport on the BDHQ survey. This may explain their exclusion from analysis sets. Further investigation is needed into those who underreport. Furthermore, Okinawa prefecture, where the survey was conducted, is the prefecture in Japan with the lowest income per inhabitant; investigation into birth weights and dietary intake in relation to income should therefore also be conducted.

CONCLUSIONS

We found the energy intake of pregnant women to be below the required amount throughout the second and third trimesters of pregnancy. During the second trimester, increasing consumption of staple foods in pregnant women with poor weight gain led to improved fetal growth because of the increased energy intake from carbohydrates. However, our analysis suggested that if a pregnant woman's weight gain is as recommended, then consuming an amount of carbohydrates near the lower limit of the reference range may effectively lower the risk for giving birth to a SGA baby.

Based on our study, we recommend that pregnant women who are underweight pre-pregnancy receive nutritional guidance to select foods that are low in fat and high in protein, while increasing carbohydrate intake up until the second trimester. If the recommended weight gain is achieved, carbohydrate intake should be decreased, and protein intake should be increased.

Dietary habits are strongly associated with the food culture surrounding pregnant women and can be difficult to improve after a woman becomes pregnant. We therefore believe that in addition to recommendations regarding gestational weight gain and dietary intake, interventions are needed in secondary schools and other educational institutions to improve the dietary habits of young women prior to them becoming pregnant.

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Remark: [A1]Note that the highlighted text has been translated as per the original; however, please check that your intended meaning has been conveyed