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Optimal weight gain in obese and overweight pregnant Japanese women

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Abstract. We aimed to determine the optimal gestational weight gain (GWG) in Japanese women with a Body Mass Index (BMI) ≥ 25 kg/m^2. The present retrospective study investigated singleton pregnancies in 6,781 Japanese women registered in the Japan Society of Obstetrics and Gynecology system in 2013. We divided overweight and obese women into four GWG categories based on the Institute of Medicine (IOM) recommended: weight loss, small weight gain, within IOM criteria, and above IOM criteria. The adjusted odds ratios and predicted probabilities of maternal and neonatal outcomes of interest with weight change were calculated. In overweight women, GWG was associated with neonatal birth weight. In the loss and small gain subgroups, there was a significant increase in small for gestational age (SGA) and low birth weight neonates (LBW). Predicted probabilities showed the lowest risk was observed in a weight gain of 0 kg; the risk sharply increased at a gain of 11.5 kg. In obese women, weight gain increased the prevalence of large for gestational age (LGA) neonates; however; SGA was not associated with GWG. Predicted probabilities showed an increase in the risk with weight gain. The observed optimal GWG was 0 to 11.5 kg in overweight, and weight loss in obese, pregnant Japanese women.

Key words: Obese, Overweight, Japanese pregnants, Gestational weight gain

PRE-PREGNANCY BODY MASS INDEX (BMI) and gestational weight gain (GWG) have been reported to be associated with pregnancy outcomes [1-6]. The Institute of Medicine (IOM) revised the GWG guidelines in 2009 and recommended that obese women (BMI ≥ 30 kg/m^2) should gain between 5 and 9 kg to obtain the best maternal and perinatal outcomes [4]. However, a few studies from Europe and North America have suggested that a GWG below the IOM guidelines is associated with more favourable pregnancy outcomes in obese women [3, 7-13].

Japanese women are more likely to be underweight than those in Europe and North America; therefore, the obesity classification used in Japan differs from that developed by the IOM [14-16]. According to the criteria developed by the Japan Society of Obstetrics and Gynecology (JSOG), women with a BMI of ≥ 25 kg/m^2 are classified as obese without further subdivision [17]. Optimal weight gain for pregnant Japanese women with a BMI ≥ 25 kg/m^2 is assessed on a case-to-case basis [18, 19]. In our previous study entitled, "Pregnancy outcomes based on pre-pregnancy body mass index in Japanese women: POBMIJ Study," we reported that the IOM classification is also applicable to pregnant Japanese women because overweight (25 kg/m$^2 \leq$ BMI <30 kg/m^2) and obese (BMI ≥ 30 kg/m^2) women have different pregnancy outcomes. In addition, when pregnancy outcomes were compared among three groups of pregnant Japanese women with GWG below, within, and above the IOM-recommended weight gain, pregnant women with GWG within the IOM criteria had the best pregnancy outcomes among those with a BMI <30 kg/m^2, whereas no differences were observed in those with a BMI ≥ 30kg/m^2 [20].

However, because we compared pregnancy outcomes among the groups classified according to only the IOM-recommended weight gain in our previous study, it was not clear whether customized weight gain categories needed to be developed for this population.

The present study was conducted as a secondary analysis of the POBMIJ Study with the objective of defining an optimal GWG in obese pregnant Japanese women. For this purpose, we conducted a large-scale retrospective study using the database of the JSOG Successive Pregnancy Birth Registry System to explore associations between GWG and pregnancy outcomes among overweight and obese Japanese women in order to determine the optimal GWG.

Methods

Study design

The present study was a retrospective investigation of women included in the JSOG registry system. Approximately 280 secondary and tertiary hospitals participated in the JSOG Successive Pregnancy Birth Registry System. A total of 186,235 women were registered in the system and the study subjects included 161,610 women who delivered singleton term live births between January 1, 2013 and December 31, 2013. This study has been approved by the ethics committee of the Yokohama City University Medical Center (B160700011).

Outcomes of interest

Pre-pregnancy BMI was calculated from the self-reported pre-pregnancy weight and height. We classified women with a BMI of 25.0–29.9 kg/m^2 as overweight, and those with a BMI of ≥30.0 kg/m^2 as obese. The following were exclusion criteria for our study: concomitant hypertension, diabetes mellitus (DM), gestational diabetes (GDM) or other underlying disease (n = 53,794), congenital anomalies (n = 1,935), and insufficient or missing data (n = 41,854) on key variables.

The following were included in the study: gestational weight changes of –12 to 48 kg, maternal height of 1.15 to 1.97 m, pre-pregnancy weight of 29.7 to 138 kg, neonatal weight at birth of 500 g to 6,000 g, and a maternal age at delivery of 11 to 59 years. The final analysis consisted of 4,941 women in the overweight group and 1,840 in the obese group (Fig. 1). GWG was calculated by subtracting the maternal pre-pregnancy weight from the weight at delivery; weight gain was divided to four categories based on the IOM recommended weight gain:

weight loss (<0 kg), small weight gain (overweight, 0 ≤ GWG < 7 kg; obese, 0 ≤ GWG < 5 kg), within the IOM criteria (overweight, 7 ≤ GWG < 11.5 kg; obese, 5 ≤ GWG < 9 kg), and above the IOM criteria (overweight, GWG ≥ 11.5 kg; obese, GWG ≥ 9 kg).

We considered ten main outcomes of interest, which are already known to be influenced by GWG [5-16, 20-27]: small for gestational age (SGA), large for gestational age (LGA), low birth weight (LBW) (<2,500 g), macrosomia (≥4,000 g), gestational hypertension, pre-eclampsia, caesarean delivery, operative virginal delivery, umbilical artery pH <7.0, and an Apgar Score at 5 min <7. SGA and LGA neonates were defined as birth weights below the 10th percentile and above 90th percentile, respectively, after matching for gestational age and sex. Gestational hypertension was defined as a case in which hypertension (systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg) developed after 20 weeks of gestation. Pre-eclampsia was defined as a case in which hypertension (systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg) and a urinary protein excretion of ≥300 mg/day developed after 20 weeks of gestation. Caesarean delivery included all primary and repeat surgical procedures used to deliver the infant; both elective and emergency caesarean deliveries were included. Gestational age was determined based on the last menstrual period. If gestational age according to the last menstrual period differed by more than 7 days from that based on the 11 week ultrasound, the latter was used to assign a gestational age.

Statistical analysis

Logistic regression analysis was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs), adjusting for confounding variables, including parity, maternal age, smoking, and gestational age. Women with a smoking habit were defined as those exposed to second-hand tobacco smoke or active smokers. Generalized estimating equations (GEE) for logistic regression were used to adjust for clustering of deliveries by hospitals. A *p* value of <0.05 was considered statistically significant.

Initially, we used the method of analysis introduced in a study by Beyerlein *et al.* [11], to calculate the predicted probability of pregnancy outcomes according to weight gain in primiparous non-smoking women with an average maternal age (overweight, 32.4 years; obese, 32.0 years) and average gestational delivery week (overweight, 38.9 weeks; obese, 38.9 weeks).
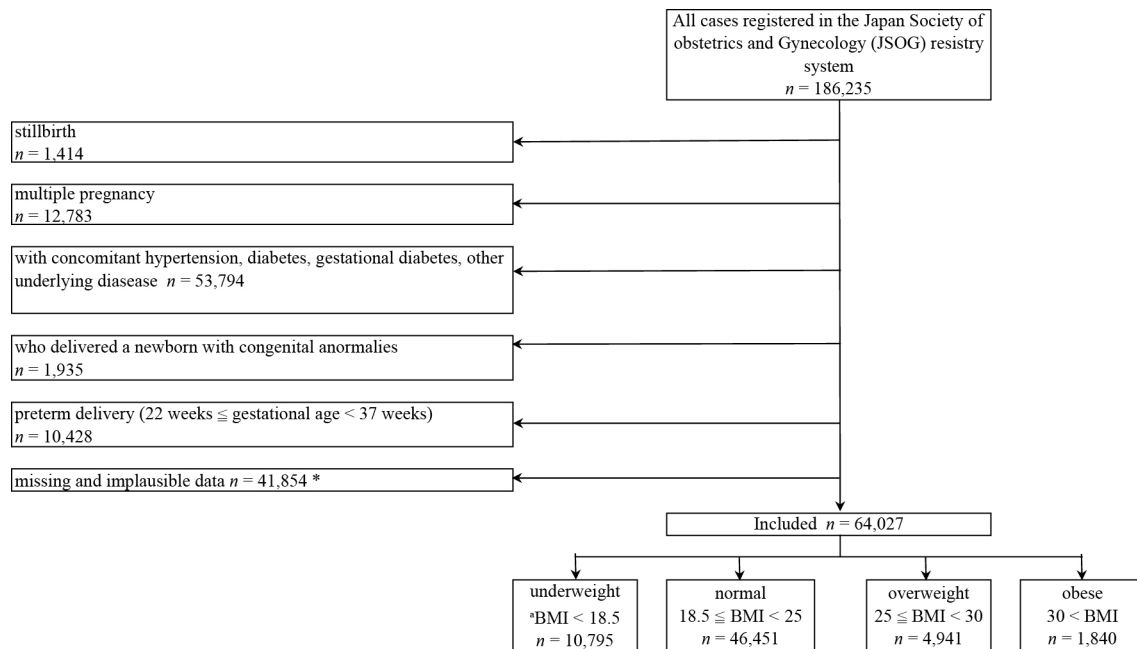
Fig. 1 Flow diagram showing total number of participants enrolled and the final number of participants according to pre-pregnancy BMI categories.

[a]BMI, Body Mass Index

* missing and implausible data: Women with missing or apparently incorrect data were excluded.

The breakdown of excluded women is summarized as follow (including duplicates):

• Pre-pregnancy BMI: (no data and outside data) $n = 15,308$
• Gestational weight change: (no data and outside of a range of –12–48 kg) $n = 8,006$
• Neonatal weight at birth: (no data and outside of a range of 500–6,000 g) $n = 101$
• Maternal age at delivery: (no data and outside of a range of 11–59 years) $n = 689$
• Apgar score at 5 minutes: (no data and implausible data) $n = 915$
• Umbilical artery pH: (no data and implausible data) $n = 21,359$
• Smoking: (no data) $n = 23,359$

Next, in order to determine the most favourable GWG based on neonatal birth weight, we investigated the maternal weight gain where the sum of the predicted probability of both SGA and LGA were below 20% in the overweight and obese groups. The cut off value was defined as 20% because SGA and LGA are defined as the lower 10% and upper 10%, respectively, of the general population. To further assess the potential maternal and neonatal risks and benefits of weight change, we sought to determine the optimal GWG based on the risk of the other adverse pregnancy outcomes listed above, which showed significant differences in the ORs among the four categories based on the weight gain recommended by IOM.

Data were expressed as means ± standard deviation or frequencies (percentages). SPSS Statistics software version 23 (IBM Corp., Armonk, NY, USA) was used for the statistical analyses.

Results

Table 1 shows the maternal characteristics and the prevalence of the adverse pregnancy outcomes between pre-pregnancy overweight and obese women. The maternal age was 32.4 ± 5.5 and 32.0 ± 5.3 in the overweight and obese groups, respectively, and the gestational age at delivery was 38.9 ± 1.3 and 38.9 ± 1.3 in the overweight and obese groups, respectively. These results were not different between the two groups. Although the prevalence of SGA and LBW was not different between the two groups, LGA (18.3% vs. 23.6%), macrosomia (2.1% vs. 3.6%), caesarean delivery (33.0% vs. 37.9%), gestational hypertension (8.2% vs. 12.7%), and preeclampsia rates (2.8% vs. 4.1%) were higher in obese women. Results from the overweight group ($N = 4,941$) showed 182 women underwent weight loss (loss subgroup, 3.7%), 1,780 had a small weight gain (small gain sub-

Table 1 Prevalence of maternal and neonatal outcome according to characteristics between overweight and obese

	Body mass index (kg/m^2)	
	25.0–29.9 n = 4,941	30 or higher n = 1,840
Maternal age (y)	32.4 ± 5.5	32.0 ± 5.3
Premiparous rate (%)	2,056 (58.3)	810 (56)
Gestational weeks at delivery	38.9 ± 1.3	38.9 ± 1.3
smoking (%)	912 (18.5)	391 (21.2)
[a]GWG (%)		
weight loss	182 (3.7)	250 (13.6)
weight less	1,780 (36.0)	577 (31.4)
recommended IOM criteria	1,877 (38.0)	560 (30.4)
excessive weight gain	1,102 (22.3)	453 (24.6)
Weight change (kg)	8.15	5.67
Pregnancy outcome (%)		
[b]SGA	269 (5.4)	99 (5.3)
[c]LGA	904 (18.3)	435 (23.6)
[d]LBW	274 (5.5)	95 (5.2)
macrosomia	104 (2.1)	67 (3.6)
cesarean delivery	1,633 (33.0)	698 (37.9)
operative vaginal delivery	330 (6.7)	111 (6.0)
gestational hypertension	406 (8.2)	234 (12.7)
preeclampsia	136 (2.8)	76 (4.1)
5 min Apgar <7	22 (0.4)	20 (1.1)
umbilical artery pH <7	14 (0.3)	7 (0.3)

[a]GWG, gestational weight gain
[b]SGA, small for gestational age
[c]LGA, large for gestational age
[d]LBW, low birth weight
Data are mean ± standard deviation or n (%)

group, 36%), 1,877 had weight gain within the IOM's criteria (within subgroup, 38%), and 1,102 had weight gain above the IOM's criteria (above subgroup, 22.3%). On the other hand, in the obese subgroup (N = 1,840) there were 250 women in the loss subgroup (13.6%), 557 in the small gain group (31.4%), 560 in the within subgroup (30.4%), and 453 women in the above subgroup women (24.6%). Overall, more women experienced weight loss in the obese group (Table 1).

Maternal and neonatal outcomes according to weight change

Tables 2 and 3 show the maternal and neonatal outcomes according to the weight change category. In the overweight group, GWG was clearly associated with neonatal birth weight. As women gained more weight, the prevalence of LGA births and macrosomia significantly increased (LGA: loss subgroup, OR 0.52, 95% Cl [0.32–0.84]; small gain subgroup, OR 0.71, 95% Cl [0.59–0.85]; above subgroup, OR 1.63, 95% Cl [1.39–1.92]) (macrosomia: above subgroup, OR 2.50, 95% Cl [1.58–3.95]). In the loss and small gain subgroups, the

Table 2 Maternal and neonatal outcomes for overweight women by weight change categories

variable		loss [a]GWG < 0 kg n = 182 (3.7%)	small 0 kg ≤ GWG < 7 kg n = 1,780 (36.0%)	within 7 kg ≤ GWG < 11.5 kg n = 1,877 (38.0%)	above 11.5 kg ≤ GWG n = 1,102 (22.3%)
[b]SGA	n (%)	20 (11.0%)	114 (6.4%)	90 (4.8%)	45 (4.1%)
	[e]OR (95% [f]Cl)	2.45 (1.45–4.15)	1.36 (1.03–1.80)	1	0.85 (0.59–1.22)
	*p value	0.001[#]	0.03*		0.37
[c]LGA	n (%)	19 (10.4%)	244 (13.7%)	345 (18.4%)	296 (26.9%)
	OR (95% Cl)	0.52 (0.32–0.84)	0.71 (0.59–0.85)	1	1.63 (1.39–1.92)
	p value	0.007[#]	0[#]		0[#]
[d]LBW	n (%)	26 (14.3%)	127 (7.1%)	89 (4.7%)	32 (2.9%)
	OR (95% Cl)	3.35 (2.05–5.47)	1.54 (1.16–2.06)	1	0.60 (0.41–0.89)
	p value	0[#]	0.003[#]		0.01*
macrosomia	n (%)	1 (0.6%)	30 (1.7%)	30 (1.6%)	43 (3.9%)
	OR (95% Cl)	0.34 (0.05–2.49)	1.06 (0.64–1.75)	1	2.50 (1.58–3.95)
	p value	0.29	0.84		0[#]
gestational hypertension	n (%)	10 (5.5%)	124 (7.0%)	153 (8.2%)	119 (10.8%)
	OR (95% Cl)	0.66 (0.34–1.25)	0.84 (0.66–1.08)	1	1.36 (1.06–1.76)
	p value	0.2	0.18		0.02*
Preeclampsia	n (%)	4 (2.2%)	37 (2.1%)	45 (2.4%)	50 (4.5%)
	OR (95% Cl)	0.92 (0.32–2.60)	0.86 (0.55–1.35)	1	1.94 (1.31–2.85)
	p value	0.87	0.52		0.001[#]
cesarean delivery	n (%)	54 (29.7%)	583 (32.8%)	618 (32.9%)	378 (34.3%)
	OR (95% Cl)	0.86 (0.61–1.22)	0.99 (0.86–1.14)	1	1.06 (0.92–1.23)
	p value	0.39	0.91		0.41
operative vaginal delivery	n (%)	19 (10.4%)	117 (6.6%)	117 (6.2%)	77 (7.0%)
	OR (95% Cl)	1.75 (1.05–2.94)	1.06 (0.82–1.38)	1	1.13 (0.84–1.51)
	p value	0.03*	0.67		0.41
5 min Apgar <7	n (%)	0	7 (0.4%)	10 (0.5%)	5 (0.5%)
	OR (95% Cl)	—	0.74 (0.26–2.11)	1	0.85 (0.27–2.66)
	p value	—	0.57		0.78
umbilical arterial pH <7	n (%)	0	3 (0.2%)	9 (0.5%)	2 (0.2%)
	OR (95% Cl)	—	0.35 (0.12–1.02)	1	0.38 (0.08–1.76)
	p value	—	0.55		0.22

[a]GWG, gestational weight gain
[b]SGA, small for gestational age
[c]LGA, large for gestational age
[d]LBW, low birth weight
[e]OR, odds ratio
[f]Cl, confidence interval
Logistic regression was used to adjust for confounding variables, including parity, maternal age, smoking, and gestational age, and generalized estimating equations (GEE) for logistic regression was used to adjust for the clustering of deliveries by hospitals.
A p value of <0.05 was considered statistically significant.
*p < 0.05
[#]p < 0.01

Table 3 Maternal and neonatal outcomes for obese women by weight change categories

variable		loss [a]GWG < 0 kg n = 250 (13.6%)	small 0 kg ≤ GWG < 5 kg n = 577 (31.4%)	within 5 kg ≤ GWG < 9 kg n = 560 (30.4%)	above 9 kg ≤ GWG n = 453 (24.6%)
[b]SGA	n (%)	17 (6.8%)	34 (5.9%)	27 (4.8%)	21 (4.6%)
	[e]OR (95% [f]Cl)	1.44 (0.74–2.82)	1.24 (0.68–2.23)	1	0.96 (0.55–1.69)
	*p value	0.29	0.48		0.89
[c]LGA	n (%)	33 (13.2%)	112 (19.4%)	142 (25.36%)	148 (32.67%)
	OR (95% Cl)	0.45 (0.30–0.67)	0.71 (0.54–0.93)	1	1.43 (1.09–1.88)
	p value	0[#]	0.013*		0.011*
[d]LBW	n (%)	23 (9.2%)	28 (4.9%)	26 (4.6%)	18 (4.0%)
	OR (95% Cl)	2.08 (1.14–3.81)	1.05 (0.60–1.82)	1	0.85 (0.48–1.50)
	p value	0.02*	0.87		0.58
macrosomia	n (%)	2 (0.8%)	15 (2.6%)	19 (3.4%)	31 (6.8%)
	OR (95% Cl)	0.23 (0.05–1.01)	0.76 (0.38–1.50)	1	2.09 (1.08–4.07)
	p value	0.05	0.43		0.03*
gestational hypertension	n (%)	30 (12.8%)	65 (11.3%)	73 (13.0%)	66 (14.6%)
	OR (95% Cl)	0.91 (0.59–1.40)	0.847 (0.60–1.19)	1	1.14 (0.79–1.63)
	p value	0.67	0.34		0.48
Preeclampsia	n (%)	8 (3.2%)	21 (3.6%)	24 (4.3%)	23 (5.1%)
	OR (95% Cl)	0.74 (0.35–1.55)	0.84 (0.48–1.50)	1	1.20 (0.66–2.17)
	p value	0.42	0.56		0.56
cesarean delivery	n (%)	85 (34.0%)	213 (36.9%)	119 (21.3%)	181 (40.0%)
	OR (95% Cl)	0.80 (0.60–1.08)	0.91 (0.72–1.16)	1	1.04 (0.81–1.33)
	p value	0.14	0.45		0.78
operative vaginal delivery	n (%)	17 (6.8%)	35 (6.1%)	33 (5.9%)	26 (5.7%)
	OR (95% Cl)	1.17 (0.64–2.12)	1.03 (0.62–1.72)	1	0.97 (0.59–1.60)
	p value	0.62	0.91		0.91
5 min Apgar <7	n (%)	6 (2.4%)	5 (0.9%)	7 (1.3%)	2 (0.4%)
	OR (95% Cl)	1.94 (0.65–5.81)	0.69 (0.24–1.99)	1	0.35 (0.09–1.42)
	p value	0.24	0.49		0.14
umbilical arterial pH <7	n (%)	0	2 (0.4%)	3 (0.5%)	2 (0.4%)
	OR (95% Cl)	—	0.65 (0.11–3.92)	1	0.82 (0.14–5.00)
	p value	—	0.64		0.83

[a]GWG, gestational weight gain
[b]SGA, small for gestational age
[c]LGA, large for gestational age
[d]LBW, low birth weight
[e]OR, odds ratio
[f]Cl, confidence interval
Logistic regression was used to adjust for confounding variables, including parity, maternal age, smoking, and gestational age, and generalized estimating equations (GEE) for logistic regression was used to adjust for the clustering of deliveries by hospitals.
A p value of <0.05 was considered statistically significant.
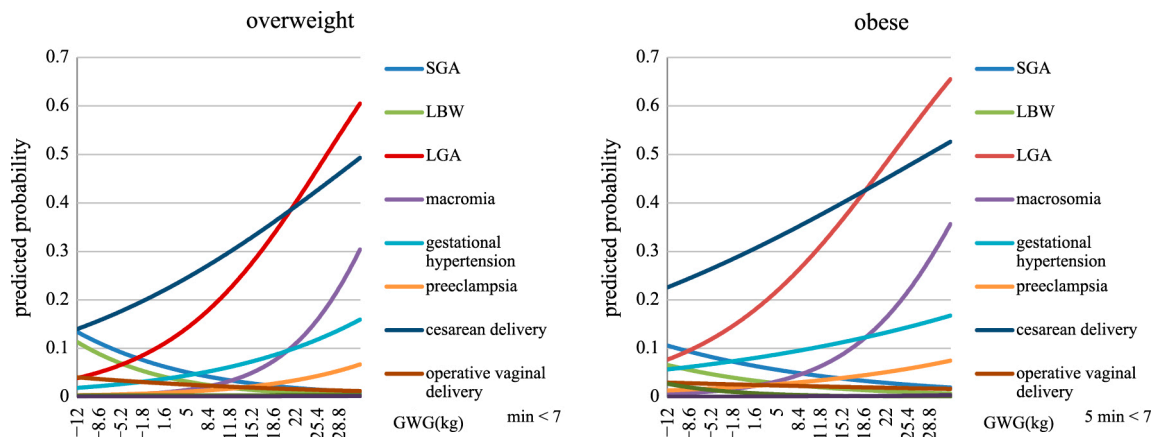*$p < 0.05$
[#]$p < 0.01$

Fig. 2 Predicted probabilities of all the 10 main maternal and neonatal outcomes by GWG as calculated by logistic regression models (overweight *n* = 4,941, obese *n* = 1,840).

SGA, small for gestational age; LBW, low birth weight; LGA, large for gestational age; UAPH, umbilical arterial pH; GWG, gestational weight gain

prevalence of SGA and LBW births significantly increased (SGA: loss subgroup, OR 2.45, 95% Cl [1.45–4.15]; small gain subgroup, OR 1.36, 95% Cl [1.03–1.80]; above subgroup, OR 0.85, 95% Cl [0.59–1.22]) (LBW: loss subgroup, OR 3.35, 95% Cl [2.05–5.47]; small gain subgroup, OR 1.54, 95% Cl [1.16–2.06]; above subgroup, OR 0.60, 95% Cl [0.41–0.89]). Although the prevalence of caesarean delivery, operative vaginal delivery, umbilical artery pH <7.0, and Apgar Score at 5 min of <7 were not clearly associated with GWG, the prevalence of gestational hypertension (OR 1.36, 95% Cl [1.06–1.76]) and pre-eclampsia (OR 1.94, 95% Cl [1.31–2.85]) were significantly higher in the above subgroup. On the other hand, an association between GWG and neonatal birth weight in the obese group was less apparent than that in the overweight group. As women gained more weight, the prevalence of LGA births increased (LGA: loss subgroup, OR 0.45, 95% Cl [0.30–0.67]; small gain subgroup, OR 0.71, 95% Cl [0.54–0.93]; above subgroup, OR 1.43, 95% Cl [1.09–1.88]), whereas the prevalence of SGA births tended to decrease, although this was not significant. Despite a lack of statistically significant differences, the loss subgroup showed the lowest prevalence of pre-eclampsia and caesarean delivery.

Predicted probabilities of primary outcomes

Fig. 2 shows the predicted probabilities of all primary outcomes. In the overweight group, the predicted probabilities of SGA and LBW births increased as weight gain

decreased. Meanwhile, as weight gain increased, the predicted probabilities of LGA births, macrosomia, caesarean delivery, gestational hypertension, and pre-eclampsia tended to increase. The predicted probabilities of operative vaginal delivery, umbilical artery pH <7.0, and an Apgar Score at 5 min of <7 were not associated with weight gain. Although similar trends were observed in the obese group, the tendency of the predicted probabilities of SGA and LBW births was less pronounced. The predicted probability of LBW births was always <10%.

Fig. 3 shows the predicted risk of SGA and LGA births by GWG as calculated by logistic regression models. The sum of the predicted probability of 20% was observed for GWG values between –12 and 5 kg in overweight women and less than –7 kg in obese women. Each value was much lower than the IOM-recommended weight gain.

Fig. 4 shows the predicted probabilities of the adverse outcomes, which indicated significant differences when compared to the IOM-recommended weight gain (overweight group: SGA, LBW, LGA, macrosomia, gestational hypertension, pre-eclampsia, and operative vaginal delivery; obese group: LBW, LGA, and macrosomia), and those of composite events. In the overweight group, as weight gain increased from the lowest point of ±0 kg, the risk increased. In particular, the risk sharply increased with a weight gain of approximately 11.5 kg. On the other hand, the obese group showed an increase in the risk along with weight gain; however, no increase
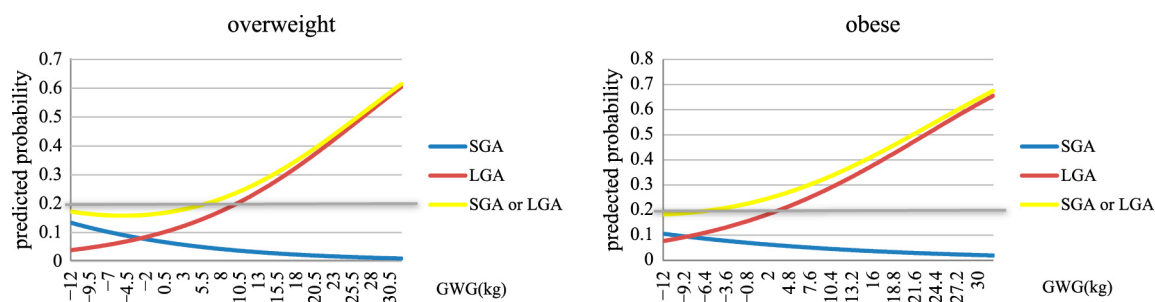
Fig. 3   Predicted probabilities of SGA and LGA births by GWG as calculated by logistic regression models (overweight *n* = 4,941, obese *n* = 1,840). The horizontal lines represent the limit of 20%.

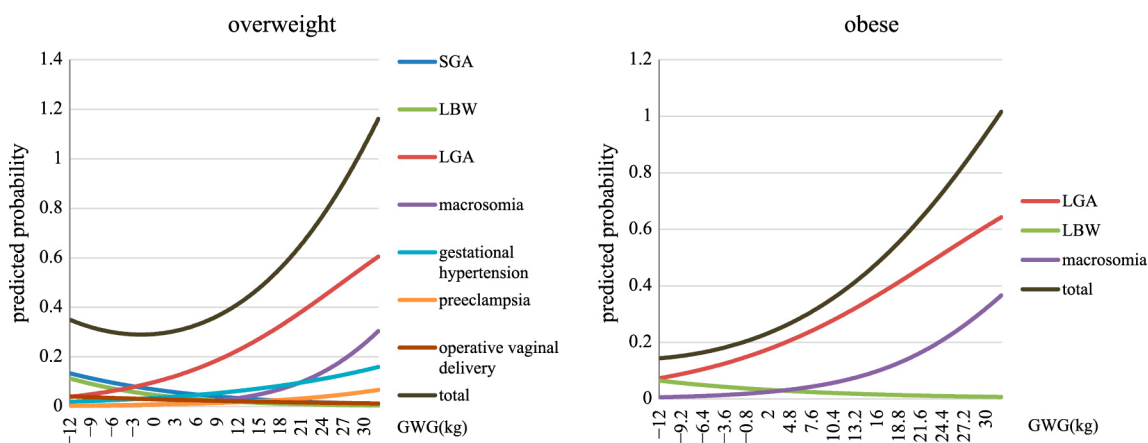SGA, small for gestational age; LGA, large for gestational age; GWG, gestational weight gain

Fig. 4   Predicted probabilities of SGA, LBW, LGA, macrosomia, gestational hypertension, preeclampsia, and operative vaginal delivery for overweight, LGA, LBW, and macrosomia for obese by GWG as calculated by logistic regression models (overweight *n* = 4,941, obese *n* = 1,840). There were statistically significant differences in the predicted probabilities of the outcomes.

SGA, small for gestational age; LBW, low birth weight; LGA, large for gestational age; GWG, gestational weight gain

in the risk due to weight loss was observed.

In the overweight group, the prevalence of SGA births increased in women with a weight gain within or below the IOM-recommended weight gain; this trend was particularly pronounced in those with weight loss. When the sum of predicted probabilities of SGA and LGA births was ≤20%, the optimal weight gain was between –12 and 5 kg. Regarding the predicted probabilities of the sum of SGA, LBW, LGA, macrosomia, gestational hypertension, preeclampsia, and operative vaginal delivery, which showed significant differences compared to the IOM-recommended weight gain, the lowest risk was observed in women with a weight gain of 0 kg, whereas the risk sharply increased in those with weight gain of approximately 11.5 kg. Based on these findings, the optimal weight gain for Japanese overweight pregnant

women was determined to range from 0 to 11.5 kg.

On the other hand, in the obese group, weight loss did not increase the prevalence of SGA births. When the sum of predicted probabilities of SGA and LGA births was ≤20%, the optimal weight gain was –7 kg. Higher weight gain was associated with higher predicted probabilities of the sum of LBW, LGA, and macrosomia, which showed significant differences compared to the IOM-recommended weight gain; therefore, weight loss was determined to be optimal for Japanese obese pregnant women.

Discussion

The results of the present study indicate that in either overweight or obese Japanese pregnant women, the

optimal weight gain that minimizes the risk of adverse maternal and neonatal outcomes has a much wider range than the IOM-recommended weight gain, and that a small weight gain is sufficient. In addition, we determined that the risk would be minimized with a weight gain of 0 to 11.5 kg in the overweight group and weight loss in the obese group.

In the overweight group, a weight gain of 0 to 11.5 kg was determined to minimize the risk without increasing poor maternal and neonatal outcomes. There are several preceding studies on weight gain in overweight pregnant women. Oken *et al.* [3] prospectively assessed the short-term and long-term outcomes of preterm birth, SGA birth, LGA birth, weight retention, and child obesity in pregnant women in Massachusetts, United States. They reported that the lowest prevalence of poor maternal and neonatal outcomes was observed in women with a weight loss of 0.03 kg/week; therefore, the preferable weight gain is lower than what is currently recommended by the IOM. In a retrospective study on pregnant women in Bavaria, Germany, Beyerlein *et al.* [11] reported that the range of weight gain that does not increase the risk of poor maternal and neonatal outcomes is considerably wide, and that overweight women might benefit from a lower weight gain than that recommended by the IOM, or weight loss in order to deliver infants with a normal birth weight. Although the results of these studies on pregnant women in Western countries were not directly applicable to our study on Japanese pregnant women, the results were consistent with ours.

Meanwhile, in overweight pregnant women, the most prominent problem associated with a weight gain lower than that recommended by the IOM is the increased risk of a SGA birth. Beyerlein *et al.* [21] reported that weight loss significantly increased the risk of a SGA birth in overweight pregnant women. Moreover, Calalano *et al.* [13], in a retrospective study on the effects of weight gain on the growth of infants in pregnant women in the United States, reported that a weight gain of ≤5 kg in overweight pregnant women increased the risk of a SGA birth; this resulted in delivery of infants with a decreased lean body mass, which is a risk factor for the development of future metabolic dysfunction due to ectopic fat accumulation.

In our study, the risk of SGA birth also significantly increased in the loss and small gain subgroups of the overweight group. However, because the prevalence of SGA birth is generally lower in overweight pregnant women than in those with a normal pre-pregnancy weight [20], the prevalence was still only 6.4%, even in the small gain subgroup of the present study. Given that the lowest predicted probability of composite adverse outcomes, which showed significant differences compared to the IOM-recommended weight gain was observed in women with a weight gain of 0 kg, the optimal weight gain for Japanese overweight pregnant women ranges from 0 to 11.5 kg, which encompasses the IOM-recommended weight gain. The present study indicates that this range is much wider than that of the IOM-recommended weight gain, and that a small weight gain can be sufficient.

In the obese group, weight loss minimized the risk without increasing poor maternal and neonatal outcomes. The loss subgroup showed no increase in the prevalence of SGA births, as well as the other poor maternal and neonatal outcomes. Since the IOM issued the recommendation for optimal GWG based on maternal and neonatal outcomes, several preceding studies have shown that weight loss could be recommended for obese pregnant women [3, 5, 8-11, 22, 23]. As with overweight pregnant women, the increased prevalence of SGA birth is also the problem associated with weight loss during pregnancy in obese pregnant women. No consensus has been reached on whether weight loss during pregnancy increases the risk of SGA birth in obese pregnant women. Bianco *et al.* [5] reported that the prevalence of SGA birth was only 4% in pregnant women with a BMI of >35 kg/m^2 who lost weight or kept it unchanged during pregnancy. Kiel *et al.* [8], who classified obese pregnant women into three groups (Class I: BMI 30–35 kg/m^2, Class II: BMI 35–40 kg/m^2, and Class III: BMI ≥40 kg/m^2), reported that the risk of a SGA birth was lower in Class II/III obese women with weight gain of <15 lb. Bogaerts *et al.* [10], who investigated the recommendable weight gain for obese pregnant women on the basis of optimal neonatal birth weight in accordance to obesity classes in Belgium, reported that maternal and neonatal outcomes were favourable without increased risk of SGA births in Class I women with a weight gain of 0 to 5 kg, Class II women with a weight loss of 0 to 5 kg, and Class III women with a weight loss of up to 15 kg. Meanwhile in a similar study, Beyerlein *et al.* [21] reported that the risk of SGA births significantly increased in Class I/II pregnant women with a weight loss of 0 to 5 kg, whereas weight loss during pregnancy was not associated with poor maternal or neonatal outcomes in Class III women. Although the obese group was not subdivided by the obesity classification in our study, the lowest predicted

probability of poor maternal and neonatal outcomes without increased risk of SGA birth was observed in the loss subgroup of the obese group. This suggests that weight loss is optimal for obese pregnant Japanese women.

The present study has several limitations. First, we used the database of the JSOG birth registry containing data from tertiary hospitals; this database had missing data from many pregnant women. Moreover, because this registry collects data from higher-level hospitals, it may have introduced selective bias in the patient background characteristics. Second, the risk of preterm birth was not evaluated. Preceding studies have demonstrated that inadequate weight gain increases the risk of preterm birth [24, 25]. Bodnar *et al.* [24] reported that a high weight gain increased the risk of medically indicated preterm births, while a low weight gain increased the risk of spontaneous preterm births in women with Class I and II obesity. Although we have revealed the association of preterm birth with Japanese and underweight women in our previous study [26], the association between weight loss and preterm birth in obese women remains unknown; prospective studies are necessary for elucidating this issue in the future. Third, we were unable to investigate the optimal weight gain for obese pregnant women according to the obesity classification because of the low prevalence of obesity in Japanese pregnant women. Subclassification of obese pregnant women may allow further investigation of the optimal weight for obese pregnant women. Fourth, the ten main outcomes of interest are all dealt as health problems of equal importance. However, although it is difficult to say whether a certain outcome is important than another, each outcome has a different impact on the health of mother and child. Thus such "weighing" of each outcome might be needed to make a definite conclusion. Finally, we did not examine the long-term outcomes of either the pregnant women or infants in this study. Nan *et al.* [27] reported that

excessive weight gain in overweight and obese pregnant women is strongly associated with increases in the weight and height of offspring in early infancy. Moreover, because GWG is directly associated with the risk of substantial postpartum weight retention and childhood obesity [3, 23, 25], there is a concern that pregnant women and their infants may develop lifestyle-related diseases in the future. To further investigate these problems, large-scale prospective studies on Japanese obese pregnant women are needed.

Conclusion

The optimal weight gain that minimized the risk of adverse birth weight outcomes in obese pregnant Japanese women had a much wider range than the IOM-recommended weight gain for both overweight and obese women, and that a small weight gain was sufficient. The optimal weight changes were a weight gain of 0 to 11.5 kg in overweight pregnant women and weight loss in obese pregnant women.

Disclosure

The authors declared no conflict of interest.

Author Contributions

Conceived and designed the experiments: JHN KE SA. Performed the experiments: JHN KE SA. Analyzed the data: JHN KE KS KK SA. Contributed reagents/materials/analysis tools: JHN KE SA. Wrote the paper: JHN SA. Supervised the study: EM

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References

1. Furber CM, McGowan L, Bower P, Kontopantelis E, Quenby S, *et al.* (2013) Antenatal interventions for reducing weight in obese woman for improving pregnancy outcome. *Cochrane Database Syst Rev* doi: 10.1002/14651858.CD009334.pub2.
2. American College of Obstetricians and Gynecologists (2013) ACOG Committee opinion no. 549: obesity in pregnancy. *Obstet Gynecol* 121: 213–217.
3. Oken E, Kleinman KP, Belfort MB, Hammitt JK, Gillman MW (2009) Associations of gestational weight gain with short- and longer-term maternal and child health outcomes. *Am J Epidemiol* 170: 173–180.
4. Institute of Medicine (US) and National Research Council (US) Committee to Reexamine IOM Pregnancy Weight Guidelines (2009) Weight gain during pregnancy; re-examining the guidelines. In: Rasmussen KM, Yaktine AL

(eds.) The National Academies Collection: Reports Funded by National Institutes of Health. National Academies Press (US), Washington (DC).

5. Bianco AT, Smilen SW, Davis Y, Lopez S, Lapinski R, *et al.* (1998) Pregnancy outcome and weight gain recommendations for the morbidly obese woman. *Obstet Gynecol* 91: 97–102.

6. Flick AA, Brookfield KF, de la Torre L, Tudela CM, Duthely L, *et al.* (2010) Excessive weight gain among obese women and pregnancy outcomes. *Am J Perinatol* 27: 333–338.

7. Hinkle SN, Sharma AJ, Dietz PM (2010) Gestational weight gain in obese mothers and associations with fetal growth. *Am J Clin Nutr* 92: 644–651.

8. Kiel DW, Dodson EA, Artal R, Boehmer TK, Leet TL (2007) Gestational weight gain and pregnancy outcomes in obese women: how much is enough? *Obstet Gynecol* 110: 752–758.

9. Blomberg M (2011) Maternal and neonatal outcomes among obese women with weight gain below the new institute of medicine recommendations. *Obstet Gynecol* 117: 1065–1070.

10. Bogaerts A, Ameye L, Martens E, Devlieger R (2015) Weight loss in obese pregnant women and risk for adverse perinatal outcomes. *Obstet Gynecol* 125: 566–575.

11. Beyerlein A, Schiessl B, Lack N, von Kries R (2009) Optimal gestational weight gain ranges for the avoidance of adverse birth weight outcomes: a novel approach. *Am J Clin Nutr* 90: 1552–1558.

12. Kominaiarek MA, Seligman NS, Dolin C, Gao W, Berghella V, *et al.* (2013) Gestational weight gain and obesity: is 20 pounds too much? *Am J Obstet Gynecol* 209: 214.e1–214.e11.

13. Catalano PM, Mele L, Landon MB, Ramin SM, Reddy UM, *et al.* (2014) Inadequate weight gain in overweight and obese pregnant women: what is the effect on fetal growth? *Am J Obstet Gynecol* 211: 137.e1–137.e7.

14. Murakami M, Ohmichi M, Takahashi T, Shibata A, Fukao A, *et al.* (2005) Pre-pregnancy body mass index as an important predictor of perinatal outcomes in Japanese. *Arch Gynecol Obstet* 271: 311–315.

15. Suzuki S (2016) Optimal weight gain during pregnancy in Japanese women. *J Clin Med Res* 8: 787–792.

16. Suzuki S (2017) Gestational weight gain in Japanese women with favorable perinatal outcomes. *J Clin Med Res* 9: 64–66.

17. Examination committee of criteria for 'obesity disease' in Japan; Japan society for the study of obesity (2002) New criteria for 'obesity disease' in Japan. *Circ J* 66: 987–992.

18. Minakami H, Maeda T, Fujii T, Hamada H, Iitsuka Y, *et al.* (2014) Guidelines for obstetrical practice in Japan: Japan Society of Obstetrics and Gynecology (JSOG) and Japan Association of Obstetricians and Gynecologists (JAOG) 2014 edition. *J Obstet Gynaecol Res* 40: 1469–1499.

19. Promotion Council for Healthy Parents and Children 21 (second edition). Ministry of Health, Labour and Welfare (2015).

20. Enomoto K, Aoki S, Toma R, Fujiwara K, Sakamaki K, *et al.* (2016) Pregnancy outcomes based on pre-pregnancy body mass index in Japanese women. *PLoS One* 11: e0157081.

21. Beyerlein A, Schiessl B, Lack N, von Kries R (2011) Associations of gestational weight loss with birth related outcome: a retrospective cohort study. *BJOG* 118: 55–61.

22. Nohr EA, Vaeth M, Baker JL, Sorensen T, Olsen J, *et al.* (2008) Combined associations of pre-pregnancy body mass index and gestational weight gain with the outcome of pregnancy. *Am J Clin Nutr* 87: 1750–1759.

23. Cedergren MI (2007) Optimal gestational weight gain for body mass index categories. *Obstet Gynecol* 110: 759–764.

24. Bodnar LM, Siega-Riz AM, Simhan HN, Himes KP, Abrams B (2010) Severe obesity, gestational weight gain, and adverse birth outcomes. *Am J Clin Nutr* 91: 1642–1648.

25. Margerison Zilko CE, Rehkopf D, Abrams B (2010) Association of maternal gestational weight gain with short-and long-term maternal and child health outcomes. *Am J Obstet Gynecol* 202: 574.e1–574.e8.

26. Fujiwara K, Aoki S, Kurasawa K, Okuda M, Takahashi T, *et al.* (2014) Associations of maternal pre-pregnancy underweight with small-for-gestational-age and spontaneous preterm birth, and optimal gestational weight gain in Japanese women. *J Obstet Gynecol Res* 40: 988–994.

27. Li N, Liu E, Guo J, Pan L, Li B, *et al.* (2013) Maternal prepregnancy body mass index and gestational weight gain on pregnancy outcomes. *PLoS One* 8: e82310.