Obesity Surgery (2020) 30:2963–2970
https://doi.org/10.1007/s11695-020-04633-x

ORIGINAL CONTRIBUTIONS

Neonatal Outcomes of Pregnancy Following Roux-en-Y Gastric Bypass: a Matched Case-Control Study

Brenda M. Machado[1] · Carina A. Blume[2] · Cláudio C. Mottin[3,4] · Michele Drehmer[5] · Beatriz D. Schaan[2,6]

Published online: 26 April 2020

Abstract

Purpose To compare perinatal outcomes and to assess the predictors of birth weight (BW) after Roux-en-Y gastric bypass (RYGB) to those women unexposed to bariatric surgery.

Materials and Methods Singleton births from women submitted to RYGB (BSG) were matched to two control births by maternal age, delivery year, and gender. Control group 1 (CG1) and control group 2 (CG2) were selected according to the prepregnancy body mass index (BMI) < 35 kg/m^2 and ≥ 35 kg/m^2, respectively, without previous bariatric surgery.

Results Fifty-eight pregnancies were evaluated in each group ($n = 174$). Neonates born after RYGB presented lower BW compared to CG1 (mean difference − 182.3 g; 95% CI − 333; − 31, $P = 0.018$) and CG2 (mean difference − 306.6 g, 95% CI − 502; − 111, $P = 0.02$). Although gestational age (GA) was similar ($P = 0.219$), fetal growth rate (in grams) per gestational week was higher in CG2 ($\beta = 196.27$, $P < 0.001$) vs. BSG ($\beta = 127.65$, $P < 0.001$), irrespective of gestational weight gain (GWG). Pregnancies post-RYGB showed lower GWG, lower BW, and higher prevalence of cesarean section than CG1 and were associated with lower BW, smaller cephalic perimeter, lower prevalence of macrosomia, hypertension, and gestational diabetes than CG2.

Conclusion Birth weight was higher in neonates from women with higher prepregnancy BMI, as compared to births from women submitted to RYGB, irrespective of GWG. Although nearly half of the RYGB mothers were classified with obesity at conception, those pregnancies were associated with better obstetric and neonatal outcomes than among women with prepregnancy BMI ≥ 35 kg/m^2 who had never undergone RYGB.

Keywords Bariatric surgery · Roux-en-Y gastric bypass · Birth weight · Gestational weight gain · Gestational age

✉ Beatriz D. Schaan
bschaan@hcpa.edu.br

Brenda M. Machado
brendamoretto@live.com

Carina A. Blume
carinablume@hotmail.com

Cláudio C. Mottin
claudiomottin@hotmail.com

Michele Drehmer
michele.drehmer@gmail.com

1 Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

2 Postgraduate Program in Medical Sciences, Endocrinology, School of Medicine, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

3 Center for Obesity and Metabolic Syndrome, Hospital São Lucas da Pontifícia, Universidade Católica do Rio Grande do Sul (PUCRS), Porto Alegre, RS, Brazil

4 School of Medicine, PUCRS, Porto Alegre, RS, Brazil

5 Department of Nutrition, Postgraduate Program in Food, Nutrition and Health, School of Medicine, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

6 Endocrine Division, Hospital de Clínicas de Porto Alegre, Rua Ramiro Barcelos, 2350, Prédio 12 - 4° andar, Porto Alegre 90035-003, RS, Brazil

Introduction

Maternal obesity is associated with increased risk of adverse obstetric and neonatal outcomes, such as excessive gestational weight gain (GWG), gestational diabetes, gestational hypertensive syndrome, cesarean section, preterm birth, macrosomia, and fetal mortality [1–3].

Roux-en-Y gastric bypass (RYGB) is a worldwide surgically induced weight loss technique. Nearly 50% of women undergoing this procedure are on reproductive age, which contributes to the high frequency of women who become pregnant after this surgical procedure [4, 5]. Although there is still no consensus in the literature, most authors recommend a period of 12 to 18 months between surgery and conception in order to prevent adverse outcomes to the fetus during this period of intense weight loss [6, 7].

Pregnancies following bariatric surgery are associated with lower GWG, lower birth weight (BW), increased risk for newborns small for gestational age (SGA), preterm birth, perinatal mortality, and greater frequency of nutritional deficiencies among pregnant woman [8–11]. However, although most women submitted to bariatric surgery conceive while still being obese, pregnancies are associated with lower risk of gestational hypertensive syndrome, gestational diabetes, excessive GWG, and newborns large for gestational age (LGA) [10, 12, 13].

Gestational weight gain is one of the most important predictors of newborn BW [14, 15]. Thus, the Institute of Medicine (IOM) presents recommendations for GWG according to the prepregnancy BMI that aim to optimize fetal growth and development and preservation of maternal health [16]. Both low BW (< 2500 g) and macrosomia (> 4000 g) are adverse outcomes that may be associated with changes in growth and development and increased risk of chronic diseases in adulthood [17, 18].

Therefore, the aim of the study is to compare perinatal outcomes and to assess the predictors of BW after maternal RYGB to two matched control groups of women unexposed to bariatric surgery prior to pregnancy in southern Brazil.

Materials and Methods

A case-control study nested within a prospective cohort included all women submitted to RYGB (BSG) between 2000 and 2013 at the Center for Obesity and Metabolic Syndrome, Hospital São Lucas, Pontifícia Universidade Católica do Rio Grande do Sul (HSL PUCRS), Brazil and who became pregnant after surgery between 2000 and 2017. For each single birth to a mother submitted to RYGB prior to pregnancy, two control births selected from both HSL PUCRS and Hospital de Clínicas de Porto Alegre (HCPA), Rio Grande do Sul, Brazil were matched by maternal age, delivery month and year and newborn gender. Control group 1 (CG1) and control group 2 (CG2) included women with prepregnancy BMI < 35 kg/m^2 and ≥ 35 kg/m^2, respectively. The Ethical Committee of both hospitals approved the study protocol, and informed consent was obtained from all participants. Figure 1 shows identification and selection of the study participants.

Data were retrieved using patient's hospital registration and telephone interviews, where the mother should have the prenatal and the pregnancy data from the Brazilian Ministry of Health registration to provide the necessary information. Demographic and socioeconomic variables analyzed were collected. Household income in *reais* was converted to dollars (a minimum monthly wage is equivalent to nearly US$267.00). Economic class was classified according to the Brazilian Criteria for Economic Classification [19].

Clinical variables included preexisting maternal diseases, hypertensive disorders, diabetes mellitus, smoking status, and alcohol consumption during pregnancy. The following categories were considered for hypertension: chronic hypertension, gestational hypertension, preeclampsia, and preeclampsia superimposed on chronic hypertension.

Prepregnancy BMI was calculated according to the weight (kg)/height^2 (m) ratio and was classified as follows: underweight (< 18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2), overweight (25.0 to 29.9 kg/m^2), and obese (≥ 30.0 kg/m^2) [20]. Gestational weight gain adequacy was classified based on the prepregnancy BMI: 12.5 to 18 kg for BMI < 18.5 kg/m^2, 11.5 to 16 kg for BMI 18.5–24.9 kg/m^2, 7 to 11.5 kg for BMI 25–29.9 kg/m^2, and 5 to 9 kg for BMI ≥ 30 kg/m^2 [16]. The total GWG was calculated by the formula: weight at delivery (kg) − prepregnancy weight (kg). The BW of the newborn was classified according to the World Health Organization (WHO) in low BW (< 2500 g) and macrosomia (> 4000 g) [20]. Gestational age (age in weeks and days assessed by gestational ultrasonography before week 20) was classified as preterm (newborn with less than 37 weeks of gestational age), term (newborn with gestational age between 37 weeks and 41 weeks and 6 days), or post-term (newborn with 42 weeks or more of gestational age) [21]. Fetal growth was evaluated considering the BW (g), length (cm) and head circumference (cm) according to gestational age and sex of the newborn [22]. We also considered gestational age in classification of BW as SGA if < P_{10}, adequate for gestational age (AGA) between P_{10} and P_{90} and LGA if > P_{90} [22].

Statistical Analysis

The distribution of variables was explored using the Kolmogorov-Smirnov test. Quantitative data were shown as mean and standard deviation (SD) or median and interquartile range. We used Pearson or Spearman correlations for the

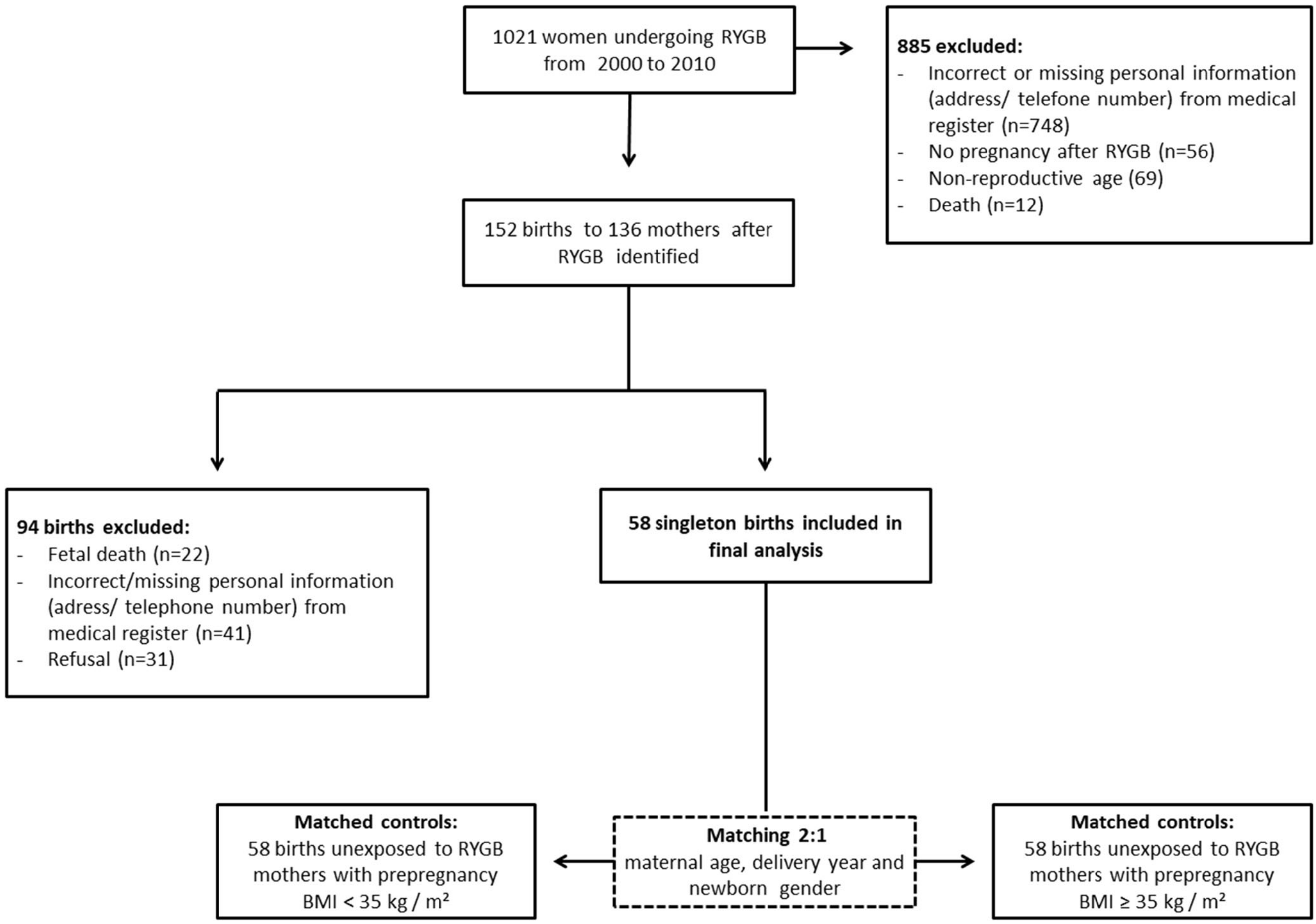

Fig. 1 Flow chart showing identification and selection of the study population. Patients exposed to Roux-en-Y gastric bypass (RYGB) prior to pregnancy were selected from Center for Obesity and Metabolic Syndrome (Hospital São Lucas PUCRS, Porto Alegre, Brazil). The matched control population unexposed to RYGB was selected from both Hospital São Lucas PUCRS and Hospital de Clínicas de Porto Alegre, Brazil

association between two quantitative variables. For comparison of more than three variables, we applied the analysis of variance (ANOVA) or Kruskal-Wallis tests. Categorical variables were described using absolute and relative frequencies.

The generalized estimation equation (GEE) was used to investigate variables associated with BW (dependent continuous variable). Potential confounding factors and mediators with $P < 0.2$ were included in the multivariate analysis. We tested for multicollinearity. Linear and logistic GEE regressions were used to evaluate the differences between groups adjusted for variables that, according to the literature and univariate analysis, influence BW. Data were analyzed using SPSS version 18.0 (IBM SPSS Statistics), and P values (two-tailed) of < 0.05 were considered significant.

Results

One hundred and seventy four single births were evaluated, 58 in each group. The mean preoperative BMI among women submitted to RYGB (BSG group) prior to pregnancy was 46.0 ± 8.5 kg/m^2. Of these, 24% was classified with a BMI between 35.0 and 39.9 k/m^2, 49% between 40.0 and 49.9 kg/m^2 and 27% ≥ 50.0 kg/m^2. The median time between surgery and conception was 34 (17–67) months, while 31% ($n = 18$) became pregnant before 18 months post-operatively; of these, seven women conceived within the first 12 months. Women who became pregnant before 18 months presented lower GWG (mean difference − 8 kg, 95% CI − 12; − 4, $P = 0.03$) compared to those who became pregnant after 18 months, although BW did not differ ($P = 0.658$).

Most women were white color (85%), and the mean prepregnancy maternal age was 32 ± 5 years in all three groups, with a minimum age of 19 and maximum of 46 years. Nulliparous women were more prevalent ($P = 0.044$) in BSG compared to CG1 (39.7% vs. 24.0%) and CG2 (39.7% vs. 19.0%).

Table 1 shows the maternal characteristics according to groups (BSG, CG1, and CG2). Groups were different regarding maternal ethnicity, maternal education, socioeconomic

Table 1 Maternal characteristics according to group ($n = 174$)

Characteristics	BSG ($N = 58$)	CG1 BMI < 35 kg/m² ($N = 58$)	CG2 BMI ≥ 35 kg/m² ($N = 58$)	P
Sociodemographic characteristics				
Maternal age (years)	32 ± 5	32 ± 5	32 ± 5	0.838
Ethnicity				
White	55 (94.8)[a]	43 (74.1)[b]	50 (86.2)[ab]	0.009
Mixed/Black	3 (5.2)[a]	15 (25.9)[b]	8 (13.8)[ab]	
Education (years)	14 ± 3[a]	11 ± 4[b]	9 ± 3[b]	< 0.001
Education, categories				
≤ 8 years	4 (6.9)[a]	12 (20.7)[ab]	16 (27.6)[b]	< 0.001
9–11 years	15 (25.9)[a]	25 (43.1)[ab]	32 (55.2)[b]	
≥ 12 years	39 (67.2)[a]	21 (36.2)[b]	10 (17.2)[b]	
Marital status				
Married/cohabiting	47 (81)	49 (84.5)	47 (81)	0.906
Single/divorced/widowed	11 (19)	9 (15.5)	11 (19)	
Household income, US$	4000 (2000–7000)[a]	2500 (1500–4500)[b]	1550 (1100–2500)[c]	< 0.001
Economic class				
A (high)	25 (43.1)[a]	11 (19)[b]	2 (3.4)[c]	< 0.001
B	14 (24)[a]	16 (27.6)[a]	7 (12)[c]	
C	7 (12)[a]	13 (22.4)[b]	15 (25.9)[b]	
D-E (low)	12 (20.7)[a]	18 (31)[b]	34 (58.6)[c]	
Clinical characteristics				
Prepregnancy BMI (kg/m²)	30 ± 6[a]	25 ± 3[b]	39 ± 5[c]	< 0.001
Prepregnancy BMI, categories				
18.5–24.9	11 (19)[a]	31 (53.4)[b]	NA	< 0.001
25–29.9	23 (39.7)	21 (36.2)	NA	
30–34.9	14 (24)	6 (10.3)	NA	
35.0–39.9	6 (10.3)[a]	NA	42 (72.4)[b]	
≥ 40	4 (6.9)[a]	NA	16 (27.6)[b]	
Gestational weight gain (kg)	10 (7–13)[a]	14 (10–19)[b]	12 (8–15)[ab]	0.007
Adequacy of gestational weight gain				
Insufficient	16 (27.6)	13 (22.4)	8 (13.8)	0.096
Adequate	14 (24)	21 (36.2)	13 (22.4)	
Excessive	28 (48.3)	24 (41.4)	37 (63.8)	
Hypertensive syndrome	3 (5.2)[a]	6 (10.3)[a]	21 (36.2)[b]	< 0.001
Gestational diabetes	2 (3.4)[a]	5 (8.6)[a]	18 (31)[b]	< 0.001
Prenatal care				
Median, visits	5 (2–10)	8 (6–11)	9 (6–11)	0.683
Smoking during pregnancy	9 (15.5)	6 (10.3)	8 (13.8)	0.794
Alcohol use during pregnancy	7 (12)	2 (3.4)	4 (9.4)	0.242

Bariatric surgery group (BSG): pregnancies of women who had undergone Roux-en-Y gastric bypass (RYGB) prior to pregnancy

Control group 1 (CG1): births of women without a history of bariatric surgery and prepregnancy BMI < 35 kg/m² , using maternal age, delivery year, and gender as matching factors

Control group 2 (CG2): births of women without a history of bariatric surgery and prepregnancy BMI ≥ 35 kg/m² , using maternal age, delivery year, and gender as matching factors

The data are presented as mean ± SD, median (interquartile range) or proportion (n, %)

Mean, median, or proportion values followed by different letters significantly differ according to analysis of variance with Tukey post hoc, Kruskal-Wallis with Dunn post hoc, chi-square, or Fisher's exact test at a significance level of 5%. The adequacy of gestational weight gain was determined according to the Institute of Medicine recommendations (IOM, 2009). Gestational hypertensive disorders include gestational hypertension, preeclampsia, and superimposed preeclampsia on chronic hypertension

BMI body mass index, NA not applicable

class, prepregnancy BMI, GWG, prevalence of hypertensive syndrome, and gestational diabetes. Although BSG presented lower GWG compared to CG1 ($P = 0.007$), there was no difference between the three groups in the categories of maternal weight gain (insufficient, adequate or excessive) [23]. Gestational age was similar between the groups (38.3 ± 1.9 weeks; $P = 0.219$). Control group 1 presented lower prevalence of cesarean section compared to BSG (41.4% vs.70.7%, $P < 0.001$) and CG2 (41.4% vs. 65.5%, $P < 0.001$). GWG remained lower in BSG ($\beta = -3.8$, $P < 0.026$) compared to CG1 and similar to CG2 ($P = 0.229$) even after adjusting for maternal ethnicity, educational level, socioeconomic class, hypertension, and gestational diabetes.

Table 2 Neonatal outcomes according to group (n = 174)

Characteristics	BSG (*N* = 58)	CG1 BMI < 35 kg/m^2 (*N* = 58)	CG2 BMI ≥ 35 kg/m^2 (*N* = 58)	*P*
Prematurity, < 37 weeks	7 (12.1)	5 (8.6)	9 (15.5)	0.216
One-minute, Apgar score	9 (8–9)	9 (8–9)	9 (7,7–9)	0.080
Five-minute, Apgar score	9.5 (9–10)	9 (9–10)	9 (9–10)	0.079
Birth weight (g)	3078.9 ± 430.5[a]	3261.2 ± 478.2[b]	3385.4 ± 629.4[b]	0.003
Fetal growth percentile	53.4 (28.7–77.3)[a]	62.2 (37.6–82.3)[a]	82.1 (55.4–95.7)[b]	< 0.001
Small for gestational age	1 (1.7)[a]	3 (5.2)[a]	1 (1.7)[a]	
Adequate for gestational age	53 (91.4)[a]	45 (77.6)[ab]	35 (60.3)[b]	
Large for gestational age	4 (6.9)[a]	10 (17.2)[a]	22 (37.9)[b]	
Birth weight < 2500 g	4 (6.9)	4 (6.9)	4 (6.9)	> 0.999
Birth weight > 4000 g	2 (3.4)[a]	3 (5.2)[a]	13 (22.4)[b]	0.010
Birth length (cm)	48.1 ± 2	48.4 ± 2.3	48.8 ± 2.8	0.231
Birth length, percentile	49.8 (17.5–67.2)	55.1 (13.2–73.6)	70.2 (22–89.3)	0.056
Cephalic perimeter (cm)	34.1 ± 1.4	34.4 ± 1.8	34.6 ± 2.2	0.327
Cephalic perimeter, percentile	80 (49.4–91.7)[a]	75 (35.8–94.5)[ab]	93.2 (69–98.5)[b]	0.042

Bariatric surgery group (BSG): pregnancies of women who had undergone Roux-en-Y gastric bypass (RYGB) prior to pregnancy

Control group 1 (CG1): births of women without a history of bariatric surgery and prepregnancy BMI < 35 kg/m^2 , using maternal age, delivery year, and gender as matching factors

Control group 2 (CG2): births of women without a history of bariatric surgery and prepregnancy BMI ≥ 35 kg/m^2 , using maternal age, delivery year, and gender as matching factors

The data are presented as mean ± SD, median (interquartile range) or proportion (*n*, %)

Mean, median or proportion values followed by different letters significantly differ according to analysis of variance with Tukey post hoc, Kruskal-Wallis with Dunn post hoc, chi-square, or Fisher's exact test at a significance level of 5%

The adequacy of gestational weight gain was determined according to the Institute of Medicine recommendations (IOM, 2009). Fetal growth classification was determined according to Intergrowth-21st charts

Table 2 shows the obstetric and neonatal outcomes. There were differences between the groups for cesarean section, BW, fetal growth percentile, and cephalic perimeter percentile. Babies born after RYGB weighed over 150 g less than those born from mothers with prepregnancy BMI < 35 kg/m^2 (mean difference − 182.3 g; 95% CI − 333; − 31, $P = 0.018$) and over 300 g less than babies born from mothers with prepregnancy BMI ≥ 35 kg/m^2 (mean difference − 306.6 g, 95% CI − 502; − 111, $P = 0.02$), while BW was similar ($P = 0.250$) among CG1 and CG2. Prepregnancy BMI was not associated with BW but was negatively associated with total GWG ($\beta = -0.279$, $P < 0.001$). In the BSG, the interval between RYGB and conception in years was associated with GWG in kg ($\beta = 0.579$, $P = 0.007$), but not with BW in grams ($\beta = 8.73$, $P = 0.606$). Neonatal outcomes were similar between those women who conceived within or after the first 18 months post-operatively for gestational age ($P = 0.609$), prematurity ($P = 0.407$), fetal growth percentile ($P = 0.193$), macrosomia ($P = 0.310$), one-minute ($P = 0.173$), and 5-min Apgar score ($P = 0.072$), birth length ($P = 0.320$) and cephalic perimeter ($P = 0.282$).

Table 3 shows the univariate regression analysis with potential predictors of BW. Gestational age was the only predictor that presented interaction effect between the three groups ($P = 0.013$). Prepregnancy BMI ($P = 0.222$), hypertension ($P = 0.766$), gestational diabetes ($P = 0.273$), smoking ($P = 0.891$), and alcohol consumption ($P = 0.643$) were not predictors of BW. Adjusting for GWG in kilograms ($\beta = 23.4$, $P < 0.001$), BSG showed similar BW as compared to CG1 ($P = 0.268$) and lower BW as compared to CG2 (mean difference − 260.8 g, 95% CI − 438.3, − 83.2, $P = 0.004$).

The variables that remained significant in the multivariate regression were GWG in kg ($\beta = 20.26$, $P < 0.001$) and gestational age in weeks ($\beta = 157.95$, $P < 0.001$) and are shown in Table 4 according to each group. In the multivariate analysis, BW remained lower in the BSG vs. CG2 (mean difference − 253.16 g; 95% CI − 383.3; − 123.1, $P < 0.001$) and similar vs. CG1 ($P = 0.881$).

Discussion

This is the first study in Latin America comparing neonatal outcomes and BW predictors from women submitted to RYGB prior to pregnancy to two different matched control groups. The difference between BSG and CG1 regarding

Table 3 Univariate regression analysis of potential variables influencing neonatal birth weight ($n = 174$)

Independent variables	*B*	Standard error	95% CI	*P*
GWG (kg)	24.38	4.68	15.21; 33.56	< 0.001
GWG above recommendation	392.48	86.69	222.55; 562.41	< 0.001
GWG below recommendation	− 249.26	71.21	− 388.83; − 109.6	< 0.001
Maternal education (years)	− 12.35	8.99	− 29.99; 5.27	0.170
Maternal ethnicity, mixed/black	185.26	91.20	6.50; 364.02	0.042
Gestational age (weeks)	161.76	15.09	132.18; 191.34	< 0.001
Prepregnancy BMI < 30 kg/m^2	− 120.44	79.72	− 276.69; 35.81	0.131

Dependent variable: birth weight (grams) adjusted for conditional matching factors: maternal age, delivery year and gender. The adequacy of gestational weight gain was determined according to Institute of Medicine recommendations (IOM, 2009).

CI confidence interval, BMI body mass index, GWG gestational weight gain

BW was entirely attributed to the lower GWG among post-RYGB women. However, even after adjusting for the main predictors, i.e., GWG and gestational age, BW remained, in average, 253 g lower among babies from post-RYGB mothers as compared to CG2.

The finding that women submitted to RYGB prior to pregnancy present lower GWG is consistent with other studies. Santulli et al. compared 24 pregnancies of women previously submitted to RYGB with two control groups (high or adequate prepregnancy BMI) and found that women who became pregnant after bariatric surgery had lower GWG compared to those with adequate prepregnancy BMI [23]. De Alencar Costa et al. compared 63 pregnancies from women previously submitted to RYGB (prepregnancy BMI 26.5 ± 4.2 kg/m^2) with 73 pregnancies of women with prepregnancy obesity and without history of surgery and found that the group submitted to bariatric surgery presented lower GWG [13]. A recent systematic review and meta-analysis comparing 14,880 pregnancies after bariatric surgery and 3,979,978 controls found increased odds ratio for SGA (2.72, 95% CI 2.32–3.20, $P < 0.001$) and for preterm birth (1.57, 95% CI 1.38–1.79, $P < 0.001$) and decreased odds ratio for LGA (0.24, 95% CI 0.14–0.41, $P < 0.001$) after RYGB [11]. In our sample, pregnancies from women after RYGB were associated with lower frequency of LGA as compared to women with higher BMI (≥ 35 kg/m^2), but not with increased SGA, neither with gestational age.

Table 4 Univariate regression analysis of gestational weight gain and gestational age on birth weight according to group

	Number	*B*	Standard error	95% CI	*P*
GWG (kg)					
BSG	58	16.43	5.41	5.82; 27.04	< 0.001
CG1	58	29.74	9.79	10.54; 48.93	0.002
CG2	58	31.32	10.54	10.64; 51.89	0.003
Gestational age (weeks)					
BSG	58	127.65	21.23	86.03; 169.27	< 0.001
CG1	58	140.89	35.33	71.65; 210.14	< 0.001
CG2	58	196.27	22.41	152.33; 240.21	< 0.001

Dependent variable: birth weight (grams) adjusted for conditional matching factors: maternal age, delivery year, and gender

Bariatric surgery group (BSG): pregnancies of women who had undergone Roux-en-Y gastric bypass (RYGB) prior to pregnancy

Control group 1 (CG1): births of women without a history of bariatric surgery and prepregnancy BMI < 35 kg/m^2, using maternal age, delivery year, and gender as matching factors

Control group 2 (CG2): births of women without a history of bariatric surgery and prepregnancy BMI ≥ 35 kg/m^2, using maternal age, delivery year, and gender as matching factors

CI confidence interval, GWG gestational weight gain

Our data shows that the interval between the RYGB and the conception was associated with GWG, but not with BW. The early post-operative period is characterized by low food intake, intense weight loss, and a high prevalence of nutritional deficiencies [7, 9, 24]. Additionally, short surgery-to-concept interval may reduce maternal weight loss; however, it does not appear to affect long-term results [25–27]. Although most authors recommend a period of 12 to 18 months between surgery and conception, there is still no consensus in the literature on this issue [6]. Gascoin et al. [28] compared cord blood of 56 neonates from mothers with prior RYGB to 56 controls from nonobese healthy mothers and found lower cord blood concentrations of calcium, zinc, vitamin A, leptin, and *insulin-like growth factor* (IGF-1) in the RYGB neonates. Gestational weight gain and gestational age were similar between the groups, while BW was lower among neonates born post-RYGB, which is in line with our results. Two other studies evaluated pregnancies after bariatric surgery and found no difference in GWG or BW stratified according to more or less than 18 months post-operatively [29, 30].

It is well described in the literature that prepregnancy obesity is associated with excessive GWG, gestational hypertensive syndrome, gestational diabetes, and macrosomia [1–3]. Although about 41% of women undergoing RYGB prior to pregnancy still show some degree of obesity, we found lower GWG and higher prevalence of cesarean section in these women as compared to pregnancies of women with prepregnancy BMI < 35 kg/m^2 and lower frequency of hypertensive syndrome, gestational diabetes, and macrosomia as compared to pregnancies of women with prepregnancy BMI ≥ 35 kg/m^2. A meta-analysis also showed that women who become pregnant after bariatric surgery have a lower risk of gestational diabetes, hypertension, and macrosomia compared to pregnancies of women with prepregnancy obesity and with no history of bariatric surgery. No significant differences were observed for cesarean section [31].

This study has some limitations inherent to an observational study. When considering the maternal weight at the time of delivery, it is possible that bias occurred due to the measured weight among women who were hospitalized after the rupture of the membranes and loss of amniotic fluid. Additionally, both control groups presented lower maternal education and socioeconomic class which can be explained because most of the women were recruited from a hospital which assists women from the Brazilian public health system. In contrast, bariatric surgery group was mostly composed by women with private health insurance access. Therefore, these results cannot be generalized.

The strengths of this study include the evaluation, for the first time in Latin America, of neonatal outcomes and BW predictors in neonates of mothers undergoing RYGB prior to pregnancy compared to two different matched control groups of different prepregnancy BMI categories.

Conclusion

Neonates from post-RYGB mothers showed lower fetal growth rate per gestational week compared to neonates from women with higher prepregnancy BMI irrespective of GWG. Moreover, pregnancies after RYGB were not associated with SGA. Although nearly half of the mothers who became pregnant after RYGB were classified with obesity at conception, those pregnancies were associated to lower prevalence of hypertensive disorders, gestational diabetes, and macrosomia than women with prepregnancy obesity who had never undergone RYGB.

Funding Information This study was funded by *Fundo de Incentivo à Pesquisa e Eventos* (FIPE) of *Hospital de Clínicas de Porto Alegre* and by National Council for Scientific and Technological Development (CNPq).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

Ethical Approval Statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Statement Informed consent was obtained from all individual participants included in the study.

References

1. Faucher MA, Barger MK. Gestational weight gain in obese women by class of obesity and select maternal/newborn outcomes: a systematic review. Women Birth. 2015;28(3):e70–9.
2. Li H, Zhao H, Xing F. A meta-analysis of the maternal body mass index and the risk of stillbirth. Zhonghua Yi Xue Za Zhi. 2015;95(25):2027–9.
3. Kim SS, Zhu Y, Grantz KL, et al. Obstetric and neonatal risks among obese women without chronic disease. Obstet Gynecol. 2016;128(1):104–12.
4. Maggard MA, Yermilov I, Li Z, et al. Pregnancy and fertility following bariatric surgery: a systematic review. JAMA. 2008;300(19):2286–96.
5. Kizy S, Jahansouz C, Downey MC, et al. National Trends in bariatric surgery 2012–2015: demographics, procedure selection, readmissions, and cost. Obes Surg. 2017;27:2933–9.
6. Bebber FE, Rizzolli J, Casagrande DS, et al. Pregnancy after bariatric surgery: 39 pregnancies follow-up in a multidisciplinary team. Obes Surg. 2011;21(10):1546–51.
7. Molin Netto BD, Earthman CP, Farias G, et al. Eating patterns and food choice as determinant of weight loss and improvement of metabolic profile after RYGB. Nutrition. 2017;33:125–31.
8. Berglind D, Willmer M, Näslund E, et al. Differences in gestational weight gain between pregnancies before and after maternal bariatric surgery correlate with differences in birth weight but not with scores on the body mass index in early childhood. Pediatr Obes. 2014;9(6):427–34.
9. Jans G, Matthys C, Bogaerts A, et al. Maternal micronutrient deficiencies and related adverse neonatal outcomes after bariatric surgery: a systematic review. Adv Nutr. 2015;6(4):420–9.
10. Johansson K, Cnattingius S, Näslund I, et al. Outcomes of pregnancy after bariatric surgery. N Engl J Med. 2015;372(9):814–24.
11. Akhter Z, Rankin J, Ceulemans D, et al. Pregnancy after bariatric surgery and adverse perinatal outcomes: a systematic review and meta-analysis. PLoS Med. 2019;16(8):e1002866.
12. Abenhaim HA, Alrowaily N, Czuzoj-Shulman N, et al. Pregnancy outcomes in women with bariatric surgery as compared with morbidly obese women. J Matern Fetal Neonatal Med. 2016;29(22):3596–601.
13. de Alencar Costa LA, Araujo Júnior E, de Lucena Feitosa FE, et al. Maternal and perinatal outcomes after bariatric surgery: a case control study. J Perinat Med. 2016;44(4):383–8.
14. Shrestha I, Sunuwar L, Bhandary S, et al. Correlation between gestational weight gain and birth weight of the infants. Nepal Med Coll J. 2010;12(2):106–9.
15. Abubakari A, Kynast-Wolf G, Jahn A. Maternal determinants of birth weight in Northern Ghana. PLoS One. 2015;10(8):e0135641.
16. IOM (Institute of Medicine), NRC (National Research Council). Weight gain during pregnancy: reexamining the guidelines. The National Academies Press. Washington (DC): The National Academies Press; 2009.
17. Schellong K, Schulz S, Harder T, et al. Birth weight and long-term overweight risk: systematic review and a meta-analysis including

643,902 persons from 66 studies and 26 countries globally. PLoS One. 2012;7(10):e47776.
18. Jornayvaz FR, Vollenweider P, Bochud M, et al. Low birth weight leads to obesity, diabetes and increased leptin levels in adults: the CoLaus study. Cardiovasc Diabetol. 2016;15:73.
19. Associação Brasileira de Empresas de Pesquisa (ABEP). Critério de classificação econômica Brasil. São Paulo: ABEP; 2014.
20. World Health Organization. Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. World Health Organ Tech Rep Ser. 1995;854:1–452.
21. World Health Organization. ICD-10: International Statistical Classification of Diseases and Related Health Problems, 10th Revision. Geneva: World Health Organization; 2011.
22. Villar J, Cheikh Ismail L, Victora CG, et al. International standards for newborn weight, length, and head circumference by gestational age and sex: the Newborn Cross-Sectional Study of the INTERGROWTH-21st Project. Lancet. 2014;384(9946):857–68.
23. Santulli P, Mandelbrot L, Facchiano E, et al. Obstetrical and neonatal outcomes of pregnancies following gastric bypass surgery: a retrospective cohort study in a French referral centre. Obes Surg. 2010;20(11):1501–8.
24. Giusti V, Theytaz F, Di Vetta V, et al. Energy and macronutrient intake after gastric bypass for morbid obesity: a 3-y observational study focused on protein consumption. Am J Clin Nutr. 2016;103(1):18–24.
25. Alatishe A, Ammori BJ, New JP, et al. Bariatric surgery in women of childbearing age. QJM. 2013;106(8):717–20.
26. Quyên Pham T, Pigeyre M, Caiazzo R, et al. Does pregnancy influence long-term results of bariatric surgery? Surg Obes Relat Dis. 2015;11(5):1134–9.
27. Shawe J, Ceulemans D, Akhter Z, et al. Pregnancy after bariatric surgery: consensus recommendations for periconception, antenatal and postnatal care. Obes Rev. 2019;20(11):1507–22.
28. Gascoin G, Gerard M, Sallé A, et al. Risk of low birth weight and micronutrient deficiencies in neonates from mothers after gastric bypass: a case control study. Surg Obes Relat Dis. 2017;13(8):1384–91.
29. Stentebjerg LL, Andersen LLT, Renault K, et al. Pregnancy and perinatal outcomes according to surgery to conception interval and gestational weight gain in women with previous gastric bypass. J Matern Fetal Neonatal Med. 2017;30(10):1182–8.
30. Wax JR, Cartin A, Wolff R, et al. Pregnancy following gastric bypass for morbid obesity: effect of surgery-to-conception interval on maternal and neonatal outcomes. Obes Surg. 2008;18(12):1517–21.
31. Yi XY, Li QF, Zhang J, et al. A meta-analysis of maternal and fetal outcomes of pregnancy after bariatric surgery. Int J Gynaecol Obstet. 2015;130(1):3–9.