


Association between gestational weight gain and pregnancy outcomes, neonatal birth weight, and maternal postpartum glucose tolerance in Japanese gestational diabetes mellitus patients: comparison of old and new gestational weight gain standards

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Abstract. In Japan, the guidelines for gestational weight gain (GWG) were revised in 2021. Under the new guidelines, pregnant women are recommended to increase their GWG. The aim of this study was to compare the incidence of adverse pregnancy outcomes (APOs), large for gestational age (LGA), and postpartum glucose tolerance in gestational diabetes mellitus (GDM) patients before and after the revised GWG standards. This retrospective cohort study enrolled 1,021 GDM patients who underwent prenatal glycemic control and a postpartum 75-g oral glucose tolerance test. The endpoint was the incidence of APOs, LGA, and postpartum impaired glucose tolerance (IGT) and diabetes mellitus (DM). There was no significant difference in the incidence of APOs and postpartum IGT and DM in GDM patients before and after the revised GWG standards. On the other hand, when the new GWG standards were applied to GDM patients, the incidence of LGA increased (adjusted odds ratio [aOR]; 1.764, 95% confidence interval [CI]; 1.180–2.637). In particular, when classified by pre-pregnancy body mass index, the incidence of LGA increased in the obese group (aOR; 5.944, 95% CI; 1.847–19.129). Future prospective cohort studies are needed to verify the efficacy and safety of appropriate GWG in Japanese GDM patients.

Key words: Gestational diabetes mellitus, Gestational weight gain, Large for gestational age, Body mass index, Pregnancy

Introduction

In mothers, abnormal pre-pregnancy body mass index (ppBMI) and gestational weight gain (GWG) are risk factors for adverse pregnancy outcomes (APOs) [1–4]. The Institute of Medicine (IOM) first published recommendations of appropriate GWG based on ppBMI for optimizing pregnancy outcomes in 1990, which were revised in 2009 [5, 6]. In Japan, the Japan Society of Obstetrics and Gynecology (JSOG) published recommended guidelines for appropriate GWG to prevent pregnancy toxemia in 1999 [7]. The GWG standards rec-

ommended by the JSOG were stricter than those recommended by the IOM. The GWG standards were revised by the Ministry of Health, Labour and Welfare (MHLW) in 2006. However, the GWG standards recommended by the MHLW were still lower than those recommended by the IOM [8]. On the other hand, the incidence of low birth weight (LBW) in Japan was approximately 9.5% as of 2015, which is significantly higher than in other developed countries [9]. The main contributing factors are speculated to be pre-pregnancy underweight mothers and inadequate GWG [10, 11]. Compared with appropriate for gestational age neonates, LBW neonates have approximately 2.3 times and 1.2 times higher risks of developing type 2 diabetes [12] and cardiovascular disease [13] in adulthood, respectively. The JSOG announced new guidelines for appropriate GWG in March 2021 [14], which are closer to the GWG standards recommended by the IOM (Table 1). The new guidelines are

Submitted Sep. 7, 2024; Accepted Dec. 30, 2024 as EJ24-0486

Released online in J-STAGE as advance publication Feb. 5, 2025

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Table 1 Guidelines for total GWG by ppBMI categories

	2009 IOM guidelines	2006 MHLW guidelines	2021 JSOG guidelines
Underweight: ppBMI < 18.5 kg/m ² (kg)	12.5–18.0	9.0–12.0	12.0–15.0
Normal weight: ppBMI = 18.5–24.9 kg/m ² (kg)	11.5–16.0	7.0–12.0	10.0–13.0
Obese 1 degree: ppBMI = 25.0–29.9 kg/m ² (kg)	7.0–11.5	≤5.0	7.0–10.0
Obese 2 degree: ppBMI ≥ 30 kg/m ² (kg)	5.0–9.0	≤5.0	≤5.0

The ppBMI categories followed the recommendations of the Japan Society for the Study of Obesity. GWG, gestational weight gain; ppBMI, pre-pregnancy body mass index; IOM, Institute of Medicine; MHLW, Ministry of Health, Labour and Welfare; JSOG, Japan Society of Obstetrics and Gynecology.

based on the GWG that results in the lowest risk of developing the following composite outcomes: LBW, macrosomia, delivery before 34 weeks, instrumental delivery, emergency cesarean delivery, and preeclampsia. However, increased GWG may increase the risk of large for gestational age (LGA) and macrosomia [3, 4]. There is concern about whether increased GWG in gestational diabetes mellitus (GDM), which is a risk factor of LGA, is acceptable [15]. A previous study reported that the revision of GWG standards has reduced the incidence of LBW in Japanese pregestational diabetes patients [16]. However, as of June 2024, no studies examining the effects of the revised GWG standards on Japanese GDM patients have been performed.

GDM is defined as “any degree of glucose intolerance with onset or first recognized during pregnancy” [17]. Even in mild cases, GDM has been reported to increase the risks of LGA, cesarean delivery, and postpartum diabetes by 1.7, 1.2, and 10 times, respectively, compared with pregnant women with normal glucose tolerance (NGT) [18, 19]. Nutritional therapy for GDM aims to provide adequate nutrition to pregnant women, ensure healthy fetal development, maintain good maternal glycemic control, and achieve adequate GWG [20]. The new GWG standards do not consider postpartum outcomes [14]. However, we hypothesized that excessive GWG in GDM patients would lead to the development of postpartum impaired glucose tolerance (IGT). Accordingly, applying the new GWG standards to GDM patients may result in an increased incidence of LGA and a deterioration in postpartum glucose tolerance. The aim of this study was to compare the incidence of APOs, LGA, and postpartum IGT and diabetes mellitus (DM) in GDM patients before and after the revised GWG standards.

Materials and Methods

The study was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical Research Involving Human Subjects, and with the approval of the NHO Kumamoto Medical Center

Ethics Review Committee (number: 1252). Since this was a retrospective, single-center, observational cohort study, the requirement for informed consent was waived. Instead, we applied the opt-out method, offering opportunities for refusal *via* the NHO Kumamoto Medical Center website.

Participants

This study enrolled 2,174 GDM patients who initially visited the Department of Diabetes and Endocrinology at NHO Kumamoto Medical Center between April 2018 and March 2023. GDM screening was performed according to JSOG recommendations [21]. Those who screened positive underwent a 75-g oral glucose tolerance test (OGTT) at an obstetrics and gynecology hospital and were diagnosed with GDM if they met the International Association of Diabetes and Pregnancy Study Groups’ GDM diagnostic criteria (defined as least one value greater than a fasting plasma glucose [PG] level of 92 mg/dL, a 1-h PG level of 180 mg/dL, or a 2-h PG level of 153 mg/dL) [17]. The enrolled GDM patients underwent glycemic control at NHO Kumamoto Medical Center during pregnancy and gave birth at an obstetrics and gynecology hospital. After delivery, 1,303 GDM patients underwent a 75-g OGTT at NHO Kumamoto Medical Center. We excluded the following patients: those who underwent a 75-g OGTT <6 weeks or ≥13 weeks after delivery ($n = 53$), those with maternal age at GDM diagnosis <18 years or ≥45 years ($n = 5$), those with ppBMI ≥ 30 kg/m² ($n = 81$), those who had a multiple pregnancy ($n = 29$), those who had a miscarriage ($n = 4$), those who had a stillbirth ($n = 5$), those with gestational age <28 weeks or ≥42 weeks ($n = 10$), residents other than Japanese nationality ($n = 5$), those with unclear GWG (outside the range of 0–20 kg) ($n = 49$), and missing data ($n = 77$), leaving a final target population of 1,021 GDM patients. The GWG standard of ppBMI ≥ 30 kg/m² was excluded from this study because it remained unchanged before and after the revision (Fig. 1).

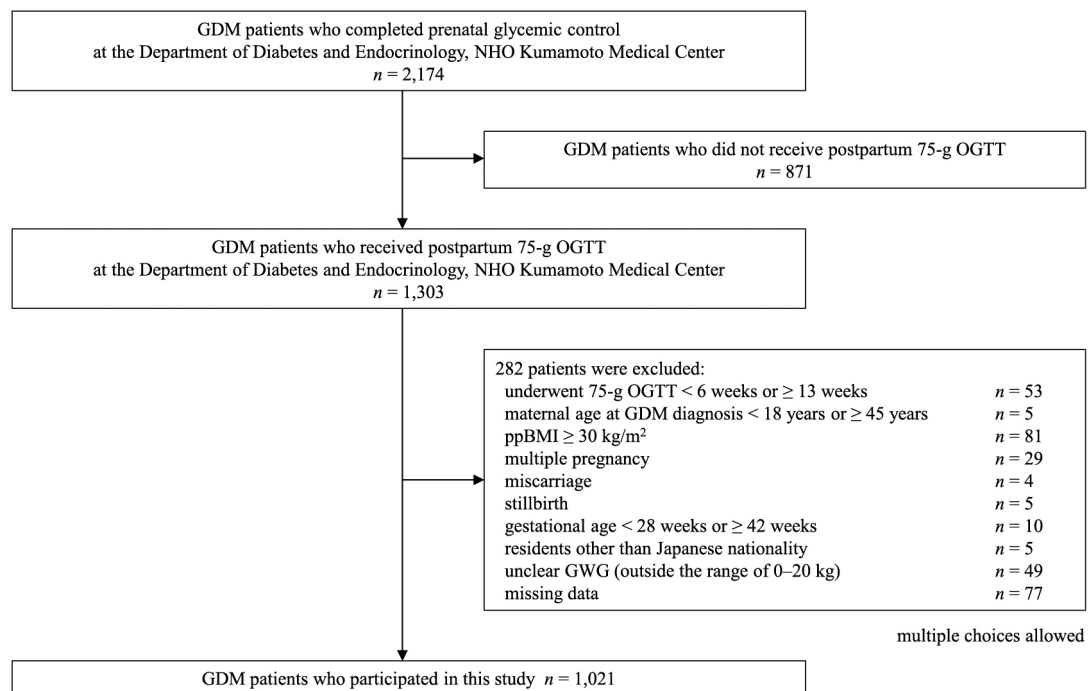


Fig. 1 Flowchart showing the number of participants. GDM, gestational diabetes mellitus; NHO, national hospital organization; OGTT, oral glucose tolerance test; ppBMI, pre-pregnancy body mass index; GWG, gestational weight gain.

Treatments

GDM patients received nutritional dietary guidance from a registered dietitian at their initial visit to NHO Kumamoto Medical Center. Daily required energy intake was calculated based on ideal body weight (BMI of 22) multiplied by 30 kcal. An additional 200 kcal was added if ppBMI was $<25 \text{ kg/m}^2$, and no additional energy intake was allocated if ppBMI was $\geq 25 \text{ kg/m}^2$ [21]. After the initial visit, GDM patients returned every 1–3 weeks for the measurement of 2-h postprandial PG levels. Additionally, patients eligible for self-monitoring of blood glucose under the Japanese medical insurance system self-measured 2-h postprandial PG levels three times a day. GDM patients whose 2-h postprandial PG levels exceeded 120 mg/dL were admitted to the hospital for medical nutritional therapy. If the glycemic targets of pre-prandial PG levels $<100 \text{ mg/dL}$ [21] or 2-h postprandial PG levels $<120 \text{ mg/dL}$ [22] were not achieved for three consecutive days after receiving medical nutritional therapy, insulin therapy was initiated. In addition, a physician from the NHO Kumamoto Medical Center recommended that GDM patients undergo a 75-g OGTT at 6–12 weeks postpartum [23].

Measurements

Maternal characteristics, including maternal age and gestational age at GDM diagnosis, birth experience, history of GDM, family history of diabetes (within 1st

degree relatives), ppBMI, 75-g OGTT PG levels (fasting, 1-h, and 2-h) and glycated hemoglobin (HbA1c) levels at GDM diagnosis, educational hospitalization for the purpose of glycemic control, insulin therapy introduction, GWG, and mode of delivery, were collected. The ppBMI categories were based on the criteria of the Japan Society for the Study of Obesity ($<18.5 \text{ kg/m}^2$ = underweight, $18.5\text{--}24.9 \text{ kg/m}^2$ = normal weight, $25.0\text{--}29.9 \text{ kg/m}^2$ = obese) [24–26]. The appropriate ranges for the old and new GWG standards were based on the MHLW (underweight = $9\text{--}12 \text{ kg}$, normal weight = $7\text{--}12 \text{ kg}$, obese = $\leq 5 \text{ kg}$) [8] and JSOG (underweight = $12\text{--}15 \text{ kg}$, normal weight = $10\text{--}13 \text{ kg}$, obese = $7\text{--}10 \text{ kg}$) [14] recommendations, respectively. Data on neonatal characteristics collected included sex, gestational age, and birth weight.

Data on APOs were collected on LBW, macrosomia, delivery before 34 weeks, instrumental delivery, emergency cesarean delivery, hypertensive disorders of pregnancy (HDP), and LGA. LBW and macrosomia were defined as birth weight $<2,500 \text{ g}$ and $\geq 4,000 \text{ g}$, respectively, regardless of gestational age [21]. LGA was defined as those with birth weight $\geq 90\text{th}$ percentile of the standard distributions for sex, birth experience, and gestational age [27].

To assess postpartum glucose tolerance, data were collected on 75-g OGTT PG levels, immunoreactive insulin (IRI) levels (fasting, 30, 60, 90, and 120-min), diagnostic classification, and HbA1c levels. The diagnostic

classification was as follows: NGT was defined as fasting PG levels <110 mg/dL and 2-h PG levels <140 mg/dL; IGT as fasting PG levels of 110–125 mg/dL, 1-h PG levels \geq 180 mg/dL, or 2-h PG levels of 140–199 mg/dL; and DM as fasting PG levels \geq 126 mg/dL or 2-h PG levels \geq 200 mg/dL [23]. In addition, homeostasis model assessment for beta cell function (HOMA- β ; fasting IRI levels [μ U/mL] \times 360/fasting PG levels [mg/dL]–63) [28] and insulinogenic index (30-min IRI levels [μ U/mL]–fasting IRI levels [μ U/mL]/30-min PG levels [mg/dL]–fasting PG levels [mg/dL]) [29] were calculated as indices of insulin secretory reserve. Homeostasis model assessment for insulin resistance (HOMA-IR; fasting PG levels [mg/dL] \times fasting IRI levels [μ U/mL]/405) [28] and insulin sensitivity index ($10,000/\sqrt{[\text{fasting PG levels \{mg/dL\} \times \text{fasting IRI levels \{μU/mL\}}] \times [\text{mean OGTT PG levels \{mg/dL\} \times \text{mean OGTT IRI levels \{μU/mL\}}]}}$) [30] were calculated as indices of insulin resistance.

Outcomes

The outcome measures were the incidence of LBW, macrosomia, delivery before 34 weeks, instrumental delivery, emergency cesarean delivery, HDP, LGA, and postpartum IGT and DM.

Statistical analysis

First, according to the old and new GWG standards, participants were stratified into inadequate GWG (iGWG), adequate GWG (aGWG), and excessive GWG (eGWG) groups, and comparisons of the three groups were performed. Then, a two-group comparison was performed between the old and new aGWG groups.

Measurements for continuous variables were expressed as mean \pm standard deviation or median (1st quartile–3rd quartile) after determining normality. For dichotomous variables, the results were expressed as frequencies (%). Comparisons between two independent groups were performed using Student's *t*-test or Mann-Whitney *U* test. Comparisons between three independent groups were performed using one-way ANOVA or Kruskal-Wallis test. Comparisons of independent categorical variables were conducted using the Chi-square test or Fisher's exact test. When significant differences were identified, post-hoc analyses were performed using the Tukey, Games-Howell, or Bonferroni methods. Bootstrapping methods were used to compare partially overlapping data.

Regarding APOs and postpartum IGT and DM: (1) the adjusted odds ratio (aOR) for the iGWG and eGWG groups were compared with those of the aGWG group, based on both the old and new GWG standards; and (2) the aOR of the new aGWG group was compared with that of the old aGWG group, with adjustments made for confounding variables reported in previous studies

[31–35]. Calculations were performed using multiple logistic regression analysis. Statistical analysis was performed using IBM SPSS Statistics 29.0 (IBM Japan, Tokyo, Japan). A *p*-value <0.05 was significant.

Results

The characteristics of all 1,021 patients with GDM are shown in Table 2.

Comparison of the incidence of outcomes by GWG categories

In the analysis using the old standards, the iGWG group was 223 patients (21.8%), aGWG group was 545 patients (53.4%), and eGWG group was 253 patients (24.8%). Postpartum HOMA- β , insulinogenic index, and HOMA-IR were significantly higher in the eGWG group, and insulin sensitivity index was significantly lower in the larger GWG categories (Supplementary Table 1). The incidence of LGA was significantly higher in the eGWG group (aOR; 2.652, 95% confidence interval [CI]; 1.783–3.944) and significantly lower in the iGWG group (aOR; 0.465, 95% CI; 0.242–0.893) compared with the aGWG group (Supplementary Table 2).

In the analysis using the new standards, the iGWG, aGWG, and eGWG groups consisted of 586 patients (57.4%), 309 patients (30.3%), and 126 patients (12.3%), respectively. Postpartum HOMA- β and HOMA-IR were significantly higher, and insulin sensitivity index was significantly lower in the eGWG group (Supplementary Table 1). The incidence of LGA was significantly lower in the iGWG group (aOR; 0.403, 95% CI; 0.263–0.616) than the aGWG group (Supplementary Table 2).

Comparison of the incidence of outcomes by the old and new aGWG groups

There were 545 patients in the old aGWG group (underweight group = 42, normal weight group = 419, obese group = 84) and 309 patients in the new aGWG group (underweight group = 31, normal weight group = 230, obese group = 48) (Supplementary Table 3). There was no significant difference in the incidence of APOs and postpartum IGT and DM in GDM patients before and after the revised GWG standards. On the other hand, when the new GWG standards were applied to GDM patients, the incidence of LGA increased (aOR; 1.764, 95% CI; 1.180–2.637). In particular, when classified by ppBMI, the incidence of LGA increased in the normal weight (aOR; 1.640, 95% CI; 1.039–2.587) and obese groups (aOR; 5.944, 95% CI; 1.847–19.129) (Table 3, Fig. 2).

Table 2 Characteristics of GDM patients

	<i>n</i> = 1,021
Maternal characteristics	
Maternal age at GDM diagnosis (years)	33.3 ± 5.0
Gestational age at GDM diagnosis (weeks)	24.0 (13.0–28.0)
Parity, <i>n</i> (%)	
Primiparous	493 (48.3)
Multiparous	528 (51.7)
History of GDM, <i>n</i> (%)	96 (9.4)
Family history of diabetes, <i>n</i> (%)	263 (25.8)
ppBMI (kg/m ²)	22.0 ± 3.1
GWG (kg)	8.6 ± 3.9
PG levels in 75-g OGTT at GDM diagnosis (mg/dL)	
Fasting	90.4 ± 9.1
At 1-h	164.2 ± 32.2
At 2-h	146.4 ± 27.8
HbA1c levels at GDM diagnosis (%)	5.2 ± 0.3
Educational hospitalization, <i>n</i> (%)	437 (42.8)
Insulin therapy, <i>n</i> (%)	504 (49.4)
Mode of delivery, <i>n</i> (%)	
Vaginal	714 (69.9)
Caesarean delivery	307 (30.1)
Neonatal characteristics	
Male, <i>n</i> (%)	492 (48.2)
Gestational age (weeks)	39.0 (38.0–40.0)
Preterm delivery (<37 weeks), <i>n</i> (%)	41 (4.0)
Birth weight (g)	3,055 ± 416
Adverse pregnancy outcomes	
LBW (<2,500g), <i>n</i> (%)	79 (7.7)
Macrosomia (≥4,000g), <i>n</i> (%)	7 (0.7)
Delivery before 34 weeks, <i>n</i> (%)	12 (1.2)
Instrumental delivery, <i>n</i> (%)	51 (5.0)
Emergency caesarean delivery, <i>n</i> (%)	142 (13.9)
HDP, <i>n</i> (%)	56 (5.5)
LGA (≥90 quartile), <i>n</i> (%)	141 (13.8)
Postpartum 75-g OGTT outcomes	
PG levels (mg/dL)	
Fasting	89.4 ± 8.2
At 30-min	149.8 ± 24.7
At 60-min	149.9 ± 35.9
At 90-min	135.5 ± 33.1
At 120-min	124.1 ± 28.0
IRI levels (μU/mL)	
Fasting	4.10 (2.85–5.83)
At 30-min	40.00 (28.70–59.45)
At 60-min	44.30 (31.50–62.65)
At 90-min	39.20 (28.00–55.35)
At 120-min	36.40 (25.30–52.80)
Postpartum 75-g OGTT diagnostic classification, <i>n</i> (%)	
NGT	681 (66.7)
IGT	323 (31.6)
DM	17 (1.7)
HOMA-β	56.98 (41.32–81.38)
Insulinogenic index	0.64 (0.41–0.97)
HOMA-IR	0.91 (0.61–1.33)
Insulin sensitivity index	7.49 (5.45–10.21)
HbA1c levels (%)	5.5 ± 0.3

Continuous variables are expressed as a mean ± standard deviation or a median (1st quartile–3rd quartile). Categorical variables are defined as *n* (%). GDM, gestational diabetes mellitus; ppBMI, pre-pregnancy body mass index; GWG, gestational weight gain; PG, plasma glucose; OGTT, oral glucose tolerance test; HbA1c, glycated hemoglobin; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age; IRI, immunoreactive insulin; NGT, normal glucose tolerance; IGT, impaired glucose tolerance; DM, diabetes mellitus; HOMA-β, homeostasis model assessment for beta cell function; HOMA-IR, homeostasis model assessment for insulin resistance.

Table 3 Comparison of the incidence of outcomes by the old and new aGWG groups

		ppBMI categories							
		Underweight group (ppBMI <18.5 kg/m ²)		Normal weight group (ppBMI = 18.5–24.9 kg/m ²)		Obese group (ppBMI = 25.0–29.9 kg/m ²)			
		Old standards aGWG group (n = 42)	New standards aGWG group (n = 31)	Old standards aGWG group (n = 419)	New standards aGWG group (n = 230)	Old standards aGWG group (n = 84)	New standards aGWG group (n = 48)		
Adverse pregnancy outcomes									
LBW (<2,500 g), n (%)		39 (7.2)	22 (7.1)	1 (2.4)	4 (12.9)	28 (6.7)	12 (5.2)	10 (11.9)	6 (12.5)
OR (95% CI)		1 (reference)	0.995 (0.559–1.652)	1 (reference)	6.074 (0.625–14.462)	1 (reference)	0.769 (0.350–1.532)	1 (reference)	1.057 (0.359–3.115)
aOR (95% CI)			0.936 (0.499–1.756)		—		0.849 (0.380–1.894)		0.586 (0.164–2.092)
Macrosomia (≥4,000 g), n (%)		3 (0.6)	2 (0.6)	0 (0.0)	0 (0.0)	2 (0.5)	2 (0.9)	1 (1.2)	0 (0.0)
OR (95% CI)		1 (reference)	1.177 (0.300–7.098)	1 (reference)	—	1 (reference)	1.829 (0.427–6.459)	1 (reference)	—
aOR ^a (95% CI)			—		—		—		—
Delivery before 34 weeks, n (%)		5 (0.9)	4 (1.3)	1 (2.4)	1 (3.2)	2 (0.5)	2 (0.9)	2 (2.4)	1 (2.1)
OR (95% CI)		1 (reference)	1.416 (0.301–6.752)	1 (reference)	1.367 (0.360–5.038)	1 (reference)	1.829 (0.425–8.041)	1 (reference)	0.872 (0.770–9.880)
aOR ^b (95% CI)			1.689 (0.445–6.416)		—		—		—
Instrumental delivery, n (%)		28 (5.1)	20 (6.5)	1 (2.4)	2 (6.5)	19 (4.5)	15 (6.5)	8 (9.5)	3 (6.3)
OR (95% CI)		1 (reference)	1.278 (0.693–2.277)	1 (reference)	2.828 (0.454–6.881)	1 (reference)	1.469 (0.665–3.159)	1 (reference)	0.633 (0.160–2.510)
aOR ^c (95% CI)			1.188 (0.647–2.183)		—		1.275 (0.625–2.601)		0.686 (0.157–3.009)
Emergency caesarean delivery, n (%)		78 (14.3)	41 (13.3)	7 (16.7)	5 (16.1)	56 (13.4)	30 (13.0)	15 (17.9)	6 (12.5)
OR (95% CI)		1 (reference)	0.916 (0.598–1.360)	1 (reference)	0.962 (0.205–3.863)	1 (reference)	0.972 (0.601–1.519)	1 (reference)	0.657 (0.237–1.825)
aOR ^c (95% CI)			0.838 (0.547–1.284)		0.603 (0.147–2.476)		0.891 (0.535–1.485)		0.545 (0.179–1.662)
HDP, n (%)		31 (5.7)	22 (7.1)	1 (2.4)	1 (3.2)	24 (5.7)	16 (7.0)	6 (7.1)	5 (10.4)
OR (95% CI)		1 (reference)	1.271 (0.686–2.158)	1 (reference)	1.367 (0.356–4.361)	1 (reference)	1.231 (0.651–2.271)	1 (reference)	1.512 (0.436–5.244)
aOR ^d (95% CI)			1.272 (0.709–2.279)		—		1.350 (0.687–2.655)		1.697 (0.336–8.564)
LGA (≥90 quartile), n (%)		60 (11.0)	54 (17.5)	4 (9.5)	1 (3.2)	50 (11.9)	41 (17.8)	6 (7.1)	12 (25.0)
OR (95% CI)		1 (reference)	1.712 (1.118–2.641)*	1 (reference)	0.317 (0.034–2.983)	1 (reference)	1.601 (1.006–2.570)*	1 (reference)	4.333 (1.506–12.465)*
aOR ^e (95% CI)			1.764 (1.180–2.637)*		—		1.640 (1.039–2.587)*		5.944 (1.847–19.129)*
Postpartum 75-g OGTT outcomes									
Postpartum 75-g OGTT IGT and DM, n (%)		170 (31.2)	93 (30.1)	9 (21.4)	10 (32.3)	136 (32.5)	63 (27.4)	25 (29.8)	20 (41.7)
OR (95% CI)		1 (reference)	0.950 (0.693–1.276)	1 (reference)	1.746 (0.563–6.102)	1 (reference)	0.785 (0.542–1.101)	1 (reference)	1.686 (0.804–3.534)
aOR ^f (95% CI)			0.970 (0.710–1.327)		1.653 (0.450–6.069)		0.828 (0.575–1.191)		1.355 (0.578–3.178)

Data are expressed as unadjusted or adjusted odds ratio (95% confidence interval). *p*-values were calculated using multiple logistic regression analysis. We used the bootstrap method to compare partially overlapping data. *p*-values <0.05 were significant, compared with the old standard aGWG group. *p*-values were expressed as **p*<0.05. The ppBMI categories followed the recommendations of the Japan Society for the Study of Obesity. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. OR, unadjusted odds ratio; aOR, adjusted odds ratio; APOs, adverse pregnancy outcomes; IGT, impaired glucose tolerance; DM, diabetes mellitus; GWG, gestational weight gain; aGWG, adequate GWG; ppBMI, pre-pregnancy body mass index; CI, confidence interval; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age. aOR is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, ppBMI, and HDP. aOR^a is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^b is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^c is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^d is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^e is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^f is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. HbA1c levels at GDM diagnosis, educational hospitalization, insulin therapy, and HDP.

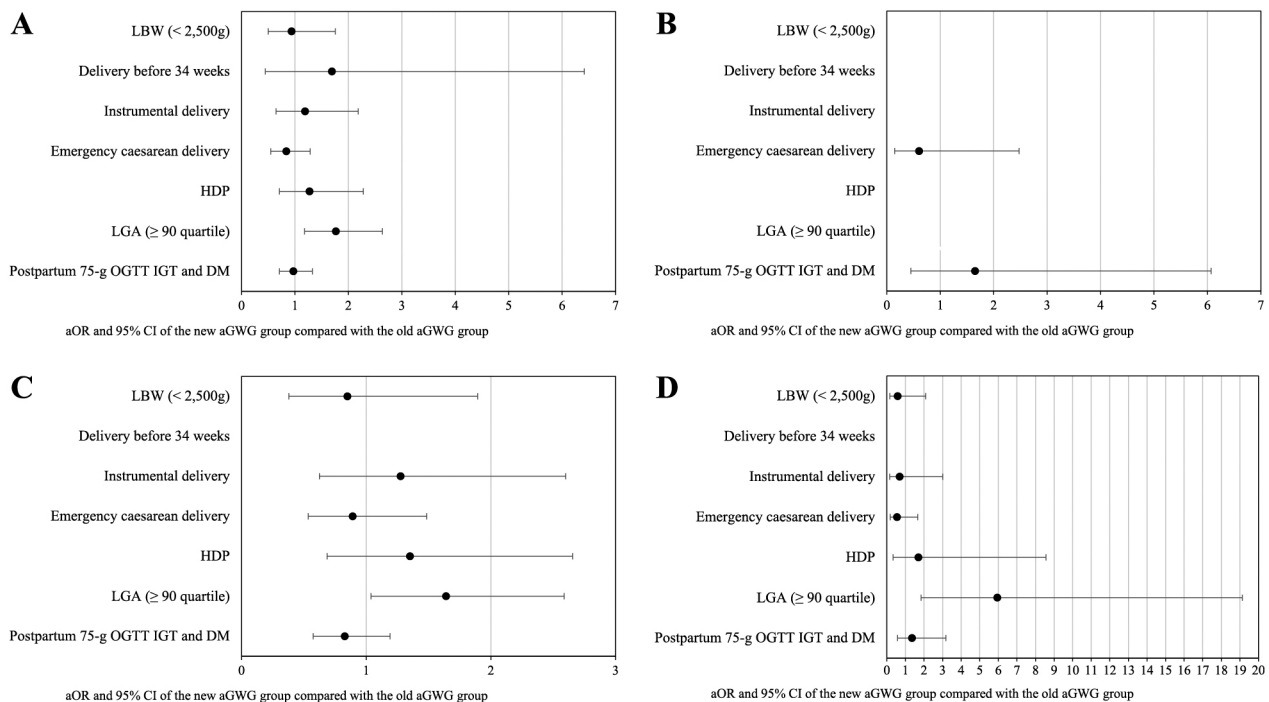


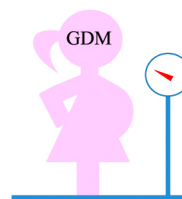
Fig. 2 The incidence of outcomes of the new aGWG group compared with the old aGWG group. (A) All cases. (B) Underweight group (ppBMI < 18.5 kg/m²). (C) Normal weight group (ppBMI = 18.5–24.9 kg/m²). (D) Obese group (ppBMI = 25.0–29.9 kg/m²). Data are expressed as adjusted odds ratio (95% confidence interval). *p*-values were calculated using multiple logistic regression analysis. We used the bootstrap method to compare partially overlapping data. *p*-values < 0.05 were significant, compared with the old standard aGWG group. The ppBMI categories followed the recommendations of the Japan Society for the Study of Obesity. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. aGWG, adequate gestational weight gain; aOR, adjusted odds ratio; CI, confidence interval; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age; OGTT, oral glucose tolerance test; IGT, impaired glucose tolerance; DM, diabetes mellitus; ppBMI, pre-pregnancy body mass index.

Discussion

There was no significant difference in the incidence of LBW in GDM patients before and after the revised GWG standards. This supports a previous study that reported no significant difference in the incidence of LBW in Chinese GDM patients between aGWG and iGWG groups based on standards recommended by the IOM [36, 37]. On the other hand, the incidence of LGA in GDM patients was higher in the eGWG group compared with the aGWG group. A previous studies reported that in Japanese GDM patients, there was a positive correlation between GWG and neonatal birth weight [38]. A study in Chinese GDM patients reported that the incidence of LGA was approximately 2.8 times higher in an eGWG group than an aGWG group based on the GWG standards recommended by the IOM [32], which supports the findings of previous studies. In the present study, when the new GWG standards were applied to GDM patients, the incidence of LGA increased. In particular, when classified by ppBMI, the incidence of LGA increased in the obese group (Graphical Abstract). However, there was

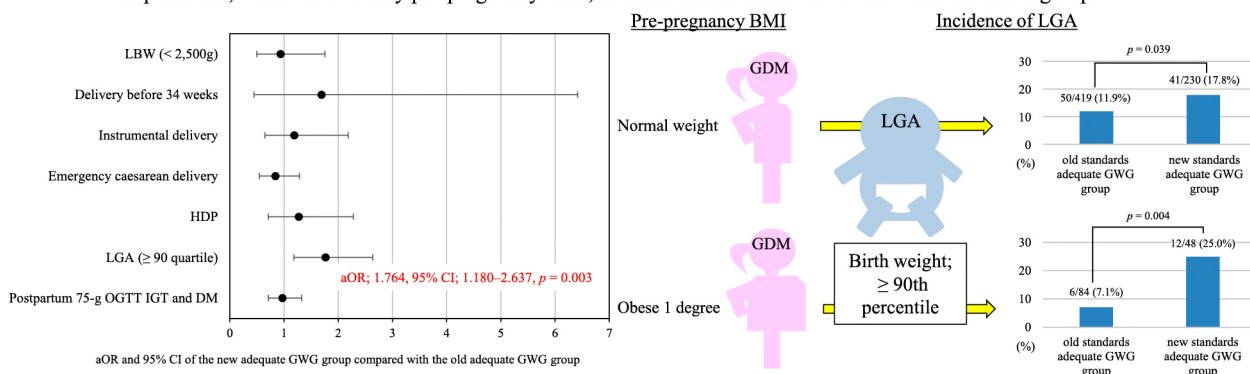
no significant difference in the incidence of postpartum IGT and DM in GDM patients before and after the revised GWG standards. Increased insulin resistance during pregnancy has been reported to be due to increases in insulin counterregulatory hormones, such as human placental lactogen, progesterone, and estrogen released from the placenta [39, 40], and in tumor necrosis factor- α , a proinflammatory cytokine produced in adipocytes [41]. As a result, in many pregnant women, insulin resistance declines rapidly after the placenta is delivered [42]. However, women with a history of GDM who have pre-pregnancy obesity [43] and postpartum obesity [44] are at increased risk of developing postpartum IGT and DM. In this study, there was no significant difference in the incidence of postpartum IGT and DM when GWG increase was allowed in GDM patients; however, postpartum insulin resistance was higher in larger GWG categories. Therefore, the tolerance of increased GWG in GDM patients may be related to the risk of developing diabetes in the future. Even after applying the new GWG standards, we believe that long-term follow-up of women with a history of GDM will remain important.

Pre-pregnancy BMI	2006 MHLW guidelines (old GWG adequate standards)	2021 JSOG guidelines (new GWG adequate standards)
Underweight: < 18.5 kg/m ²	9.0 – 12.0 kg	12.0 – 15.0 kg
Normal weight: 18.5 – 24.9 kg/m ²	7.0 – 12.0 kg	10.0 – 13.0 kg
Obese 1 degree: 25.0 – 29.9 kg/m ²	≤ 5.0 kg	7.0 – 10.0 kg
Obese 2 degree: ≥ 30kg/m ²	≤ 5.0 kg	≤ 5.0 kg



The aim of this study was to compare the incidence of APOs, LGA, and postpartum glucose tolerance in GDM patients before and after the revised GWG standards.

When the new GWG standards were applied to GDM patients, the incidence of LGA increased. In particular, when classified by pre-pregnancy BMI, the incidence of LGA was increased in the obese group.



This study has several limitations. First, selection bias cannot be ruled out because this study is not representative of the entire GDM population. Second, preeclampsia is included in the composite outcome for the development of the new GWG standards, but this was not investigated in this study and was substituted with HDP. Third, maternal ppBMI and GWG were calculated from self-reported pre-pregnancy and predelivery weight or from records in the Maternal and Child Health Handbook; thus, recall bias cannot be ruled out. Fourth, GWG management was performed by multiple obstetrician-gynecologists affiliated with different medical institutions. Therefore, it is unclear whether the GWG standards recommended by the IOM, MHLW, or JSOG were consistently used to manage GWG in the subjects in this study. Fifth, in order to compare the incidence of APOs, LGA, and postpartum glucose tolerance by old and new GWG standards, this study was conducted as a retrospective cohort study that could be started early, would be relatively less time consuming, and easier to pass research ethics review. On the other hand, because it is a retrospective cohort study, we were unable to verify the effectiveness and safety of the new GWG standards. A prospective cohort study based on the results of this study

is needed in the future. Furthermore, to clarify the validity of the results of this study, further studies in a wider area and larger population are necessary. A prospective cohort study of Japanese patients with GDM is necessary, incorporating the following into the protocol: (1) collaboration with an obstetrician-gynecologist and diabetologist, (2) a randomized controlled trial comparing the old and new GWG groups, (3) follow-up on maternal postpartum glucose tolerance, and (4) an investigation into the long-term prognosis of the children.

Pre-pregnancy obesity is a risk factor for developing GDM, with the incidence reportedly being approximately 2.1 times higher than in pregnant women with pre-pregnancy normal weight [45]. In this study, when the new GWG standards were applied to GDM patients, the incidence of LGA increased. In particular, when classified by ppBMI, the incidence of LGA was increased in the obese group. The present study recommends maintaining a normal weight before pregnancy when applying the new GWG standards to Japanese pregnant women.

Acknowledgments

The authors gratefully appreciate the very helpful

assistance of medical staff in NHO Kumamoto Medical Center. We would like to thank Medical English Service (www.med-english.com) for English language editing.

Disclosure

The authors declare no conflict of interest.

Contributions

A Yamashita was responsible for conceptualization, methodology, formal analysis, investigation, data cura-

tion, writing—original draft, visualization, and project administration. M Kaku, T Ideguchi, S Nishida, and H Kinoshita were responsible for conceptualization, methodology, writing—review & editing, and visualization. T Nishikawa was responsible for conceptualization, methodology, resources, writing—review & editing, and supervision.

Funding

This study was supported by grants from the Japan Association for Diabetes Education and Care.

Supplementary Table 1 Characteristics of GDM patients in the old and new standards by GWG categories

	Old GWG standards			<i>p</i> value	Post-hoc test		
	iGWG group (<i>n</i> = 223)	aGWG group (<i>n</i> = 545)	eGWG group (<i>n</i> = 253)		aGWG group vs. iGWG group	aGWG group vs. eGWG group	iGWG group vs. eGWG group
Maternal characteristics							
Maternal age at GDM diagnosis (years)	34.4 ± 4.6	33.1 ± 5.0	32.9 ± 5.0	0.001	0.003	0.826	0.003
Gestational age at GDM diagnosis (weeks)	24.0 (13.0–26.0)	24.0 (14.0–28.0)	24.0 (13.0–28.0)	0.099			
Parity, <i>n</i> (%)				0.157			
Primiparous	107 (48.0)	251 (46.1)	135 (53.4)				
Multiparous	116 (52.0)	294 (53.9)	118 (46.6)				
History of GDM, <i>n</i> (%)	21 (9.4)	49 (9.0)	26 (10.3)	0.846			
Family history of diabetes, <i>n</i> (%)	52 (23.3)	135 (24.8)	76 (30.0)	0.183			
ppBMI (kg/m ²)	20.7 ± 2.3	21.9 ± 3.0	23.3 ± 3.5	<0.001	<0.001	<0.001	<0.001
GWG (kg)	4.9 ± 1.8	8.4 ± 3.0	12.4 ± 3.7	<0.001	<0.001	<0.001	<0.001
PG levels in 75-g OGTT at GDM diagnosis (mg/dL)							
Fasting	88.5 ± 9.1	90.4 ± 8.8	92.0 ± 9.3	<0.001	0.024	0.055	<0.001
At 1-h	167.3 ± 32.6	162.9 ± 31.6	164.3 ± 33.2	0.226			
At 2-h	154.9 ± 28.2	144.6 ± 27.9	142.7 ± 25.6	<0.001	<0.001	0.626	<0.001
HbA1c levels at GDM diagnosis (%)	5.1 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	0.039	0.142	0.536	0.032
Educational hospitalization, <i>n</i> (%)	104 (46.6)	226 (41.5)	107 (42.3)	0.414			
Insulin therapy, <i>n</i> (%)	115 (51.6)	259 (47.5)	130 (51.4)	0.453			
Mode of delivery, <i>n</i> (%)				0.909			
Vaginal	157 (70.4)	378 (69.4)	179 (70.8)				
Caesarean delivery	66 (29.6)	167 (30.6)	74 (29.2)				
Neonatal characteristics							
Male, <i>n</i> (%)	103 (46.2)	260 (47.7)	129 (51.0)	0.548			
Gestational age (weeks)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	0.012	0.030	1.000	0.017
Preterm delivery (<37 weeks), <i>n</i> (%)	12 (5.4)	16 (2.9)	13 (5.1)	0.169			
Birth weight (g)	2,899 ± 377	3,059 ± 394	3,182 ± 450	<0.001	<0.001	<0.001	<0.001
Adverse pregnancy outcomes							
LBW (<2,500g), <i>n</i> (%)	25 (11.2)	39 (7.2)	15 (5.9)	0.075			
Macrosomia (≥4,000g), <i>n</i> (%)	0 (0.0)	3 (0.6)	4 (1.6)	0.112			
Delivery before 34 weeks, <i>n</i> (%)	3 (1.3)	5 (0.9)	4 (1.6)	0.476			
Instrumental delivery, <i>n</i> (%)	9 (4.0)	28 (5.1)	14 (5.5)	0.737			
Emergency caesarean delivery, <i>n</i> (%)	28 (12.6)	78 (14.3)	36 (14.2)	0.804			
HDP, <i>n</i> (%)	13 (5.8)	31 (5.7)	12 (4.7)	0.834			
LGA (≥90 quartile), <i>n</i> (%)	12 (5.4)	60 (11.0)	69 (27.3)	<0.001	0.045	<0.001	<0.001
Postpartum 75-g OGTT outcomes							
PG levels (mg/dL)							
Fasting	88.0 ± 7.6	89.4 ± 8.6	90.4 ± 7.5	0.005	0.067	0.231	0.003
At 30-min	148.0 ± 25.3	150.6 ± 25.4	149.6 ± 22.5	0.431			
At 60-min	149.3 ± 37.7	150.8 ± 36.6	148.5 ± 32.5	0.686			
At 90-min	136.9 ± 35.1	136.0 ± 33.7	133.2 ± 30.0	0.409			
At 120-min	125.6 ± 30.4	123.2 ± 27.7	124.9 ± 26.3	0.483			
IRI levels (μU/mL)							
Fasting	3.49 (2.56–5.35)	3.97 (2.74–5.62)	4.90 (3.48–6.86)	<0.001	0.075	<0.001	<0.001
At 30-min	37.80 (26.00–53.70)	39.00 (27.75–59.35)	45.00 (32.75–65.45)	<0.001	0.197	0.003	<0.001
At 60-min	40.30 (28.00–57.50)	44.60 (31.30–62.30)	49.60 (35.15–66.25)	<0.001	0.024	0.076	<0.001
At 90-min	37.60 (27.00–50.60)	39.10 (27.40–58.50)	41.70 (30.15–53.70)	0.130			
At 120-min	35.90 (23.80–50.40)	35.10 (24.70–50.50)	39.60 (26.80–56.00)	0.024	1.000	0.027	0.100
Postpartum 75-g OGTT diagnostic classification, <i>n</i> (%)							
NGT	141 (63.2)	375 (68.8)	165 (65.2)				
IGT	75 (33.6)	163 (29.9)	85 (33.6)				
DM	7 (3.1)	7 (1.3)	3 (1.2)				
HOMA-β	53.07 (37.69–72.80)	55.48 (40.30–79.18)	68.18 (47.35–89.82)	<0.001	0.565	<0.001	<0.001
Insulinogenic index	0.58 (0.38–0.87)	0.61 (0.40–0.95)	0.74 (0.47–1.16)	<0.001	0.378	0.001	<0.001
HOMA-IR	0.77 (0.51–1.15)	0.89 (0.58–1.24)	1.09 (0.77–1.60)	<0.001	0.061	<0.001	<0.001
Insulin sensitivity index	8.21 (6.01–11.78)	7.66 (5.61–10.31)	6.57 (4.93–8.63)	<0.001	0.026	<0.001	<0.001
HbA1c levels (%)	5.5 ± 0.3	5.5 ± 0.3	5.5 ± 0.3	0.315			

Continuous variables are expressed as mean ± standard deviation or median (1st quartile–3rd quartile). Categorical variables are defined as *n* (%). *p*-values were calculated using one-way ANOVA or Kruskal-Wallis test for continuous variables, and Chi-squared test or Fisher's exact test for categorical variables. If there were significant differences, post-hoc tests were performed using Tukey, Games-Howell, or Bonferroni. *p*-values <0.05 were significant. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. GDM, gestational diabetes mellitus; GWG, gestational weight gain; iGWG, inadequate GWG; aGWG, adequate GWG; eGWG, excessive GWG; ppBMI, pre-pregnancy body mass index; PG, plasma glucose; OGTT, oral glucose tolerance test; HbA1c, glycated hemoglobin; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age; IRI, immunoreactive insulin; NGT, normal glucose tolerance; IGT, impaired glucose tolerance; DM, diabetes mellitus; HOMA-β, homeostasis model assessment for beta cell function; HOMA-IR, homeostasis model assessment for insulin resistance.

Supplementary Table 1 Cont.

	New GWG standards			<i>p</i> value	Post-hoc test		
	iGWG group (<i>n</i> = 586)	aGWG group (<i>n</i> = 309)	eGWG group (<i>n</i> = 126)		aGWG group vs. iGWG group	aGWG group vs. eGWG group	iGWG group vs. eGWG group
Maternal characteristics							
Maternal age at GDM diagnosis (years)	33.8 ± 4.8	32.8 ± 5.1	32.7 ± 5.0	0.005	0.011	0.992	0.072
Gestational age at GDM diagnosis (weeks)	24.0 (13.0–27.0)	24.0 (13.0–29.0)	25.0 (14.0–29.0)	0.097			
Parity, <i>n</i> (%)				0.006	0.024	1.000	0.057
Primiparous	258 (44.0)	165 (53.4)	70 (55.6)				
Multiparous	328 (56.0)	144 (46.6)	56 (44.4)				
History of GDM, <i>n</i> (%)	62 (10.6)	25 (8.1)	9 (7.1)	0.311			
Family history of diabetes, <i>n</i> (%)	145 (24.7)	77 (24.9)	41 (32.5)	0.177			
ppBMI (kg/m ²)	22.0 ± 3.2	21.6 ± 2.9	23.1 ± 3.1	<0.001	0.134	<0.001	0.001
GWG (kg)	6.1 ± 2.6	10.8 ± 1.6	14.9 ± 2.5	<0.001	<0.001	<0.001	<0.001
PG levels in 75-g OGTT at GDM diagnosis (mg/dL)							
Fasting	89.8 ± 8.9	90.9 ± 9.4	91.9 ± 8.9	0.029	0.196	0.526	0.044
At 1-h	165.8 ± 32.1	161.2 ± 31.8	164.0 ± 33.8	0.130			
At 2-h	149.6 ± 28.3	142.2 ± 26.0	141.6 ± 27.5	<0.001	<0.001	0.973	0.009
HbA1c levels at GDM diagnosis (%)	5.2 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	0.093			
Educational hospitalization, <i>n</i> (%)	256 (43.7)	123 (39.8)	58 (46.0)	0.395			
Insulin therapy, <i>n</i> (%)	296 (50.5)	140 (45.3)	68 (54.0)	0.182			
Mode of delivery, <i>n</i> (%)				0.928			
Vaginal	407 (69.5)	218 (70.6)	89 (70.6)				
Caesarean delivery	179 (30.5)	91 (29.4)	37 (29.4)				
Neonatal characteristics							
Male, <i>n</i> (%)	282 (48.1)	144 (46.6)	66 (52.4)	0.549			
Gestational age (weeks)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	0.001	0.022	0.779	0.005
Preterm delivery (<37 weeks), <i>n</i> (%)	24 (4.1)	13 (4.2)	4 (3.2)	0.874			
Birth weight (g)	2,988 ± 399	3,091 ± 419	3,275 ± 403	<0.001	<0.001	<0.001	<0.001
Adverse pregnancy outcomes							
LBW (<2,500g), <i>n</i> (%)	53 (9.0)	22 (7.1)	4 (3.2)	0.073			
Macrosomia (≥4,000g), <i>n</i> (%)	2 (0.3)	2 (0.6)	3 (2.4)	0.049	1.000	0.444	0.123
Delivery before 34 weeks, <i>n</i> (%)	6 (1.0)	4 (1.3)	2 (1.6)	0.342			
Instrumental delivery, <i>n</i> (%)	25 (4.3)	20 (6.5)	6 (4.8)	0.351			
Emergency caesarean delivery, <i>n</i> (%)	79 (13.5)	41 (13.3)	22 (17.5)	0.467			
HDP, <i>n</i> (%)	28 (4.8)	22 (7.1)	6 (4.8)	0.319			
LGA (≥90 quartile), <i>n</i> (%)	49 (8.4)	54 (17.5)	38 (30.2)	<0.001	<0.001	0.009	<0.001
Postpartum 75-g OGTT outcomes							
PG levels (mg/dL)							
Fasting	89.1 ± 8.6	89.6 ± 7.5	90.2 ± 7.7	0.337			
At 30-min	149.6 ± 25.8	149.5 ± 23.4	151.4 ± 22.4	0.738			
At 60-min	151.1 ± 37.8	148.2 ± 33.0	148.6 ± 33.6	0.479			
At 90-min	137.7 ± 35.3	132.7 ± 29.7	132.3 ± 29.6	0.048	0.077	0.993	0.215
At 120-min	125.3 ± 29.9	121.7 ± 24.8	124.4 ± 25.9	0.188			
IRI levels (μU/mL)							
Fasting	3.85 (2.69–5.66)	4.11 (3.01–5.74)	5.10 (3.63–6.75)	<0.001	0.177	0.003	<0.001
At 30-min	38.20 (27.80–57.75)	44.00 (29.45–60.85)	46.00 (33.38–69.40)	<0.001	0.148	0.123	0.001
At 60-min	43.20 (30.68–62.23)	44.10 (31.75–60.75)	53.25 (35.65–74.03)	0.008	1.000	0.059	0.006
At 90-min	39.10 (27.58–57.05)	38.90 (28.00–53.10)	42.55 (29.83–55.38)	0.568			
At 120-min	35.95 (25.68–52.05)	35.60 (23.60–52.00)	39.35 (26.93–58.15)	0.103			
Postpartum 75-g OGTT diagnostic classification, <i>n</i> (%)							
NGT	383 (65.4)	216 (69.9)	82 (65.1)				
IGT	188 (32.1)	92 (29.8)	43 (34.1)				
DM	15 (2.6)	1 (0.3)	1 (0.8)				
HOMA-β	55.12 (38.44–79.97)	57.60 (43.66–79.79)	68.58 (50.67–89.95)	<0.001	0.329	0.009	<0.001
Insulinogenic index	0.60 (0.40–0.92)	0.67 (0.42–1.00)	0.74 (0.48–1.18)	0.005	0.322	0.191	0.005
HOMA-IR	0.86 (0.56–1.26)	0.91 (0.64–1.30)	1.12 (0.81–1.57)	<0.001	0.177	0.001	<0.001
Insulin sensitivity index	7.78 (5.67–10.62)	7.46 (5.51–10.02)	6.36 (4.63–8.50)	<0.001	0.499	0.010	<0.001
HbA1c levels (%)	5.5 ± 0.3	5.5 ± 0.3	5.5 ± 0.3	0.832			

Continuous variables are expressed as mean ± standard deviation or median (1st quartile–3rd quartile). Categorical variables are defined as *n* (%). *p*-values were calculated using one-way ANOVA or Kruskal-Wallis test for continuous variables, and Chi-squared test or Fisher's exact test for categorical variables. If there were significant differences, post-hoc tests were performed using Tukey, Games-Howell, or Bonferroni. *p*-values <0.05 were significant. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. GDM, gestational diabetes mellitus; GWG, gestational weight gain; iGWG, inadequate GWG; aGWG, adequate GWG; eGWG, excessive GWG; ppBMI, pre-pregnancy body mass index; PG, plasma glucose; OGTT, oral glucose tolerance test; HbA1c, glycated hemoglobin; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age; IRI, immunoreactive insulin; NGT, normal glucose tolerance; IGT, impaired glucose tolerance; DM, diabetes mellitus; HOMA-β, homeostasis model assessment for beta cell function; HOMA-IR, homeostasis model assessment for insulin resistance.

Supplementary Table 2 Comparison of the incidence of outcomes by GWG categories

	Old GWG standards			New GWG standards		
	iGWG group (<i>n</i> = 223)	aGWG group (<i>n</i> = 545)	eGWG group (<i>n</i> = 253)	iGWG group (<i>n</i> = 586)	aGWG group (<i>n</i> = 309)	eGWG group (<i>n</i> = 126)
Adverse pregnancy outcomes						
LBW (<2,500 g), <i>n</i> (%)	25 (11.2)	39 (7.2)	15 (5.9)	53 (9.0)	22 (7.1)	4 (3.2)
OR (95% CI)	1.638 (0.966–2.779)	1 (reference)	0.818 (0.442–1.513)	1.297 (0.773–2.176)	1 (reference)	0.428 (0.144–1.267)
aOR (95% CI)	1.296 (0.696–2.411)		0.580 (0.269–1.252)	1.173 (0.644–2.137)		0.309 (0.074–1.292)
Macrosomia (≥4,000 g), <i>n</i> (%)	0 (0.0)	3 (0.6)	4 (1.6)	2 (0.3)	2 (0.6)	3 (2.4)
OR (95% CI)	—	1 (reference)	2.902 (0.645–13.065)	0.526 (0.074–3.750)	1 (reference)	3.744 (0.618–22.681)
aOR ^a (95% CI)	—		1.363 (0.268–6.924)	0.239 (0.022–2.548)		2.220 (0.316–15.585)
Delivery before 34 weeks, <i>n</i> (%)	3 (1.3)	5 (0.9)	4 (1.6)	6 (1.0)	4 (1.3)	2 (1.6)
OR (95% CI)	1.473 (0.349–6.215)	1 (reference)	1.735 (0.462–6.516)	0.789 (0.221–2.816)	1 (reference)	1.230 (0.222–6.801)
aOR ^b (95% CI)	1.714 (0.386–7.615)		1.615 (0.360–5.675)	0.669 (0.185–2.425)		1.132 (0.191–6.699)
Instrumental delivery, <i>n</i> (%)	9 (4.0)	28 (5.1)	14 (5.5)	25 (4.3)	20 (6.5)	6 (4.8)
OR (95% CI)	0.777 (0.360–1.673)	1 (reference)	1.082 (0.559–2.092)	0.644 (0.352–1.179)	1 (reference)	0.722 (0.283–1.844)
aOR ^c (95% CI)	0.932 (0.409–2.125)		0.908 (0.458–1.801)	0.746 (0.397–1.403)		0.659 (0.248–1.753)
Emergency caesarean delivery, <i>n</i> (%)	28 (12.6)	78 (14.3)	36 (14.2)	79 (13.5)	41 (13.3)	22 (17.5)
OR (95% CI)	0.860 (0.541–1.366)	1 (reference)	0.993 (0.648–1.522)	1.019 (0.679–1.527)	1 (reference)	1.383 (0.786–2.434)
aOR ^c (95% CI)	0.795 (0.476–1.328)		0.775 (0.485–1.240)	1.034 (0.670–1.596)		1.332 (0.730–2.430)
HDP, <i>n</i> (%)	13 (5.8)	31 (5.7)	12 (4.7)	28 (4.8)	22 (7.1)	6 (4.8)
OR (95% CI)	1.026 (0.527–2.000)	1 (reference)	0.826 (0.417–1.636)	0.665 (0.368–1.165)	1 (reference)	0.652 (0.258–1.649)
aOR ^d (95% CI)	0.949 (0.470–1.918)		0.657 (0.314–1.374)	0.593 (0.327–1.075)		0.620 (0.236–1.627)
LGA (≥90 quartile), <i>n</i> (%)	12 (5.4)	60 (11.0)	69 (27.3)	49 (8.4)	54 (17.5)	38 (30.2)
OR (95% CI)	0.460 (0.242–0.872)*	1 (reference)	3.031 (2.062–4.456)**	0.431 (0.285–0.652)**	1 (reference)	2.039 (1.261–3.297)*
aOR ^e (95% CI)	0.465 (0.242–0.893)*		2.652 (1.783–3.944)**	0.403 (0.263–0.616)**		1.624 (0.984–2.681)
Postpartum 75-g OGTT outcomes						
Postpartum 75-g OGTT IGT and DM, <i>n</i> (%)	82 (36.8)	170 (31.2)	88 (34.8)	203 (34.6)	93 (30.1)	44 (34.9)
OR (95% CI)	1.283 (0.925–1.779)	1 (reference)	1.176 (0.858–1.613)	1.231 (0.915–1.656)	1 (reference)	1.246 (0.803–1.934)
aOR ^f (95% CI)	1.346 (0.949–1.908)		1.140 (0.815–1.594)	1.213 (0.891–1.652)		1.082 (0.677–1.728)

Data are expressed as unadjusted or adjusted odds ratio (95% confidence interval). *p*-values were calculated using multiple logistic regression analysis. *p*-values <0.05 were significant, compared with the aGWG group. *p*-values were expressed as **p*<0.05, ***p*<0.001. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. OR, unadjusted odds ratio; aOR, adjusted odds ratio; APOs, adverse pregnancy outcomes; IGT, impaired glucose tolerance; DM, diabetes mellitus; GWG, gestational weight gain; iGWG, inadequate GWG; aGWG, adequate GWG; eGWG, excessive GWG; CI, confidence interval; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age. aOR is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, ppBMI, and HDP. aOR^a is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, ppBMI, and HDP. aOR^b is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, ppBMI, and HDP. aOR^c is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^d is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^e is adjusted for maternal age at GDM diagnosis, primiparous, gestational age, male, and ppBMI. aOR^f is adjusted for maternal age at GDM diagnosis, history of GDM, family history of diabetes, ppBMI, HbA1c levels at GDM diagnosis, educational hospitalization, insulin therapy, and HDP.

Supplementary Table 3 Characteristics of GDM patients in the old and new standards aGWG groups by ppBMI categories

	Old standards aGWG group (<i>n</i> = 545)	New standards aGWG group (<i>n</i> = 309)	ppBMI categories						<i>p</i> value	
			Underweight group (ppBMI < 18.5 kg/m ²)		Normal weight group (ppBMI = 18.5–24.9 kg/m ²)		Obese group (ppBMI = 25.0–29.9 kg/m ²)			
			Old standards aGWG group (<i>n</i> = 42)	New standards aGWG group (<i>n</i> = 31)	Old standards aGWG group (<i>n</i> = 419)	New standards aGWG group (<i>n</i> = 230)	Old standards aGWG group (<i>n</i> = 84)	New standards aGWG group (<i>n</i> = 48)		
Maternal characteristics										
Maternal age at GDM diagnosis (years)	33.1 ± 5.0	32.8 ± 5.1	31.5 ± 4.8	32.5 ± 4.8	33.4 ± 5.0	32.5 ± 5.3	32.5 ± 4.9	34.1 ± 4.4	0.065	
Gestational age at GDM diagnosis (weeks)	24.0 (14.0–28.0)	24.0 (13.0–29.0)	25.0 (14.8–29.0)	24.0 (12.0–29.0)	25.0 (14.0–29.0)	24.5 (13.0–29.0)	24.0 (13.5–25.0)	24.0 (12.3–28.8)	0.561	
Parity, <i>n</i> (%)									0.015	
Primiparous	251 (46.1)	165 (53.4)	20 (47.6)	16 (51.6)	193 (46.1)	129 (56.1)	38 (45.2)	20 (41.7)		
Multiparous	294 (53.9)	144 (46.6)	22 (52.4)	15 (48.4)	226 (53.9)	101 (43.9)	46 (54.8)	28 (58.3)		
History of GDM, <i>n</i> (%)	49 (9.0)	25 (8.1)	3 (7.1)	3 (9.7)	36 (8.6)	13 (5.7)	10 (11.9)	9 (18.8)	0.175	0.281
Family history of diabetes, <i>n</i> (%)	135 (24.8)	77 (24.9)	9 (21.4)	7 (22.6)	101 (24.1)	52 (22.6)	25 (29.8)	18 (37.5)	0.668	0.361
ppBMI (kg/m ²)	21.9 ± 3.0	21.6 ± 2.9	17.7 ± 0.5	17.4 ± 0.7	21.2 ± 1.7	21.1 ± 1.6	27.3 ± 1.6	26.6 ± 1.3	0.298	0.011
GWG (kg)	8.4 ± 3.0	10.8 ± 1.6	10.6 ± 1.2	12.9 ± 0.9	9.4 ± 1.5	11.1 ± 1.0	2.4 ± 1.6	8.3 ± 1.1	<0.001	<0.001
PG levels in 75-g OGTT at GDM diagnosis (mg/dL)										
Fasting	90.4 ± 8.8	90.9 ± 9.4	88.4 ± 9.1	88.6 ± 13.3	90.2 ± 9.0	90.6 ± 8.8	92.6 ± 7.2	93.8 ± 8.2	0.533	0.400
At 1-h	162.9 ± 31.6	161.2 ± 31.8	157.7 ± 38.9	158.5 ± 39.3	162.0 ± 31.4	159.2 ± 31.1	169.9 ± 27.6	172.9 ± 27.9	0.251	0.544
At 2-h	144.6 ± 27.9	142.2 ± 26.0	140.7 ± 30.8	146.6 ± 23.0	144.8 ± 27.7	141.0 ± 27.4	145.6 ± 27.5	145.2 ± 20.6	0.085	0.925
HbA1c levels at GDM diagnosis (%)	5.2 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	5.2 ± 0.3	5.3 ± 0.3	0.986	0.021
Educational hospitalization, <i>n</i> (%)	226 (41.5)	123 (39.8)	13 (31.0)	14 (45.2)	174 (41.5)	89 (38.7)	39 (46.4)	20 (41.7)	0.482	0.597
Insulin therapy, <i>n</i> (%)	259 (47.5)	140 (45.3)	17 (40.5)	16 (51.6)	201 (48.0)	98 (42.6)	41 (48.8)	26 (54.2)	0.190	0.554
Mode of delivery, <i>n</i> (%)									0.641	0.439
Vaginal	378 (69.4)	218 (70.6)	28 (66.7)	24 (77.4)	297 (70.9)	167 (72.6)	53 (63.1)	27 (56.3)		
Caesarean delivery	167 (30.6)	91 (29.4)	14 (33.3)	7 (22.6)	122 (29.1)	63 (27.4)	31 (36.9)	21 (43.8)		
Neonatal characteristics										
Male, <i>n</i> (%)	260 (47.7)	144 (46.6)	21 (50.0)	12 (38.7)	201 (48.0)	105 (45.7)	38 (45.2)	27 (56.3)	0.571	0.223
Gestational age (weeks)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	40.0 (38.0–40.0)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	39.0 (38.0–40.0)	38.0 (38.0–39.8)	0.122	0.058
Preterm delivery (<37 weeks), <i>n</i> (%)	16 (2.9)	13 (4.2)	1 (2.4)	3 (9.7)	11 (2.6)	5 (2.2)	4 (4.8)	5 (10.4)	0.723	0.285
Birth weight (g)	3,059 ± 394	3,091 ± 419	3,077 ± 372	2,969 ± 443	3,065 ± 388	3,115 ± 396	3,018 ± 436	3,056 ± 497	0.133	0.649

Continuous variables are expressed as mean ± standard deviation or median (1st quartile–3rd quartile). Categorical variables are defined as *n* (%). *p*-values were calculated using Student's *t*-test or Mann-Whitney *U* test for continuous variables, and Chi-squared test or Fisher's exact test for categorical variables. In addition, we used the bootstrap method to compare partially overlapping data. *p*-values <0.05 were significant. The ppBMI categories followed the recommendations of the Japan Society for the Study of Obesity. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. GDM, gestational diabetes mellitus; GWG, gestational weight gain; aGWG, adequate GWG; ppBMI, pre-pregnancy body mass index; PG, plasma glucose; OGTT, oral glucose tolerance test; HbA1c, glycated hemoglobin; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age; IRL, immunoreactive insulin; NGT, normal glucose tolerance; DM, diabetes mellitus; HOMA-β, homeostasis model assessment for beta cell function; HOMA-IR, homeostasis model assessment for insulin resistance.

Supplementary Table 3 Cont.

	ppBMI categories											
	Old standards aGWG group (<i>n</i> = 545)	New standards aGWG group (<i>n</i> = 309)	<i>p</i> value	Underweight group (ppBMI < 18.5 kg/m ²)		<i>p</i> value	Normal weight group (ppBMI = 18.5–24.9 kg/m ²)		<i>p</i> value	Obese group (ppBMI = 25.0–29.9 kg/m ²)		<i>p</i> value
				Old standards aGWG group (<i>n</i> = 42)	New standards aGWG group (<i>n</i> = 31)		Old standards aGWG group (<i>n</i> = 419)	New standards aGWG group (<i>n</i> = 230)		Old standards aGWG group (<i>n</i> = 84)	New standards aGWG group (<i>n</i> = 48)	
Adverse pregnancy outcomes												
LBW (<2,500g), <i>n</i> (%)	39 (7.2)	22 (7.1)	0.984	1 (2.4)	4 (12.9)	0.156	28 (6.7)	12 (5.2)	0.458	10 (11.9)	6 (12.5)	0.920
Macrosomia (≥4,000g), <i>n</i> (%)	3 (0.6)	2 (0.6)	1.000	0 (0.0)	0 (0.0)	—	2 (0.5)	2 (0.9)	0.618	1 (1.2)	0 (0.0)	1.000
Delivery before 34 weeks, <i>n</i> (%)	5 (0.9)	4 (1.3)	0.421	1 (2.4)	1 (3.2)	0.672	2 (0.5)	2 (0.9)	0.445	2 (2.4)	1 (2.1)	0.701
Instrumental delivery, <i>n</i> (%)	28 (5.1)	20 (6.5)	0.416	1 (2.4)	2 (6.5)	0.571	19 (4.5)	15 (6.5)	0.277	8 (9.5)	3 (6.3)	0.745
Emergency caesarean delivery, <i>n</i> (%)	78 (14.3)	41 (13.3)	0.672	7 (16.7)	5 (16.1)	0.951	56 (13.4)	30 (13.0)	0.908	15 (17.9)	6 (12.5)	0.418
HDP, <i>n</i> (%)	31 (5.7)	22 (7.1)	0.405	1 (2.4)	1 (3.2)	1.000	24 (5.7)	16 (7.0)	0.534	6 (7.1)	5 (10.4)	0.527
LGA (≥90 quartile), <i>n</i> (%)	60 (11.0)	54 (17.5)	0.008	4 (9.5)	1 (3.2)	0.387	50 (11.9)	41 (17.8)	0.039	6 (7.1)	12 (25.0)	0.004
Postpartum 75-g OGTT outcomes												
PG levels (mg/dL)												
Fasting	89.4 ± 8.6	89.6 ± 7.5	0.769	86.1 ± 5.6	88.6 ± 6.9	0.089	89.2 ± 7.3	89.2 ± 7.4	0.969	92.2 ± 13.7	92.2 ± 7.8	0.989
At 30-min	150.6 ± 25.4	149.5 ± 23.4	0.544	150.4 ± 25.8	150.7 ± 26.4	0.962	150.4 ± 24.2	149.7 ± 23.4	0.761	151.8 ± 31.1	147.7 ± 21.9	0.426
At 60-min	150.8 ± 36.6	148.2 ± 33.0	0.290	140.6 ± 34.9	146.6 ± 34.0	0.465	150.9 ± 35.1	146.9 ± 33.5	0.171	155.3 ± 43.6	155.2 ± 29.4	0.993
At 90-min	136.0 ± 33.7	132.7 ± 29.7	0.148	123.6 ± 29.0	133.0 ± 36.0	0.214	136.5 ± 32.1	130.8 ± 28.6	0.019	140.2 ± 41.4	141.6 ± 29.8	0.832
At 120-min	123.2 ± 27.7	121.7 ± 24.8	0.437	115.1 ± 22.9	128.8 ± 28.7	0.031	122.8 ± 26.1	119.0 ± 23.7	0.067	128.9 ± 35.5	130.3 ± 24.5	0.806
IRI levels (μU/mL)												
Fasting	3.97 (2.74–5.62)	4.11 (3.01–5.74)	0.183	3.13 (2.41–4.26)	3.40 (2.79–4.23)	0.503	3.84 (2.67–5.38)	3.95 (2.99–5.55)	0.143	5.57 (3.98–8.12)	5.79 (3.78–7.67)	0.863
At 30-min	39.00 (27.75–59.35)	44.00 (29.45–60.85)	0.258	38.40 (28.30–61.68)	37.20 (21.90–61.40)	0.584	37.90 (26.90–57.10)	44.50 (28.28–60.73)	0.134	43.95 (30.95–74.63)	44.00 (34.70–60.70)	0.833
At 60-min	44.60 (31.30–62.30)	44.10 (31.75–60.75)	0.987	47.15 (23.60–62.33)	37.60 (24.80–53.70)	0.562	43.50 (30.50–60.50)	43.60 (31.13–60.50)	0.700	49.15 (39.80–71.88)	51.70 (36.48–71.43)	0.835
At 90-min	39.10 (27.40–58.50)	38.90 (28.00–53.10)	0.640	37.60 (23.78–50.70)	36.30 (24.20–49.40)	0.784	38.10 (27.00–57.20)	38.25 (26.40–55.80)	0.768	46.15 (32.65–67.00)	43.45 (35.83–53.95)	0.726
At 120-min	35.10 (24.70–50.50)	35.60 (23.60–52.00)	0.975	30.85 (21.98–42.13)	38.70 (27.40–45.80)	0.267	34.20 (24.10–50.00)	34.25 (23.18–51.23)	0.824	39.35 (30.85–62.98)	42.85 (27.00–63.10)	0.960
Postpartum 75-g OGTT diagnostic classification, <i>n</i> (%)												
NGT	375 (68.8)	216 (69.9)	0.372	33 (78.6)	21 (67.7)	0.297	283 (67.5)	167 (72.6)	0.180	59 (70.2)	28 (58.3)	0.288
IGT	163 (29.9)	92 (29.8)		9 (21.4)	10 (32.3)		132 (31.5)	63 (27.4)		22 (26.2)	19 (39.6)	
DM	7 (1.3)	1 (0.3)		0 (0.0)	0 (0.0)		4 (1.0)	0 (0.0)		3 (3.6)	1 (2.1)	
HOMA-β	55.48 (40.30–79.18)	57.60 (43.66–79.79)	0.216	48.43 (38.18–76.62)	46.39 (37.13–62.40)	0.639	53.86 (38.90–72.45)	56.96 (43.28–76.99)	0.074	83.39 (51.43–107.58)	76.07 (50.61–97.42)	0.600
Insulinogenic index	0.61 (0.40–0.95)	0.67 (0.42–1.00)	0.254	0.58 (0.43–1.02)	0.56 (0.34–1.00)	0.676	0.58 (0.38–0.90)	0.63 (0.39–1.00)	0.188	0.76 (0.48–1.08)	0.75 (0.50–0.96)	0.992
HOMA-IR	0.89 (0.58–1.24)	0.91 (0.64–1.30)	0.186	0.70 (0.50–0.87)	0.75 (0.61–0.86)	0.284	0.85 (0.57–1.18)	0.90 (0.63–1.21)	0.173	1.27 (0.89–1.78)	1.38 (0.85–1.83)	0.795
Insulin sensitivity index	7.66 (5.61–10.31)	7.46 (5.51–10.02)	0.437	9.14 (7.18–11.76)	8.01 (6.79–9.81)	0.267	7.93 (5.77–10.64)	7.68 (5.76–10.42)	0.451	6.03 (3.89–7.73)	5.50 (4.53–7.73)	0.917
HbA1c levels (%)	5.5 ± 0.3	5.5 ± 0.3	0.876	5.4 ± 0.2	5.5 ± 0.2	0.558	5.5 ± 0.3	5.5 ± 0.3	0.624	5.5 ± 0.5	5.6 ± 0.3	0.782

Continuous variables are expressed as mean ± standard deviation or median (1st quartile–3rd quartile). Categorical variables are defined as *n* (%). *p*-values were calculated using Student's *t*-test or Mann-Whitney *U*-test for continuous variables, and Chi-squared test or Fisher's exact test for categorical variables. In addition, we used the bootstrap method to compare partially overlapping data. *p*-values <0.05 were significant. The ppBMI categories followed the recommendations of the Japan Society for the Study of Obesity. The GWG categories of the old and new standards followed the recommendations of the Ministry of Health, Labour and Welfare and the Japan Society of Obstetrics and Gynecology, respectively. GDM, gestational diabetes mellitus; GWG, gestational weight gain; aGWG, adequate GWG; ppBMI, pre-pregnancy body mass index; PG, plasma glucose; OGTT, oral glucose tolerance test; HbA1c, glycated hemoglobin; LBW, low birth weight; HDP, hypertensive disorders of pregnancy; LGA, large for gestational age; IRI, immunoreactive insulin; NGT, normal glucose tolerance; IGT, impaired glucose tolerance; DM, diabetes mellitus; HOMA-β, homeostasis model assessment for beta cell function; HOMA-IR, homeostasis model assessment for insulin resistance.

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