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QUANTITATIVE RESEARCH

Interprovincial variation in pre-pregnancy body mass index and gestational weight gain and their impact on neonatal birth weight with respect to small and large for gestational age

Sarah D. McDonald[1] · Christy Woolcott[2] · Núria Chapinal[3] · Yanfang Guo[4] · Phil Murphy[5] · Susie Dzakpasu[6]

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Abstract

Objectives To explore provincial variation in both excess and inadequate pre-pregnancy body mass index (BMI) and gestational weight gain (GWG) and their impact on small- and large-for-gestational-age (SGA, LGA) infants.

Methods Four provinces with a perinatal database capturing the required exposures participated: British Columbia (BC), Ontario (ON), Nova Scotia (NS), and Newfoundland and Labrador (NL). In multiple, concurrent retrospective studies, we included women ≥ 19 years, who gave birth from 22^{+0} to 42^{+6} weeks' gestation, to a live singleton from April 2013–March 2014. From adjusted odds ratios, we calculated population attributable fractions (PAF) of SGA and LGA for BMI and GWG.

Results The proportion of overweight and obese women increased from western to eastern Canada. In BC, ON, NS, and NL, the proportions of women who were overweight were 21.1%, 24.0%, 23.7%, and 25.4%, while obesity proportions were 14.2%, 18.1%, 24.2%, and 29.8%, respectively. Excess GWG affected 53.9%, 49.9%, 57.6%, and 65.6% of women, respectively. Excess GWG contributed to 29.5–42.5% of LGA, compared with the PAFs for overweight (6.8–12.0%) and obesity (13.2–20.6%). Inadequate GWG's contribution to SGA (4.8–12.3%) was higher than underweight BMI's (2.9–6.2%).

Conclusion In this interprovincial study, high and increasing proportions of women from west to east had excess pre-pregnancy BMI, and between half to two thirds had excess GWG. The contributions of GWG outside of recommendations to SGA and LGA were greater than that of low or high BMI. GWG is a potentially modifiable determinant of SGA and LGA across Canada.

Résumé

Objectifs Explorer les écarts provinciaux dans l'indice de masse corporelle (IMC) élevé ou faible avant la grossesse et le gain de poids (GPG) excessif ou insuffisant durant la grossesse et leur effet sur la naissance de nourrissons petits ou gros pour l'âge gestationnel (PAG, GAG).

Méthode Ont participé quatre provinces ayant des bases de données périnatales saisissant les données requises : la Colombie-Britannique (C.-B.), l'Ontario (Ont.), la Nouvelle-Écosse (N.-É.) et Terre-Neuve-et-Labrador (T.-N.-L.). Dans plusieurs études rétrospectives parallèles, nous avons inclus les femmes ≥19 ans ayant accouché entre la 22^{e+0} et la 42^{e+6} semaine de grossesse d'un enfant unique vivant entre avril 2013 et mars 2014. D'après les rapports de cotes ajustés, nous avons calculé les fractions attribuables dans la population (FAP) des nourrissons PAG et GAG selon l'IMC et le GPG.

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✉ Sarah D. McDonald
mcdonals@mcmaster.ca

1 Department of Obstetrics & Gynecology, Department of Health Research Methods, Evidence, and Impact, Department of Radiology, McMaster University, 1280 Main Street West, Room 3N52B, Hamilton, ON L8S 4K1, Canada

2 Departments of Obstetrics & Gynaecology and Pediatrics, Dalhousie University, Halifax, NS, Canada

3 Perinatal Services BC, Vancouver, Canada

4 Better Outcomes Registry & Network, Ottawa, ON, Canada

5 Perinatal Program Newfoundland and Labrador, and Disciplines of Obstetrics and Gynecology and Pediatrics, Faculty of Medicine, Memorial University, Newfoundland, St. John's, NL, Canada

6 Maternal, Child and Youth Health Unit, Public Health Agency of Canada, Ottawa, ON, Canada

Résultats La proportion de femmes en surpoids et obèses augmente d'ouest en est au Canada. En C.-B., en Ont., en N.-É. et à T.-N.-L., les proportions de femmes en surpoids étaient de 21,1 %, 24 %, 23,7 % et 25,4 %, et les proportions de femmes obèses étaient de 14,2 %, 18,1 %, 24,2 % et 29,8 %, respectivement. Le GPG excessif a touché 53,9 %, 49,9 %, 57,6 % et 65,6 % des femmes, respectivement. Le GPG excessif a contribué à 29,5–42,5 % des nourrissons GAG, comparativement aux FAP pour le surpoids (6,8–12 %) et l'obésité (13,2–20,6 %). La contribution du GPG insuffisant aux nourrissons PAG (4,8–12,3 %) était supérieure à celle du faible IMC (2,9–6,2 %).

Conclusion Dans cette étude interprovinciale, les proportions de femmes ayant un IMC élevé avant la grossesse étaient élevées et augmentaient d'ouest en est, et entre la moitié et les deux tiers des femmes ont eu un GPG excessif. La contribution d'un GPG hors de l'intervalle recommandé à la naissance de nourrissons PAG et GAG était supérieure à la contribution d'un IMC faible ou élevé. À l'échelle du Canada, le GPG est un déterminant potentiellement modifiable de la naissance de nourrissons PAG et GAG.

Keywords Pregnancy · Weight gain · Body mass index · Fetal macrosomia · Infant · Small for gestational age

Mots-clés Grossesse · Prise de poids · Indice de masse corporelle · Macrosomie fœtale · Nourrisson · Petit pour l'âge gestationnel

Introduction

Given the current obesity epidemic, identification and quantification of modifiable risk factors are a public health goal. Excess gestational weight gain (GWG) is a key risk factor for high infant birth weight (Bergmann et al. 2003; Nohr et al. 2008), which in turn is associated with a doubling of the risk of offspring being overweight (Schellong et al. 2012) or obese (Yu et al. 2011) in childhood and adulthood. Inadequate GWG is associated with being born small for gestational age (SGA) (Stotland et al. 2006), which through rebound growth in turn has been associated with increased central fat mass and body mass index (BMI) in childhood (Ong et al. 2000).

The Institute of Medicine (IOM) released guidelines in 2009 for weight gain during pregnancy which were adopted by Health Canada in 2010 (Institute of Medicine and National Research Council of the National Academies 2009; Health Canada, Expert Advisory Group on National Nutrition Pregnancy Guidelines 2011). Both excess and inadequate GWG significantly increase maternal and infant risks. Although there are well-documented risks with excess GWG for mothers, including increased risks of high blood pressure (Cedergren 2006), diabetes (Thorsdottir et al. 2002), cesarean section (Thorsdottir et al. 2002), postpartum weight retention (Nehring et al. 2011), and obesity (Rooney et al. 2005), we were interested in large for gestational age (LGA) and SGA as key perinatal outcomes which are associated with obesity in later life. Women who are obese also have increased risks of LGA (Dzakpasu et al. 2015) as well as other complications, including many of the ones noted for excess weight gain, and additionally anesthetic difficulties (Davies et al. 2010) and congenital anomalies in their infants (Callaway et al. 2006; Gilboa et al. 2010; Werler et al. 1996).

Analysis of data from the Canadian Maternity Experiences Survey (2005–2006) estimated that the population attributable fraction (PAF) of LGA with excess GWG was 16%; and inadequate GWG's PAF exceeded that of prenatal smoking for SGA (Dzakpasu et al. 2015). These data were informative about GWG as an important clinical and public health issue in Canada; however, they are now a decade old and warrant re-examination. Other limitations included potential volunteer bias and recall bias as the data were collected 5–14 months postpartum.

The aim of this study was to understand: (1) the provincial variation of excess or inadequate maternal pre-pregnancy BMI and GWG in singleton pregnancies, using the Canadian provincial perinatal databases and (2) the impact of maternal pre-pregnancy BMI and GWG on two key perinatal indicators, LGA and SGA.

Methods

Study design

We followed the *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE) guideline. We conducted parallel, retrospective cohort studies using four provincial perinatal databases that had information on both BMI and GWG, namely British Columbia (BC), Ontario (ON), Nova Scotia (NS), and Newfoundland and Labrador (NL). Each database performs quality checks of their data and captures information on almost all hospital births in its province. Each province analyzed its data on hospital births from April 1, 2013 to March 31, 2014, the most recent year for which all provinces had data cleaned and available at the time of the study's commencement.

Inclusion criteria

We included women 19 years of age or more, who gave birth to a live, singleton fetus between 22 weeks + 0 days to 42 weeks + 6 days gestation for whom information on pre-pregnancy BMI (or pre-pregnancy weight and height) and

GWG were available and plausible, i.e., for BMI, 15–70 kg/m^2, and for GWG, − 30 to 50 kg.

Exclusion criteria

We excluded women with missing data on infant birthweight and sex, and/or parity data, as our primary outcome could not be calculated or stratified without this information (Supplemental Table 1). We excluded women with late pregnancy termination or suspected lethal, chromosomal, or other major anomaly which would significantly impact birthweight. In order to maintain statistical independence, we excluded the second gestation in women who had two births in the study year.

Outcomes

Our two outcomes were LGA (> 90% for gestational age and sex) and SGA (< 10% for gestational age and sex relative to a national standard) (Kramer et al. 2001).

Analyses

We compared baseline characteristics with descriptive statistics to characterize the cohorts. We categorized women according to our two main exposures: pre-pregnancy BMI and GWG, using the World Health Organization standard (World Health Organization 2000) as underweight (BMI < 18.5 kg/m^2), normal weight (18.5 ≤ BMI < 25 kg/m^2), overweight (25 ≤ BMI < 30 kg/m^2) or obese (BMI ≥ 30 kg/m^2), and the 2009 IOM recommendations for weight gain, adopted by Health Canada, as weight gain above, within or below the recommendations for their BMI (Health Canada 2010). The recommended total GWG ranges from 12.5–18 kg for underweight women to 5–9 kg for obese women (Health Canada 2010). If height was missing from the current pregnancy, we used height in the most recent previous pregnancy to minimize missing data.

Because GWG is associated with gestational length, we accounted for the duration of gestation in our calculations. We assumed a 2-kg weight gain in the first trimester as per the IOM guidelines and subtracted this amount from the total reported weight gain to obtain GWG during the second and third trimesters of pregnancy. We then subtracted 13 weeks for the duration of first trimester from the gestational age at birth to obtain the number of weeks in the remainder of the pregnancy. We compared this GWG in the remainder of the pregnancy (i.e., second and third trimesters) to the IOM's recommended GWG during this period, accounting for women's pre-pregnancy BMI. For women whose gestations extended beyond 40 weeks, we extrapolated using the recommended weekly gain for the second and third trimesters.

We conducted univariable regression models and then adjusted for confounders, but not mediators (e.g., when the main exposure was GWG, in calculating the adjusted odds, we controlled for pre-pregnancy BMI among other factors; but when BMI category was the key exposure, we did not control for GWG as it was a mediator of the outcomes of LGA and SGA). Covariates included maternal age, parity, socio-economic status, smoking, chronic physical health conditions, gestational diabetes, preeclampsia, and mental health conditions pre-pregnancy or during pregnancy.

Prior to calculating regression models, we tested for correlation between variables using Spearman's correlation coefficient. If the correlation coefficient was < 0.8, both variables were included in the model. If ≥ 0.8, only one of the two was included, with selection based on the one with the best biologically plausible/most important relationship to the outcome based on the research team's expertise. Covariates were then removed from the model if they were statistically non-significant or not a confounder. Significance was evaluated at the 0.05 level or confounding as a change of 15% or higher in the effect of BMI or GWG on the birth outcome being modeled. We included smoking during pregnancy, as an important perinatal predictor, in all of the models. Results were stratified by parity (nulliparous vs. parous women) because of parity's importance on perinatal outcomes.

We estimated the contribution to our outcomes of BMI (underweight, overweight, or obese BMI versus normal weight) and GWG (less or more than recommended versus within recommendation), and for comparison, smoking (Supplemental Tables 2–4a–c), using PAFs (Ruckinger et al. 2009). We calculated adjusted PAFs directly from our multivariable logistic regression models, using SAS to calculate the sequential and average attributable fraction method which takes into account that ORs are adjusted for confounders (Ruckinger et al. 2009). Hence, PAFs incorporate the magnitude of the increased risk due to, for example, excess GWG and its prevalence, in order to provide an estimate of the potential reduction in the outcome if women who gained above recommendations were to gain within recommendations. Negative PAFs indicate protective effects. Our focus was on positive PAFs, which estimate the contribution of each risk factor to a particular outcome.

Results

The distribution of BMI, GWG, and other covariates is presented in Table 1. We found that the proportions of women who were either overweight or obese increased from west to east, from 35.3%, to 42.1%, 47.9%, and 55.2% in BC, ON, NS, and NL, respectively. Separately, 21.1%, 24.0%, 23.7%, and 25.4% of women were overweight and 14.2%, 18.1%, 24.2%, and 29.8% were obese in BC, ON, NS, and NL, respectively. The proportion of underweight women decreased from west to east, from 6.0%, to 5.8%, 4.0%, and 3.4% in BC, ON, NS, and NL, respectively. Excess GWG occurred in 53.9%, 49.9%, 57.6%, and 65.6% of women, respectively. The corresponding proportions of women with inadequate GWG were 20.3%, 19.3%, 20.8%, and 15.4%. For women

Table 1 Baseline characteristics in four prenatal cohorts from British Columbia, Ontario, Nova Scotia, and Newfoundland and Labrador

	BC			ON			NS			NL		
	All women *N* (%) (and definition where applicable)	Nulliparous	Parous	All women	Nulliparous	Parous	All women	Nulliparous	Parous	All women	Nulliparous	Parous
BMI (kg/m^2)												
Median (IQR)	23.2 (20.8, 26.8)	22.8 (20.6, 26.1)	23.6 (21.1, 27.6)	23.9 (21.1, 28.1)	23.3 (20.8, 27.3)	24.5 (21.5, 28.7)	24.8 (21.7, 29.8)	24.2 (21.5, 29.0)	25.2 (21.9, 30.4)	25.8 (22.4, 31.1)	25.7 (22.2, 30.5)	26.1 (22.7, 31.6)
Underweight	1312 (6.0)	752 (6.9)	560 (5.1)	5414 (5.8)	2828 (7.0)	2525 (4.8)	224 (4.0)	114 (4.4)	110 (3.6)	78 (3.4)	42 (3.9)	36 (2.9)
Normal weight	12,887 (58.8)	6756 (61.7)	6131 (55.8)	48,877 (52.2)	22,401 (55.8)	26,157 (49.2)	2695 (48.1)	1321 (51.2)	1374 (45.5)	962 (41.4)	461 (42.8)	501 (40.2)
Overweight	4628 (21.1)	2112 (19.3)	2516 (22.9)	22,449 (24.0)	8675 (21.6)	13,709 (25.8)	1330 (23.7)	591 (22.9)	739 (24.5)	590 (25.4)	279 (25.9)	311 (25.0)
Obese	3103 (14.2)	1324 (12.1)	1779 (16.2)	16,946 (18.1)	6238 (15.5)	10,752 (20.2)	1353 (24.2)	554 (21.5)	799 (26.4)	692 (29.8)	295 (27.4)	397 (31.9)
GWG < recommended	4443 (20.3)	1955 (17.9)	2488 (22.6)	18,087 (19.3)	6391 (15.9)	11,764 (22.1)	1165 (20.8)	430 (16.7)	735 (24.3)	358 (15.4)	117 (10.9)	241 (19.4)
GWG = recommended	5676 (25.9)	2835 (25.9)	2841 (25.9)	28,875 (30.8)	11,650 (29.0)	17,018 (32.0)	1209 (21.6)	534 (20.7)	675 (22.3)	440 (19.0)	189 (17.6)	251 (20.2)
GWG > recommended	11,811 (53.9)	6154 (56.2)	5657 (51.5)	46,724 (49.9)	22,101 (55.1)	24,361 (45.8)	3228 (57.6)	1616 (62.6)	1612 (53.3)	1524 (65.6)	771 (71.6)	753 (60.5)
Maternal age at birth (years)												
19–24	2561 (11.7)	1783 (16.3)	778 (7.1)	12,760 (13.6)	7981 (19.9)	4769 (9.0)	1227 (21.9)	767 (29.7)	460 (15.2)	436 (18.8)	266 (24.7)	170 (13.7)
25–29	6188 (28.2)	3609 (33.0)	2579 (23.5)	27,276 (29.1)	14,111 (35.2)	13,039 (24.5)	1608 (28.7)	810 (31.4)	798 (26.4)	770 (33.2)	395 (36.7)	375 (30.1)
30–34	8091 (36.9)	3767 (34.4)	4324 (39.4)	33,866 (36.2)	12,963 (32.3)	20,752 (39.1)	1795 (32.0)	728 (28.2)	1067 (35.3)	769 (33.1)	312 (28.9)	457 (36.7)
≥ 35	5090 (23.2)	1785 (16.3)	3305 (30.1)	19,784 (21.1)	5087 (12.7)	14,583 (27.4)	972 (17.4)	275 (10.7)	697 (23.1)	347 (14.9)	104 (9.7)	243 (19.5)
Nulliparous	10,944 (49.9)	–	–	40,155 (43.1)	–	–	3022 (53.9)	–	–	1077 (46.4)	–	–
Income												
QAIPPE = 5	3410 (15.6)	1693 (15.5)	1717 (15.6)	14,989 (16.5)	8019 (20.3)	11,636 (22.3)	691 ((15.1)	295 (13.8)	369 (16.3)	N/A	N/A	N/A
QAIPPE = 4	4467 (20.4)	2174 (19.9)	2293 (20.9)	18,143 (20.0)	8162 (20.7)	10,259 (19.6)	1040 (22.7)	490 (22.8)	440 (22.6)	N/A	N/A	N/A
QAIPPE = 3	4684 (21.4)	2307 (21.1)	2377 (21.6)	18,862 (20.8)	8414 (21.3)	10,768 (20.6)	1052 (23.0)	512 (23.9)	540 (22.2)	N/A	N/A	N/A
QAIPPE = 2	4837 (22.1)	2456 (22.4)	2381 (21.7)	19,404 (21.4)	8589 (21.8)	11,387 (21.8)	960 (21.0)	464 (21.6)	496 (20.4)	N/A	N/A	N/A
QAIPPE = 1	4532 (20.7)	2314 (21.1)	2218 (20.2)	19,232 (21.2)	6242 (15.8)	8231 (15.7)	836 (18.3)	385 (17.9)	451 (18.5)	N/A	N/A	N/A
Education												
Not graduated from high school	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	149 (6.4)	48 (4.5)	101 (8.1)
Graduated from high school	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	356 (15.3)	151 (14.0)	205 (16.5)
Beyond high school	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	158 (6.8)	71 (6.6)	87 (7.0)
College or university degree (including trade)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1598 (68.8)	781 (72.5)	817 (65.6)
Missing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	61 (2.6)	26 (2.4)	35 (2.8)
Smoked	1576 (7.2)	715 (6.5)	861 (7.8)	10,000 (10.8)	3995 (10.0)	6015 (11.4)	983 (17.6)	376 (14.6)	607 (20.2)	335 (14.4)	118 (11.0)	217 (17.4)

Table 1 (continued)

	BC			ON			NS			NL		
	All women	Nulliparous	Parous	All women	Nulliparous	Parous	All women	Nulliparous	Parous	All women	Nulliparous	Parous
	N (%) (and definition where applicable)											
Physical health conditions before pregnancy												
Hypertension	132 (0.6)	59 (0.5)	73 (0.7)	895 (1.0)	356 (0.9)	535 (1)	71 (1.3)	32 (1.2)	39 (1.3)	30 (1.3)	16 (1.5%)	14 (1.1%)
Diabetes (I or II)	149 (0.7)	69 (0.6)	80 (0.7)	(901 (1.0)	337 (0.9)	566 (1.1)	52 (0.9)	22 (0.9)	30 (1.0)	34 (1.5)	21 (1.9%)	13 (1.0%)
Health conditions during pregnancy												
GDM	2728 (12.4)	1253 (11.4)	1475 (13.4)	5265 (5.8)	2008 (5.2)	3231 (6.3)	371 (6.6)	167 (6.5)	204 (6.8)	163 (7.0)	70 (6.5)	93 (7.5)
Preeclampsia	417 (1.9)[a]	285 (2.6)[a]	132 (1.2)[a]	682 (0.7)	449 (1.1)	229 (0.4)	115 (2.1)	91 (3.5)	24 (0.8)	47 (2.0)	36 (3.3)	11 (0.9)
Mental health conditions before or during pregnancy												
Depression	2511 (11.4)	1258 (11.5)	1253 (11.4)	8245 (8.9)	3092 (7.7)	5144 (9.7)	408 (7.3)	176 (6.8)	232 (7.7)	[b]	[b]	[b]
Other	1723 (7.9)	794 (7.3)	929 (8.5)	5204 (5.6)	2598 (6.5)	2594 (4.9)	476 (8.5)	215 (8.3)	261 (8.6)	24 (1.0)	17 (1.6)	7 (0.6)
Gestational age at birth												
22 + 0 to 33 + 6	372 (1.7)	190 (1.7)	182 (1.7)	1045 (1.1)	492 (1.2)	522 (1)	58 (1.0)	32 (1.2)	26 (0.9)	24 (1.0)	18 (1.7)	6 (0.5)
34 + 0 to 36 + 6	1440 (6.6)	706 (6.4)	734 (6.7)	4172 (4.5)	1856 (4.6)	2304 (4.3)	283 (5.1)	140 (5.4)	143 (4.7)	106 (4.6)	56 (5.2)	50 (4.0)
37 + 0 to 41 + 6	19,933 (90.9)	9917 (90.6)	10,016 (91.2)	88,025 (94.0)	37,491 (93.4)	50,175 (94.4)	5171 (92.3)	2355 (91.3)	2816 (93.2)	2190 (94.3)	1002 (93.0)	1188 (95.4)
42 + 0 to 42 + 6	185 (0.8)	131 (1.2)	54 (0.5)	444 (0.5)	303 (0.8%)	142 (0.3)	90 (1.6)	53 (2.1)	37 (1.2)	[b]	[b]	[b]
Birthweight (g)												
Mean (SD)	3403 (534)	3359 (535)	3448 (528)	3395 (548)	3349 (535)	3431 (552)	3442 (534)	3383 (524)	3492 (539)	3487 (532)	3426 (561)	3540 (500)
SGA (< 10%)	1443 (6.6)	955 (8.7)	488 (4.4)	8490 (9.1)	4671 (11.6)	3787 (7.1)	432 (7.7)	243 (9.4)	189 (6.3)	133 (5.7)	74 (6.9)	59 (4.7)
AGA (10–90%)	17,535 (80.0)	8896 (81.3)	8639 (78.6)	75,161 (80.4)	32,343 (80.6)	42,615 (80.2)	4454 (79.5)	2099 (81.4)	2355 (77.9)	1840 (79.2)	883 (81.9)	957 (76.9)
LGA (> 90%)	2952 (13.5)	1093 (10.0)	1859 (16.9)	9918 (10.6)	3149 (7.8)	6768 (12.7)	716 (12.8)	238 (9.2)	478 (15.8)	349 (15.0)	120 (11.1)	229 (18.4)

Abbreviations: AGA, appropriate for gestational age; BC, British Columbia; BMI, body mass index; GDM, gestational diabetes mellitus; GWG, gestational weight gain; IQR, interquartile range; LGA, large for gestational age; *N*, number; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; QAIPPE, quintile of annual income per person equivalent; SD, standard deviation; SGA, small for gestational age

[a] Gestational hypertension

[b] Values under 5 not displayed

19 years or more giving birth to a live, singleton infant with a first pregnancy in our time span, without a lethal structural, genetic, or chromosomal anomaly, and had information on BMI, this was 72.9%, 82.4%, 75.7%, and 57.1% of the original population of women giving birth in BC, ON, NS, and NL, respectively; and when the inclusion criteria of data on GWG was added, these proportions were 53.5%, 70.3%, 67.2%, and 42.2%, respectively. The proportions of women who smoked in BC, ON, NS, and NL were 7.2%, 10.8%, 17.6%, and 14.4%, respectively.

Association between adverse infant size and BMI and GWG

Large for gestational age

We determined that 13.5%, 10.6%, 12.8%, and 15.0% of women overall had an LGA baby in BC, ON, NS, and NL, respectively, ranging from a low of 7.8% for nulliparous women in ON to a high of 18.4% for parous women in NL (Table 1). Women who were underweight or gained below the guidelines generally had lower odds of LGA than women with normal BMI or had normal weight gain, respectively (Table 2). Women who were overweight, obese, or gained above recommendations had increased odds of LGA compared to women of normal BMI or weight gain.

Small for gestational age

We found that the proportion of SGA was 6.6%, 9.1%, 7.7%, and 5.7% in BC, ON, NS, and NL, respectively, ranging from a low of 4.4% for parous women in BC to a high of 11.6% for nulliparous women in ON (Table 1). Women who were underweight or gained below recommendations had significantly greater odds of SGA in all provinces except NL (Table 3).

Population attributable fractions for adverse infant size

We calculated the fraction of LGA and SGA attributable to each main determinant, BMI, and weight gain, independently (Table 4). In Supplementary Table 4c, we also presented PAFs for smoking, as another key perinatal determinant, for comparison.

Large for gestational age

Overall, the contribution to LGA of weight gain above the recommendations (29.5%, 31.9%, 32.1%, and 42.5% in BC, ON, NS, and NL, respectively) was greater than that of either overweight BMI (11.1%, 10.4%, 6.8%, and 12.0%) or obese BMI (13.2%, 17.2%, 16.7%, and 20.6%). In all provinces, nulliparous women had larger PAFs for LGA due to excess GWG compared with parous women, with the highest PAF being in nulliparous women in NL (56.6%). In terms of overweight and obesity, nulliparous women in NL displayed the highest PAFs for LGA (20.1% and 22.3%, respectively).

Small for gestational age

Overall, the contribution of GWG below recommendations to SGA (10.6%, 9.2%, 12.3%, and 4.8% in BC, ON, NS, and NL, respectively) was greater than that of underweight BMI (4.0%, 3.6%, 6.2%, and 2.9%, respectively), although the odds of SGA were generally higher for underweight women. In terms of weight gain below recommendations, parous women in NS had the highest PAF for SGA (19.7%), while in terms of underweight, nulliparous women in NS experienced the highest PAF (6.4%). The PAFs for smoking for all women ranged from 3.6% to 15.6% (Supplementary Table 4c).

Discussion

In this Canadian interprovincial study of the effects of pre-pregnancy BMI and weight gain on SGA and LGA, high and increasing proportions of women from west to east had excess pre-pregnancy BMI and between half to two thirds had excess GWG. The PAFs for LGA from excess GWG ranged from 30% to 43%, while inadequate GWG contributed 5–12% of SGA. GWG's contributions to PAFs for SGA and LGA exceeded those of BMI. It is important to note that there would be a tradeoff such that if excess GWG were eliminated (i.e., women gained within recommendations), we would expect, on the basis of our data, that a reasonable proportion of LGA would be prevented. However, this would also increase the proportion of SGA infants.

Stratification by parity showed that, compared to parous women, nulliparous women had higher prevalence of excess GWG and more pronounced ORs for LGA from excess GWG (with a single exception of the OR for excess GWG in NS), resulting in generally higher PAFs for LGA.

Conversely, compared to nulliparous women, parous women had a higher prevalence of inadequate GWG and higher ORs for SGA from inadequate GWG, resulting in higher PAFs for SGA.

Variation in the PAFs across provinces may be explained in part by trends in the prevalence of certain BMI and GWG categories and the associations between these categories and SGA and LGA. The contribution of overweight BMI to LGA decreased from west to east, except in NL. The decreasing PAFs for LGA attributed to overweight BMI is likely due to the corresponding ORs, which followed a similar decreasing trend from west to east, with the exception of NL. On the other hand, obese BMI increasingly contributed to LGA from west to east, likely due to the steady increase observed in the

Table 2 Adjusted odds ratios for the associations between body mass index and gestational weight gain and large for gestational age in British Columbia, Ontario, Nova Scotia, and Newfoundland

	BC		ON		NS		NL	
	Crude risk (%)	Adjusted OR (95% CI)	Crude risk (%)	Adjusted OR (95% CI)	Crude risk (%)	Adjusted OR (95% CI)	Crude risk (%)	Adjusted OR (95% CI)
All women								
BMI								
Underweight	4.7	0.45 (0.34, 0.58)	3.3	0.44 (0.37, 0.52)	5.4	0.58 (0.32, 1.06)	4.0	0.46 (0.14, 1.51)
Normal weight	10.4	Ref	7.8	Ref	9.8	Ref	9.8	Ref
Overweight	17.8	1.81 (1.65, 1.99)	12.7	1.66 (1.58, 1.76)	13.7	1.43 (1.17, 1.75)	17.8	1.87 (1.37, 2.55)
Obese	23.5	2.53 (2.28, 2.80)	18.4	2.50 (2.36, 2.63)	19.2	2.09 (1.73, 2.52)	21.8	2.28 (1.70, 3.05)
GWG								
< Recommended	8.0	0.78 (0.68, 0.90)	5.8	0.76 (0.70, 0.82)	7.6	0.75 (0.56, 1.02)	10.7	1.13 (0.66, 1.92)
=Recommended	8.9	Ref	7.1	Ref	8.6	Ref	7.5	Ref
> Recommended	17.7	1.91 (1.71, 2.12)	14.7	2.04 (1.93, 2.16)	16.3	1.98 (1.57, 2.49)	18.5	2.51 (1.67, 3.76)
Nulliparous								
BMI								
Underweight	3.9	0.48 (0.33, 0.70)	2.8	0.47 (0.37, 0.59)	[a]	0.53 (0.19, 1.47)	2.4	0.45 (0.06, 3.41)
Normal weight	7.8	Ref	5.9	Ref	7.2	Ref	5.9	Ref
Overweight	12.5	1.67 (1.42, 1.95)	10.0	1.73 (1.58, 1.90)	8.9	1.25 (0.88, 1.79)	15.4	2.57 (1.52, 4.33)
Obese	20.3	2.90 (2.47, 3.42)	14.2	2.50 (2.27, 2.75)	15.8	2.40 (1.76, 3.28)	16.7	2.63 (1.56, 4.43)
GWG								
< recommended	5.2	0.79 (0.61, 1.02)	3.4	0.72 (0.61, 0.85)	4.7	0.71 (0.39, 1.27)	9.4	1.93 (0.65, 5.76)
=recommended	5.9	Ref	4.3	Ref	5.8	Ref	3.3	Ref
> recommended	13.4	2.06 (1.73, 2.46)	11.0	2.26 (2.04, 2.51)	11.6	1.89 (1.26, 2.84)	13.4	3.43 (1.46, 8.06)
Parous								
BMI								
Underweight	5.9	0.42 (0.29, 0.60)	3.9	0.42 (0.34, 0.52)	7.3	0.62 (0.29, 1.30)	5.7	0.49 (0.11, 2.10)
Normal weight	13.1	Ref	9.4	Ref	12.3	Ref	13.5	Ref
Overweight	22.2	1.89 (1.67, 2.13)	14.5	1.63 (1.52, 1.74)	17.6	1.53 (1.19, 1.96)	20.0	1.57 (1.06, 2.34)
Obese	25.9	2.33 (2.04, 2.65)	20.8	2.49 (2.33, 2.66)	21.6	1.94 (1.54, 2.46)	25.6	2.12 (1.48, 3.02)
GWG								
< Recommended	10.2	0.78 (0.65, 0.93)	7.1	0.77 (0.70, 0.84)	9.3	0.77 (0.54, 1.10)	11.4	0.90 (0.49, 1.65)
=Recommended	11.9	Ref	9.1	Ref	10.8	Ref	10.8	Ref
> Recommended	22.4	1.83 (1.60, 2.09)	18.0	1.95 (1.82, 2.08)	21	2.01 (1.53, 2.66)	23.7	2.27 (1.43, 3.63)

Abbreviations: BC, British Columbia; BMI, body mass index; CI, confidence interval; GWG, gestational weight gain; *N*, number; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; OR, odds ratio; ref, reference

[a] Actual value suppressed due to restrictions in database

prevalence of obesity, unlike that of overweight BMI. The attribution of LGA to excess GWG also increased easterly, reflecting increases in both the prevalence of excess GWG and its OR associated with LGA. With the exception of NS, the PAFs for SGA associated with underweight BMI and with inadequate GWG followed similar trends as the provincial prevalence of underweight BMI and inadequate GWG, decreasing from west to east.

This recent assessment of maternal BMI and weight gain was as close to a national level as was possible since the Canadian Maternity Experiences Survey in 2005–2006. Analysis of data from the Maternity Experiences Survey indicated that the contribution of high or low pre-pregnancy BMI and GWG to adverse pregnancy outcomes was larger than those of smoking despite receiving less attention from health care providers and the public (Dzakpasu et al. 2015). Although both our study and that based on the Maternity Experiences Survey found similarly high rates of women gaining in excess of the guidelines (up to 60% and 59.4%, respectively), since our adjusted ORs were larger, our PAFs were much higher for LGA (in BC, ON, NS, and NL, the PAFs were 29.5%, 31.9%, 32.1%, and 42.5%, respectively,

Table 3 Adjusted odds ratios for the associations between body mass index and gestational weight gain and small for gestational age in British Columbia, Ontario, Nova Scotia, and Newfoundland

	BC		ON		NS		NL	
	Crude risk (%)	Adjusted OR (95% CI)	Crude risk (%)	Adjusted OR (95% CI)	Crude risk (%)	Adjusted OR (95% CI)	Crude risk (%)	Adjusted OR (95% CI)
All women								
BMI								
Underweight	12.0	1.68 (1.40, 2.01)	16.4	1.65 (1.52, 1.80)	22.0	2.59 (1.82, 3.69)	14.5	1.63 (0.81, 3.28)
Normal weight	7.1	Ref	9.9	Ref	8.4	Ref	7.5	Ref
Overweight	5.1	0.71 (0.62, 0.83)	7.3	0.73 (0.69, 0.78)	5.6	0.65 (0.50, 0.86)	4.1	0.55 (0.34, 0.90)
Obese	4.3	0.60 (0.50, 0.72)	6.6	0.64 (0.60, 0.69)	6.2	0.73 (0.56, 0.94)	3.8	0.53 (0.33, 0.86)
GWG								
< Recommended	10.8	1.54 (1.34, 1.77)	14.4	1.51 (1.42, 1.60)	13.6	1.62 (1.24, 2.11)	8.6	1.31 (0.76, 2.26)
=Recommended	7.7	Ref	10.2	Ref	9.1	Ref	7.7	Ref
> Recommended	4.5	0.58 (0.51, 0.67)	6.3	0.59 (0.56, 0.63)	5.1	0.55 (0.43, 0.72)	4.6	0.71 (0.45, 1.11)
Nulliparous								
BMI								
Underweight	14.1	1.57 (1.26, 1.95)	18.4	1.57 (1.41, 1.75)	23.7	2.81 (1.74, 4.52)	17.1	1.79 (0.73, 4.39)
Normal weight	9.4	Ref	12.5	Ref	9.2	Ref	8.8	Ref
Overweight	6.6	0.67 (0.56, 0.82)	9.5	0.73 (0.67, 0.80)	7.0	0.73 (0.51, 1.06)	4.8	0.56 (0.29, 1.08)
Obese	5.5	0.56 (0.44, 0.72)	8.6	0.65 (0.59, 0.72)	9.6	1.04 (0.74, 1.46)	4.6	0.54 (0.28, 1.04)
GWG								
< Recommended	14.9	1.56 (1.31, 1.86)	19.6	1.49 (1.37, 1.62)	16.9	1.35 (0.93, 1.95)	8.4	0.87 (0.37, 2.04)
=Recommended	10.3	Ref	14.0	Ref	12.4	Ref	10.3	Ref
> Recommended	6.0	0.60 (0.51, 0.71)	8.1	0.58 (0.54, 0.63)	6.4	0.50 (0.36, 0.70)	5.9	0.66 (0.37, 1.19)
Parous								
BMI								
Underweight	9.1	1.99 (1.45, 2.72)	14.1	1.78 (1.57, 2.03)	20.2	2.36 (1.39, 3.98)	11.4	1.26 (0.40, 3.95)
Normal weight	4.6	Ref	7.8	Ref	7.6	Ref	6.3	Ref
Overweight	3.8	0.80 (0.63, 1.01)	5.9	0.73 (0.67, 0.80)	4.5	0.57 (0.38, 0.86)	3.5	0.56 (0.26, 1.17)
Obese	3.3	0.68 (0.51, 0.90)	5.5	0.63 (0.57, 0.70)	3.8	0.46 (0.30, 0.70)	3.1	0.51 (0.26, 1.03)
GWG								
< Recommended	7.5	1.48 (1.18, 1.86)	11.7	1.52 (1.40, 1.66)	11.6	1.94 (1.31, 2.87)	8.7	1.73 (0.81, 3.71)
=Recommended	5.1	Ref	7.7	Ref	6.5	Ref	5.6	Ref
> Recommended	2.8	0.56 (0.44, 0.70)	4.6	0.61 (0.56, 0.67)	3.7	0.62 (0.41, 0.93)	3.2	0.77 (0.37, 1.58)

Abbreviations: BC, British Columbia; BMI, body mass index; CI, confidence interval; GWG, gestational weight gain; *N*, number; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; OR, odds ratio; ref, reference

Table 4 Adjusted population attributable fractions for small for gestational age and large for gestational age associated with BMI and GWG in British Columbia, Ontario, Nova Scotia, and Newfoundland

	SGA				LGA			
	BC PAF (95% CI)	ON PAF (95% CI)	NS PAF (95% CI)	NL PAF (95% CI)	BC PAF (95% CI)	ON PAF (95% CI)	NS PAF (95% CI)	NL PAF (95% CI)
All women								
BMI								
Underweight	4.0 (2.5, 5.6)	3.6 (3.0, 4.3)	6.2 (3.3, 9.1)	2.9 (− 1.9, 7.8)	− 2.3 (− 2.9, − 1.8)	− 2.1 (− 2.4, − 1.7)	− 1.1 (− 2.1, − 0.1)	− 0.9 (− 2.0, 0.2)
Normal weight	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Overweight	− 6.0 (− 8.4, − 3.6)	− 6.4 (− 7.6, − 5.0)	− 8.3 (− 13.0, − 3.5)	− 13.3 (− 22.9, − 3.5)	11.1 (9.2, 12.9)	10.4 (9.2, 11.4)	6.8 (2.8, 10.8)	12.0 (5.9, 18.1)
Obese	− 5.6 (− 7.6, − 3.7)	− 6.7 (− 7.6, − 5.7)	− 6.6 (− 11.7, − 1.5)	− 15.5 (− 26.0, − 5.0)	13.2 (11.3, 15.1)	17.2 (16.1, 18.4)	16.7 (12.2, 21.1)	20.6 (13.4, 27.8)
GWG								
< Recommended	10.6 (7.1, 14.1)	9.2 (7.8, 10.6)	12.3 (5.8, 18.8)	4.8 (− 4.7, 14.3)	− 2.9 (− 4.7, − 1.2)	− 3.0 (− 3.9, − 2.2)	− 3.5 (− 7.2, 0.2)	1.0 (− 3.4, 5.4)
=Recommended	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> Recommended	− 23.7 (− 29.6, − 17.9)	− 20.7 (− 23.1, − 17.9)	− 27.2 (− 40.2, − 14.1)	− 19.6 (− 46.4, 7.2)	29.5 (25.1, 33.8)	31.9 (29.5, 34.2)	32.1 (22.8, 41.5)	42.5 (27.4, 57.7)
Nulliparous								
BMI								
Underweight	3.6 (1.6, 5.6)	3.5 (2.5, 4.5)	6.4 (2.6, 10.2)	3.8 (− 3.1, 10.7)	− 2.7 (− 3.7, − 1.7)	− 2.6 (− 3.2, − 1.9)	− 1.4 (− 3.1, 0.3)	− 1.0 (− 2.9, 0.9)
Normal weight	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Overweight	− 6.4 (− 9.2, − 3.5)	− 5.7 (− 7.2, − 4.1)	− 5.6 (− 11.8, 0.7)	− 12.6 (− 25.5, 0.3)	8.9 (6.2, 11.7)	10.9 (9.1, 12.9)	4.1 (− 2.5, 10.6)	20.1 (8.9, 31.3)
Obese	− 5.4 (− 7.3, − 3.6)	− 5.5 (− 6.7, − 4.0)	0.8 (− 5.9, 7.5)	− 13.8 (− 27.3, − 0.3)	14.8 (11.9, 17.7)	15.8 (13.9, 17.7)	19.6 (11.9, 27.3)	22.3 (9.9, 34.8)
GWG								
< Recommended	9.8 (5.5, 14.2)	7.4 (5.8, 9.0)	6.6 (− 1.2, 14.3)	− 1.6 (− 11.7, 8.4)	− 2.3 (− 4.6, 0.1)	− 2.5 (− 3.9, − 1.4)	− 3.2 (− 8.5, 2.1)	3.6 (− 2.2, 9.4)
=Recommended	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> Recommended	− 23.2 (− 31.5, − 15.0)	− 24.1 (− 27.6, − 20.4)	− 37.4 (− 56.9, − 17.9)	− 27.3 (− 67.4, 12.8)	35.6 (28.4, 42.8)	40.4 (35.8, 44.8)	34.0 (14.7, 53.3)	56.6 (31.6, 81.6)
Parous								
BMI								
Underweight	4.9 (2.1, 7.8)	3.7 (2.8, 4.7)	5.9 (1.5, 10.3)	1.3 (− 5.5, 8.0)	− 2.1 (− 2.8, − 1.5)	− 1.8 (− 2.1, − 1.5)	− 0.9 (− 2.1, 0.2)	− 0.8 (− 2.1, 0.5)
Normal weight	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Overweight	− 4.7 (− 9.3, − 0.1)	− 7.2 (− 9.0, − 5.3)	− 11.8 (− 19.6, − 4.0)	− 13.0 (− 28.2, 2.3)	12.2 (10.0, 14.5)	10.1 (8.7, 11.3)	8.1 (3.2, 13.1)	8.0 (0.9, 15.2)
Obese	− 5.5 (− 9.1, − 2.0)	− 8.2 (− 9.8, − 6.6)	− 17.0 (− 25.0, − 8.9)	− 18.3 (− 36.2, − 0.3)	12.2 (10.1, 14.4)	17.8 (16.5, 19.2)	15.1 (9.6, 20.7)	19.4 (9.8, 29.0)
GWG								
< Recommended	11.7 (4.4, 19.0)	11.3 (8.7, 13.7)	19.7 (8.4, 30.9)	13.8 (− 6.3, 33.9)	− 3.4 (− 5.7, − 1.0)	− 3.3 (− 4.4, − 2.1)	− 3.6 (− 8.5, 1.2)	− 1.1 (− 7.3, 5.1)
=Recommended	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
> Recommended	− 24.3 (− 35.3, − 13.3)	− 16.8 (− 20.2, − 13.8)	− 17.9 (− 34.8, − 1.0)	− 11.5 (− 45.1, 22.1)	26.2 (20.7, 31.7)	28.2 (25.6, 30.7)	30.8 (20.1, 41.5)	36.8 (19.7, 53.8)

Abbreviations: BC, British Columbia; BMI, body mass index; GWG, gestational weight gain; LGA, large for gestational age; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; PAF, population attributable fraction; ref, reference; SGA, small for gestational age versus 15.9% estimated from the Maternity Experiences Survey) (Dzakpasu et al. 2015). While we used provincial perinatal databases based on medical records, the Maternity Experiences Survey was conducted by telephone interview from 5 to 14 months postpartum, and hence may have been susceptible to recall and reporting biases (Dzakpasu et al. 2008). For instance, women are more likely to self-report a longer gestation than is recorded in medical records (Adegboye and Heitmann 2008). The overestimation of gestational age could lead to an underestimation of GWG, which may in turn underestimate the prevalence of excess GWG. Both the Canadian Maternity Experiences Survey and other studies, such as the data in the IOM guidelines based on the Pregnancy Nutrition Surveillance System, have shown that pre-pregnancy weight is a key determinant of GWG, i.e., a larger proportion of overweight or obese women have GWG above the recommendations compared to underweight or normal weight women (Institute of Medicine and National Research Council of the National Academies 2009; Lowell and Miller 2010).

International comparison supports the finding of the important impact of weight and weight gain on LGA. For overweight combined with obesity, the PAF for LGA ranged from 15.3% in a multi-ethnic community in Amsterdam (Djelantik et al. 2012) to 16.3% in Berlin (Reiss et al. 2015), to 9.5–22.4% in Florida (Kim et al. 2014), while in contrast our PAFs for overweight ranged from 6.8% to 11.1% and for obesity varied from 13.1% to 17.2%. A Florida study (Kim et al. 2014) reported similar PAFs for LGA from excess GWG to those we found (33.3% to 37.7% vs 29.5% to 42.5%, respectively).

Strengths of our study include its innovative approach to compare provincial data since no national Canadian database has information on pre-pregnancy weight and GWG, and it has been more than a decade since there was information available across the country. Second, the databases we used provide population-based data, a significant advantage over survey data, as our data on weight gain were from antenatal records rather than self-report. Third, we used PAFs to estimate the theoretical proportions of SGA and LGA that would be removed if the exposure was completely removed. Fourth, the main exposures and outcomes were derived the same way in all provinces and we were able to adjust for a number of covariates, although there may still be some residual confounding.

Our study's limitations include the inability to completely harmonize the covariate data, such as variation in assessment of socio-economic status across provinces. Second, the World Health Organization identifies lower BMI cut-offs for many Asian populations for BMI-associated risks *outside of pregnancy* (World Health Organization Expert Consultation 2004); however, since we did not have reliable information on ethnicity, we used the general World Health Organization cutoffs for all women. As a result, Asian women classified as underweight in our study may in reality have been at lower risk for SGA than Caucasian women in the same classification. Since the proportion of Asian women is higher in BC and ON than in NS (Statistics Canada 2016), the underweight BMI group in BC and ON may have been composed of women at lower risk than expected. This may then have contributed to the smaller OR between underweight BMI and SGA in these provinces. Third, we used pre-pregnancy BMI, which is based on self-reported pre-pregnancy weight, which although well correlated with measured weight, tends to underestimate it (Huber 2007; Schieve et al. 1999; Bodnar et al. 2010). Fourth, we did not perform imputation for missing data to maintain feasibility of this study, which is one of the first to compare data from provincial perinatal databases. A previous study on the impact of bias on the association between maternal weight and SGA/LGA found that there were no significant changes in the pattern of associations after correcting data, but that the magnitude of associations could be under- or overestimated. For example, after correction, there was a tendency towards a decrease in the magnitude of the association between overweight/obese and LGA, as the women who were originally classified as overweight/obese were those with the highest BMIs and therefore at highest risk of having an LGA birth (Dzakpasu et al. 2016). The direction of any bias if data were not missing at random in our study is uncertain. Fifth, provincial participation was incomplete, as some provincial perinatal databases like Alberta's do not contain weight gain. Although five provinces have both maternal weight and weight gain, due to capacity constraints, one province, Prince Edward Island, was unable to participate, although was interested in doing so.

Future work should include the need for ongoing Canada-wide surveillance of maternal weight and weight gain as key perinatal indicators. Not only given the sizeable PAFs for excess GWG on LGA and inadequate GWG on SGA, consideration of adding the required variables to other provincial and national perinatal databases, as well as to the national hospital discharge abstract database, would be important from a public health prevention point of view but also given the implications for projecting impact on the health care systems of each province. Other aspects for future research include that although many women may not be receiving or recalling counseling from health care providers about weight gain (McDonald et al. 2011), a recent meta-synthesis of qualitative studies found that many women both desire consistent recommendations from their care providers earlier in pregnancy than is currently occurring and require provision of information to counteract the misconception that "big babies are healthy babies" (Vanstone et al. 2016). In 2014, Perinatal Services BC targeted weight gain during pregnancy for health promotion and disease prevention (Perinatal Services BC 2017), and the impact on provincial GWG rates would be important to evaluate. The PAFs for other outcomes should also be taken into consideration to more fully understand the impacts of population-level interventions on GWG. Finally, future study of a 5% or 3% cutoff for small infant size rather than the 10% would decrease some of the false positive diagnoses, particularly in some ethnicities such as women of Asian descent.

Conclusion

In this interprovincial study, elevated and increasing proportions of women from west to east across Canada begin pregnancy with excess weight or gain too much weight during pregnancy. Excess GWG was a larger contributor to LGA than either overweight or obese BMI. Similarly, the contribution of inadequate GWG to SGA exceeded that of underweight BMI. Hence, GWG is a potentially-modifiable, important determinant of key adverse perinatal outcomes across Canada, making it an important focus not only for public health but also for care providers and women.

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Compliance with ethical standards

Conflict of interest None to declare.

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