Contribution of prepregnancy body mass index and gestational weight gain to caesarean birth in Canada

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Abstract

Background: Overweight and obese women are known to be at increased risk of caesarean birth. This study estimates the contribution of prepregnancy body mass index (BMI) and gestational weight gain (GWG) to caesarean births in Canada.

Methods: We analyzed data from women in the Canadian Maternity Experiences Survey who had a singleton term live birth in 2005-2006. Adjusted odds ratios for caesarean birth across BMI and GWG groups were derived, separately for nulliparous women and parous women with and without a prior caesarean. Population attributable fractions of caesarean births associated with above normal BMI and excess GWG were calculated.

Results: The overall caesarean birth rate was 25.7%. Among nulliparous and parous women without a previous caesarean birth, rates in obese women were 45.1% and 9.7% respectively, and rates in women who gained above their recommended GWG were 33.5% and 8.0% respectively. Caesarean birth was more strongly associated with BMI than with GWG. However, due to the high prevalence of excess GWG (48.8%), the proportion of caesareans associated with above normal BMI and excess GWG was similar [10.1% (95% CI: 9.9-10.2) and 10.9% (95% CI: 10.7-11.1) respectively]. Overall, one in five (20.2%, 95% CI: 20.0-20.4) caesarean births was associated with above normal BMI or excess GWG.

Conclusions: Overweight and obese BMI and above recommended GWG are significantly associated with caesarean birth in singleton term pregnancies in Canada. Strategies to reduce caesarean births must include measures to prevent overweight and obese BMI prior to conception and promote recommended weight gain throughout pregnancy.

Keywords: Population attributable fractions, Maternal weight, Caesarean section

Background

The prevalence of overweight and obesity, defined as a body mass index (BMI) of 25-29.9 kg/m² and ≥ 30 kg/m² respectively, has been increasing globally [1]. In Canada, based on measured height and weight, the prevalence of obesity among adult women rose from 16% in 1978 to 23% in 2004 [2]. Correspondingly, rates of obesity are also increasing among pregnant women. Overweight and obese women are known to be at increased risk of serious pregnancy complications including caesarean birth [3-6]. These caesarean births in turn increase women’s risk of infection, haemorrhage, damage to the intestines or bladder, and negatively affect early parenting outcomes [7-9]. Caesarean births also increase the risk of long-term complications such as abnormal placentation during subsequent pregnancies and place excess strain on the healthcare system [7,10,11]. Canadian caesarean birth rates rose from 18% in 1995-1996 to 28% in 2010-2011 [12,13].

The concomitant increase in overweight and obesity and caesarean births make it important to study to what degree maternal weight is contributing to these births. During pregnancy, maternal weight is a product of both prepregnancy body mass index (BMI), hereafter referred to as BMI, and gestational weight gain (GWG). Estimating
the magnitude of the independent as well as joint association between these determinants and caesarean births is essential for designing interventions that promote healthy pregnancy outcomes. However, to date, few studies have quantified the proportion of caesarean births at the population level that are associated with above normal BMI [14-16] and no studies have quantified the proportion associated with excess GWG. Data from the Canadian Maternity Experiences Survey provided a unique opportunity to address this issue for Canada.

Methods

Study population

This study used data from the Public Health Agency of Canada’s Canadian Maternity Experiences Survey (MES). The MES was a cross-sectional survey of a stratified random sample of women who had a singleton live birth in Canada between November 2005 and May 2006. Women were identified using recent births drawn from a Census-based sampling frame. Women were eligible for the study if they were at least 15 years of age and were living with their infant at the time of data collection. Women living on First Nations reserves or in institutions were excluded. Data were collected by female interviewers between October 2006 and January 2007 using a computer-assisted telephone interview application. The majority (97%) of interviews were conducted between five and nine months postpartum. Out of 8,244 eligible women, 6,421 (78%) agreed to participate. In consideration of the sample design and non-participation, each MES record was assigned a sampling weight. The 6,421 respondents were thus weighted to derive a final sample of 5,591 women weighted to represent 67,058 women.

Outcomes

The primary outcome was caesarean birth (planned and unplanned). Caesarean births were classified as planned if the decision about the mode of birth was made before the woman went into labour.

Determinants

Prepregnancy BMI and GWG were the principal exposures of interest. They were derived from the following questions:

i) How tall are you without shoes on?
ii) Just before your pregnancy, how much did you weigh?
iii) How much weight did you gain during your pregnancy?

We categorized women according to the World Health Organization (WHO) standard as either being underweight (BMI < 18.5 kg/m²), normal weight (18.5 ≤ BMI < 25), overweight (25 ≤ BMI < 30) or obese (BMI ≥ 30). Women were also classified according to the Institute of Medicine’s recommended GWG ranges (Table 1) [18], as having gained above, within or below the recommended weight for their BMI.

Covariates

We studied additional reproductive, health care, sociodemographic and psychosocial characteristics as potential confounders of the association between BMI, GWG and mode of birth. Birthweight-for-gestational-age was derived using a Canadian reference to categorize infants below the standard 10th percentile as small-for-gestational age (SGA) and those above the standard 90th percentile as large-for-gestational age (LGA) [19]. Sociodemographic variables assessed included the household’s low income cut-off level (LICO), which is a measure of the income threshold below which a family will likely spend 20 percentage points more than the average family on food, shelter and clothing [20]. Ethnicity was based on mother’s country of birth, grouped according to world regions; mothers born in Canada were categorized as Aboriginal off-reserve and non-Aboriginal. The MES questions for variables whose definitions are not self-evident are indicated in Table 2. Categorizations (for non-dichotomized variables) used in analyses are indicated in Table 3 in the results section.

Statistical analysis

Percentages were used to report observed distributions of BMI and GWG across maternal characteristics. We calculated adjusted odds ratios (ORs) for having a
caesarean birth using multivariable logistic regression. With the exception of maternal age, all variables were treated as categorical in regression models. Records with missing values for covariates other than LICO were excluded from models (< 4%). Due to a larger number of missing LICO values (8.0%), a missing category was included for this variable. We calculated ORs across BMI and GWG groups for caesarean births overall as well as for unplanned and planned caesarean births. Normal BMI and within recommended GWG were the reference groups.

BMI and GWG were included in all multivariable models in order to estimate their independent associations (ORs) with caesarean birth. Other covariates were selected into models purposefully using the following steps [21]. Based on the Wald test from univariable logistic regression models, we initially included any variable with a p-value below 0.25. Covariates were then removed from the model if they were statistically non-significant and not a confounder. Significance was evaluated at the 0.05 level and confounding as a change of 15% or higher in the effect of BMI or GWG on the mode of birth outcome being modeled. To address significant interaction between parity, prior caesarean, BMI, GWG and mode of birth, we assessed results from models with and without these variables.

The contribution to caesarean births of overweight or obese BMI and more than recommended GWG was estimated using population attributable fractions (PAFs). The calculation of PAFs has the advantage of incorporating the increased risk due to high BMI or GWG and the prevalence of these two determinants, in order to provide an estimate of the potential reduction in caesarean birth if high BMI and GWG were eliminated. We calculated PAFs directly from our multivariable logistic regression models using the sequential and average attributable fraction method which takes into account that ORs are adjusted for confounders [22].

All analyses were carried out using sampling weights. We calculated variances using bootstrap weights to capture the variability introduced by the sample design and weighting adjustments [23]. We used SAS EG software, Version 5.1, copyright SAS Institute Inc. [24]. Review by an ethics board was not required, as the MES data are anonymous and this study did not generate identifying information.

**Results**

The prevalence of overweight and obese BMI was 20.9% and 13.3% respectively. Almost one-half (48.8%) of women gained above the recommended weight for their BMI. The two determinants were strongly associated with each other; 60.3% of obese versus 30.2% of underweight women gained more than the recommended weight and

| Table 2 Definitions of selected covariates |
|-------------------------------------------|
| **Variable**                              | **MES question**                                                                 |
| **Reproductive/health care factors**      |                                                                                   |
| Health care provider started labour       | Did your healthcare provider try to start or induce your labour by the use of medication or some other technique? |
| Prepregnancy health problems              | Before your pregnancy, did you have any medical conditions or health problems that required you to take medication for more than 2 weeks, have special care or extra tests during your pregnancy? |
| During pregnancy health problems          | During your pregnancy, did you develop any new medical conditions or health problems that required you to take medication for more than 2 weeks, have special care or extra tests? |
| Antenatal care provider                   | From which type of healthcare provider, such as an obstetrician, family doctor or midwife, did you receive most of (your prenatal) care? |
| **Psychosocial factors**                  |                                                                                   |
| Support                                   | During your pregnancy, how often was support available to you when you needed it? None/a little/some/most/all of the time. |
| Stressful life events                     | High stress was defined as experiencing 3 or more of the following 12 events in the year before the birth: close family member hospitalized, move to a new address, homelessness, woman or partner lost job, woman or partner went to jail, more than usual arguments with partner, partner not wanting pregnancy, separation or divorce, bills that could not be paid, a physical fight, someone close having a problem with alcohol or drugs, someone close dying. |
| History of depression                     | Before your pregnancy, had you ever been prescribed anti-depressants or been diagnosed with depression? |
| Percent of study sample | 5.9  | 60.0  | 20.9  | 13.3  | 18.1  | 33.1  | 48.8  |
|-------------------------|------|-------|-------|-------|-------|-------|-------|
| **Recommended GWG**     |      |       |       |       |       |       |       |
| Below                   | 14.5 | 11.9  | 17.5  |       |       |       |       |
| Within                  | 32.0 | 33.8  | 35.5  |       |       |       |       |
| Above                   | 32.3 | 35.9  | 31.8  |       |       |       |       |

**Reproductive/health care factors**

**Maternal age at birth**

| ≤24   | 27.3 | 14.7  | 13.5  | 14.3  | 14.5  | 11.9  | 17.5  |
|-------|------|-------|-------|-------|-------|-------|-------|
| 25-29 | 29.4 | 33.8  | 34.8  | 38.0  | 32.0  | 33.8  | 35.5  |
| 30-34 | 30.2 | 33.3  | 34.3  | 32.8  | 32.3  | 35.9  | 31.8  |
| ≥35   | 13.2 | 18.2  | 17.4  | 15.0  | 21.2  | 18.3  | 15.2  |

| Nulliparous | 50.3 | 47.5  | 37.8  | 40.6  | 39.6  | 41.2  | 49.0  |

**Birthweight-for-gestational age**

| SGA   | 17.0 | 8.2   | 7.4   | 6.2   | 13.6  | 8.6   | 6.1   |
|-------|------|-------|-------|-------|-------|-------|-------|
| AGA   | 78.2 | 85.2  | 78.4  | 77.0  | 81.0  | 81.6  | 79.5  |
| LGA   | 4.7  | 9.6   | 14.2  | 16.8  | 5.4   | 9.8   | 14.4  |

**Health care provider started labour**

| 36.6 | 42.5 | 47.6 | 58.9 | 41.1 | 41.6 | 49.3 |
|------|------|------|------|------|------|------|
| Prepregnancy health problems | 14.1 | 12.7 | 16.7 | 19.3 | 15.2 | 14.3 | 14.3 |
| During pregnancy health problems | 17.3 | 22.3 | 23.2 | 32.7 | 27.1 | 22.2 | 23.0 |

**Antenatal care provider**

| Obstetrician/gynaecologist | 59.0 | 58.6 | 56.6 | 60.2 | 61.1 | 58.9 | 57.1 |
| General practitioner | 36.0 | 34.2 | 36.5 | 35.7 | 33.1 | 34.4 | 36.0 |
| Midwife/nurse | 5.0 | 7.3 | 6.9 | 4.2 | 5.8 | 6.7 | 6.9 |

**Sociodemographic factors**

**Low-income-cut-off**

| ≤LICO | 29.7 | 15.8 | 18.5 | 21.0 | 198 | 16.3 | 18.2 |
| >LICO | 57.6 | 76.3 | 73.6 | 72.3 | 725 | 75.5 | 73.8 |
| Missing | 12.7 | 7.9 | 7.9 | 6.7 | 7.7 | 8.2 | 8.0 |

**Education**

| Less than high school | 14.4 | 5.5 | 6.6 | 8.2 | 6.5 | 4.5 | 8.1 |
| High school graduate | 21.7 | 17.5 | 20.6 | 24.6 | 18.3 | 19.0 | 20.0 |
| Post-secondary diploma | 31.8 | 36.2 | 39.3 | 43.2 | 37.6 | 35.7 | 38.8 |
| University graduate | 32.1 | 40.8 | 33.4 | 24.0 | 37.6 | 40.9 | 33.2 |

**Region/province**

| Atlantic | 3.4 | 4.8 | 7.2 | 9.2 | 3.9 | 5.4 | 6.7 |
| Quebec | 25.6 | 24.8 | 25.3 | 20.5 | 24.4 | 26.2 | 23.1 |
| Ontario | 40.7 | 38.7 | 34.5 | 40.3 | 39.1 | 37.8 | 38.0 |
| Prairies | 17.6 | 18.0 | 22.0 | 20.3 | 18.6 | 18.0 | 20.0 |
| British Columbia | 12.6 | 13.4 | 10.5 | 9.12 | 13.5 | 12.1 | 11.7 |
| Territories | 0.1 | 0.4 | 0.5 | 0.6 | 0.6 | 0.4 | 0.4 |
| Urban residence | 87.2 | 82.5 | 80.4 | 79.6 | 84.9 | 82.3 | 80.7 |

**Ethnicity (country of birth)**

| Canada/Aboriginal off-reserve | 2.4 | 3.4 | 4.4 | 6.1 | 2.5 | 2.7 | 5.3 |
| Canada/non-Aboriginal | 57.2 | 71.0 | 77.7 | 78.8 | 65.5 | 72.5 | 75.4 |
| Europe/Western | 4.7 | 7.1 | 4.0 | 4.8 | 6.3 | 5.9 | 5.9 |
| Africa/Mid East/Latin | 10.6 | 7.3 | 7.7 | 5.1 | 10.2 | 7.9 | 5.8 |
12.2% of obese versus 24.8% of underweight women gained less than the recommended weight. The distribution of covariates within BMI and GWG groups is shown in Table 3.

**Association between caesarean birth and prepregnancy BMI and GWG**

The overall caesarean birth rate was 25.7%, with substantial variation across parity and prior caesarean group strata. Among nulliparous women, parous women with no prior caesarean and parous women with a prior caesarean, caesarean birth rates were 29.6%, 5.8% and 80.2% respectively. Among nulliparous and parous women without a previous caesarean, rates in obese women were 45.1% and 9.7% respectively, and rates in women who gained above their recommended GWG were 33.5% and 8.0% respectively (Table 4). The incidence of caesarean births increased in all groups as BMI and GWG increased, except for GWG among parous women with a prior caesarean. In this group the trend was reversed; but adjusted ORs were not significantly different (Table 4). The high caesarean birth rates (above 75%) in parous women with a prior caesarean and low rates (below 10%) in parous women with no prior caesarean limited the scope for detecting significant decreases or increases in risk in these groups.

The adjusted risk of caesarean birth did not differ significantly between underweight and normal-weight women; it also did not differ significantly between women who gained less than the recommended amount and those who gained within the recommended amount (Table 4). The risk was significantly elevated among women who were overweight (OR = 1.23 [1.04-1.47]), obese (OR = 1.95 [1.61-2.36]), or had gained more than the recommended amount (OR = 1.36 [1.17-1.59]). Among nulliparous women who were overweight, obese or above their recommended GWG, the overall risk of caesarean birth was increased, with most of the increase attributable to unplanned caesareans. Among parous women with no prior caesarean, the risk of caesarean birth was low, but significantly elevated among those who were obese (OR = 2.03 [1.17-3.53]) or above their recommended GWG (OR = 1.75 [1.13-2.71]). There was no significant relationship between caesarean births and BMI or GWG among women with a previous caesarean (Table 4). Adjusting for women’s reports that their health care provider tried to induce labour, or that they experienced health problems before or during pregnancy, did not significantly change these risk patterns (data not shown).

**Population attributable fractions of caesarean births associated with BMI and GWG**

The fractions of caesarean births associated with overweight or obese BMI and more than recommended GWG are presented in Table 5. Among all women, 10.1% (9.9-10.2) of caesareans were associated with overweight or obese BMI and 10.9% (10.7-11.1) were associated with above recommended GWG. One in five caesareans (20.2% [20.0-20.4]) was associated with either above normal BMI or excess GWG. Results were similar for nulliparous women. In parous women with no previous caesarean, the proportion of caesareans associated with above recommended GWG was twice that of overweight or obese BMI (23.6% [23.0-24.2] versus 10.9% [10.4-11.4]). Almost one third (31.8% [31.3-32.4]) of caesarean births in this group were associated with either above normal BMI or excess GWG.

**Discussion**

The nationally representative nature of the MES allowed us to estimate PAFs of caesarean births associated with overweight and obese BMI and above recommended GWG. We found that one in five (20.2%) caesarean births was associated with above normal BMI or excess GWG. Overall, a similar proportion of caesarean births was associated with above normal BMI and excess GWG (10.1% and 10.9%, respectively), but these proportions

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**Table 3 Distribution (%) of covariates across prepregnancy body mass index (BMI) and gestational weight gain (GWG) categories**

| East/South Asia/Pacific | 25.2 | 11.2 | 6.2 | 5.4 | 15.5 | 11.1 | 7.6 |
|-------------------------|------|------|-----|-----|------|------|-----|
| Married††               | 84.2 | 93.1 | 93.0 | 89.2 | 92.3 | 93.9 | 90.6 |

*Some columns do not sum to 100% due to rounding. † Regression models used continuous age variable. ‡ SGA: small-for-gestational-age, AGA: average-for-gestational-age, LGA: large-for-gestational-age. †† Among women who attempted vaginal birth. † Married or common law.
varied substantially with parity and previous caesarean status. As expected, the incidence of caesarean births increased with increasing BMI and GWG, with a stronger association with unplanned caesarean births. Although causality cannot be inferred due to the observational nature of our data, it is noteworthy that in principle, if the caesarean births associated with BMI and GWG were eliminated, Canada’s caesarean rate among singleton term pregnancies could be reduced by up to a fifth, e.g. from 25.7% to 20.6%. There is no consensus on an optimal caesarean rate. However, a rate of 20.6% in singleton term pregnancies would bring the overall caesarean rate closer to the 5%-15% range suggested by WHO [25].

Few previous studies have calculated the PAF of caesareans due to maternal weight. Lu et al. attributed 11.6% of caesareans in Alabama in 1995-1999 to obesity (> 29.0 kg/m²) at the first prenatal visit, an increase from

| Table 4 Crude risks (%) and adjusted* odds ratios (ORs) for caesarean birth, by parity and previous caesarean status |
|---------------------------------------------------------------|
|                                                                 |
| **Caesarean birth** | **Unplanned caesarean** | **Planned caesarean** |
|---------------------|-------------------------|-----------------------|
| % | OR (95% CI) | % | OR (95% CI) | % | OR (95% CI) |
| All women | | | | | |
| Underweight | 20.9 | 1.01 (0.74,1.38) | 8.3 | 0.82 (0.52,1.29) | 12.6 | 1.25 (0.82,1.91) |
| Normal weight | 22.9 | 1 | 11.0 | 1 | 11.9 | 1 |
| Overweight | 28.3 | 1.23 (1.04,1.47) | 13.5 | 1.38 (1.08,1.76) | 14.8 | 1.10 (0.88,1.37) |
| Obese | 36.8 | 1.95 (1.61,2.36) | 19.1 | 2.29 (1.77,2.96) | 17.6 | 1.45 (1.13,1.85) |
| GWG < recommended | 20.1 | 0.89 (0.71,1.10) | 7.6 | 0.77 (0.56,1.06) | 12.4 | 0.99 (0.75,1.30) |
| GWG = recommended | 22.8 | 1 | 10.3 | 1 | 12.6 | 1 |
| GWG > recommended | 29.8 | 1.36 (1.17,1.59) | 15.7 | 1.40 (1.12,1.74) | 14.1 | 1.23 (1.01,1.51) |
| Nulliparous | | | | | |
| Underweight | 22.3 | 0.96 (0.62,1.50) | 12.9 | 0.76 (0.45,1.27) | 9.4 | 1.53 (0.70,3.34) |
| Normal weight | 25.9 | 1 | 19.7 | 1 | 6.2 | 1 |
| Overweight | 34.9 | 1.37 (1.05,1.78) | 27.4 | 1.36 (1.02,1.81) | 7.5 | 1.18 (0.75,1.85) |
| Obese | 45.1 | 2.29 (1.72,3.06) | 37.7 | 2.41 (1.78,3.25) | 7.3 | 1.13 (0.63,2.03) |
| GWG < recommended | 23.6 | 0.87 (0.64,1.19) | 15.4 | 0.79 (0.54,1.15) | 7.9 | 1.08 (0.63,1.84) |
| GWG = recommended | 25.9 | 1 | 19.5 | 1 | 6.4 | 1 |
| GWG > recommended | 33.5 | 1.35 (1.08,1.70) | 26.9 | 1.43 (1.12,1.84) | 6.6 | 0.98 (0.66,1.48) |
| Parous, no prior caesarean | | | | | |
| Underweight | 3.5 | 0.84 (0.22,3.17) | 2.6 | 1.41 (0.29,6.89) | 0.9 | 0.37 (0.01,13.96) |
| Normal weight | 4.8 | 1 | 2.1 | 1 | 2.7 | 1 |
| Overweight | 6.6 | 1.01 (0.61,1.69) | 4.2 | 1.38 (0.71,2.71) | 2.4 | 0.66 (0.27,1.61) |
| Obese | 9.7 | 2.03 (1.17,3.53) | 5.3 | 2.26 (1.04,4.87) | 4.4 | 1.73 (0.78,3.83) |
| GWG < recommended | 3.4 | 0.79 (0.40,1.57) | 1.0 | 0.45 (0.13,1.56) | 2.4 | 1.20 (0.48,3.02) |
| GWG = recommended | 4.5 | 1 | 2.5 | 1 | 2.0 | 1 |
| GWG > recommended | 8.0 | 1.75 (1.13,2.71) | 4.4 | 1.75 (0.96,3.20) | 3.5 | 1.68 (0.85,3.32) |
| Parous, prior caesarean | | | | | |
| Underweight | 77.3 | 1.37 (0.43,4.36) | 6.9 | 1.13 (0.06,20.79) | 70.4 | 1.26 (0.43,3.65) |
| Normal weight | 77.9 | 1 | 5.9 | 1 | 72.1 | 1 |
| Overweight | 84.3 | 1.53 (0.85,2.77) | 8.0 | 1.67 (0.61,4.62) | 76.3 | 1.18 (0.69,2.01) |
| Obese | 82.3 | 1.50 (0.77,2.91) | 9.7 | 2.01 (0.71,5.66) | 72.7 | 1.08 (0.62,1.91) |
| GWG < recommended | 82.2 | 1.14 (0.57,2.29) | 8.5 | 1.22 (0.39,3.79) | 73.7 | 1.05 (0.53,2.00) |
| GWG = recommended | 80.0 | 1 | 7.6 | 1 | 72.4 | 1 |
| GWG > recommended | 79.8 | 1.03 (0.62,1.71) | 6.4 | 0.76 (0.29,1.96) | 73.4 | 1.14 (0.71,1.81) |

[Statistically significant values are bolded.]

*All women: BMI models adjusted for GWG and GWG models adjusted for BMI; also adjusted for maternal age, parity, weight-for-gestational age, prepregnancy health problems, antenatal care provider, low-income-cut-off, educational attainment, province of residence, ethnicity, support, stress and history of depression.

Parity/previous caesarean subgroups: adjusted for same covariates, except parity.
Table 5 Adjusted* population attributable fractions (PAFs) of caesarean births associated with overweight or obese prepregnancy body mass index (BMI) or above recommended gestational weight gain (GWG)

|                           | All women | Nulliparous | Parous, no prior caesarean | Parous, prior caesarean |
|---------------------------|-----------|-------------|---------------------------|------------------------|
| Overweight or obese (BMI ≥ 25) | 10.1 (9.9, 10.2) | 11.1 (10.9, 11.2) | 10.9 (10.4, 11.4) | 3.3 (3.2, 3.5) |
| GWG > recommended         | 10.9 (10.7, 11.1) | 10.7 (10.5, 10.9) | 23.6 (23.0, 24.2) | 0.3 (0.1, 0.4) |
| Overweight or obese (BMI ≥ 25) or GWG > recommended | 20.2 (20.0, 20.4) | 21.1 (20.9, 21.3) | 31.8 (31.3, 32.4) | 3.6 (2.4, 3.8) |

*All women: BMI models adjusted for GWG and GWG models adjusted for BMI; also adjusted for maternal age, parity, weight-for-gestational age, prepregnancy health problems, antenatal care provider, low-income-cut-off, educational attainment, province of residence, ethnicity, support, stress and history of depression. Parity/previous caesarean subgroups: adjusted for all previous covariates except parity.

3.9% in 1980-1984 [14]. A Utah study attributed 38.8% of caesareans in 2001 to overweight or obesity at the time of birth thus also taking into account GWG [15]. Our PAF for overweight and obesity combined (10.1%) was similar to Lu et al.’s value for obesity alone, suggesting that a lower fraction of caesareans was attributable to high maternal weight in Canada in 2005-2006 compared to Alabama in 1995-1999. This is likely in part due to a lower Canadian prevalence of obesity (13.3%) than in Alabama (36.4%). Comparing our results to those in Utah is complicated by their use of maternal weight at birth as the determinant rather than BMI and recommended GWG. This methodological difference along with possible differences in the maternal weight distribution and obstetric practice in Utah and Canada may explain the much higher PAF observed in that study.

It is also noteworthy that compared to overweight and obese BMI, a similar proportion of caesarean births was associated with excess GWG due to the high prevalence of above recommended GWG. The additional risk posed by GWG was attenuated among parous women with previous caesarean births at high risk of repeat caesarean births, while it was magnified among parous women without a previous caesarean birth at low risk of caesareans. Among parous women without a prior caesarean birth the overall rate of caesarean birth was less than half the population rate; however, twice as many caesarean births were associated with above recommended GWG compared to overweight or obese BMI (23.6% versus 10.9%). Unfortunately, few women report being counselled about GWG [26]. This represents a missed opportunity for prevention, since health care providers are likely more able to impact GWG than BMI, as few women seek preconception care but most receive prenatal care within the first trimester [27].

Our study has some limitations. Although self-reported data on BMI and GWG are highly correlated with measured values, they tend to underestimate these values [28,29]. This could have resulted in overestimated associations between BMI, GWG and caesarean births [28]. Additionally, some residual confounding likely remains as we were unable to consider unmeasured factors. Data on indications for caesarean births would have increased our understanding of studied associations [30]. We were also not able to adjust for weight-related clinical conditions such as pre-eclampsia and diabetes, though there is some uncertainty about the degree to which such conditions are on the causal pathway, and should therefore not be adjusted for [4]. In addition, we made multiple comparisons which increases the chance of significant findings [31]; however, the associations noted in the results are plausible and we reported precise confidence intervals to support interpretation.

Conclusions
In summary, our study found that one in five caesarean births in singleton term pregnancies in women 18 years and older was associated with above normal BMI or excess GWG, and this proportion is likely to increase as the prevalence of overweight and obesity rises. Nulliparous women with above normal BMI and excess GWG are at particular risk for unplanned caesareans. Strategies to reduce caesarean births in Canada must include measures to prevent overweight and obese BMI prior to conception and promote recommended weight gain throughout pregnancy.

Competing interests
The authors declare that they have no competing interests.

Authors’ contributions
SD and SD Mc conceived and guided the study. SD, J and RSK developed statistical methods and SD carried out statistical analysis. SD and SD Mc drafted and revised the manuscript on the basis of comments from other authors. All authors contributed to the interpretation of the data, critically reviewed all drafts of the manuscript and approved the final version submitted for publication.

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References

1. Stevens GA, Singh GM, Lu Y, Danaei G, Lin JK, Finucane MM, Bahalim AN, McIntire RK, Gutierrez HR, Cowan M, Paciorek CJ, Farzadfar F, Riley L, Ezzati M, The Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (Body Mass Index): National, regional, and global trends in adult overweight and obesity prevalences. Popul Health Metr 2013, 10:22.

2. Tjepkema M: Adult obesity. Health Rep 2006, 17:25–35.

3. Nohr EA, Vaeth M, Baker JL, Sørensen TI, Olsen J, Rasmussen KM: Adult obesity. Am J Obstet Gynecol 2005, 193:1375–1364.

4. Nohr EA, Vaeth M, Biker IL, Sørensen TI, Olsen J, Rasmussen KM: Combined associations of prepregnancy body mass index and gestational weight gain with outcomes of pregnancy. Am J Clin Nutr 2008, 87:1750–1759.

5. Arendts K, Qiu Q, Gruslin A: Obesity in pregnancy: pre-conception to postpartum consequences. J Obstet Gynaecol Can 2008, 30:477–488.

6. The Society of Gynaecologists and Obstetricians of Canada (SGOC): Risling C-Section Rates Add Risks During Childbirth And Place Excess Strain On The Healthcare System, Warn Canadian Obstetricians. Ottawa: SGOC News Release; 2008.

7. Liu S, Liston RW, Joseph KS, Heaman M, Sauve R, Kramer MS, for the Maternal Health Study Group of the Canadian Perinatal Surveillance System: Maternal mortality and severe morbidity associated with low-risk planned cesarean delivery versus planned vaginal delivery at term. Can Med Ass J 2007, 176:455–460.

8. Chalmers B, Kaczorowski J, Darling E, Heaman M, Fell DB, O’Rourke C, Hornbrook MC, Contribution between obesity during pregnancy and increased use of health care. New Engl J Med 2008, 358:1444–1453.

9. Liu S, Kocherginsky M, Hibbard J: Abnormal placentation: twenty-year analysis. Am J Obstet Gynecol 2005, 192:1458–1461.

10. Public Health Agency of Canada (PHAC): Canadian Perinatal Health Report. 200th edition. Ottawa: PHAC, 2008.

11. Public Health Agency of Canada (PHAC): Perinatal Health Indicators for Canada. Ottawa: PHAC; 2013. in press.

12. Lu GC, Rouse DJ, DuBard M, Cliver S, Kimberlin D, Hauth JC: The effect of the increasing prevalence of maternal obesity on perinatal morbidity. Am J Obstet Gynecol 2001, 185:849–854.

13. LaCoursiere D, Bloebaum L, Duncan J, Varner M: Population-based trends and correlates of maternal overweight and obesity, Utah 1991-2001. Am J Obstet Gynecol 2005, 192:832–839.

14. Oteng-Ntim E, Koepka J, Seidel P, Wandelmeier S, Doyle P: Impact of obesity on pregnancy outcome in different ethnic groups: calculating population attributable fractions. PLoS One 2013, 8:e53749.

15. Dzakpasu S, Kaczorowski J, Chalmers B, Heaman M, Duggan J, Neusy E, for the Maternity Experiences Study Group of the Canadian Perinatal Surveillance System: The Canadian maternity experiences survey: design and methods. J Obstet Gynaecol Can 2008, 30:207–216.

16. Institute of Medicine: Weight Gain During Pregnancy: Reassessing the Guidelines. Washington, DC: The National Academies Press; 2009.

17. Kramer MS, Platt RW, Wen SW, Joseph KS, Allen A, Abrahamowicz M, Blondel B, Brabant G, for the Fetal/Infant Health Study Group of the Canadian Perinatal Surveillance System: A new and improved population-based Canadian reference for birth weight for gestational age. Pediatrics 2001, 108:e35.

18. Statistics Canada: Low Income Cut-Offs. http://www.statcan.gc.ca/pub/75f0020m/2009002/h2-en.html#n1 Accessed March 20, 2014.

19. Brunac Z, Gaus C, Williams D, Horner D: Purposeful selection of variables in logistic regression. Source Code for Bio Med 2008, 8:17.

20. Ruckinger S, von Kries R, Toschie A: An illustration of and programs estimating attributable fractions in large scale surveys considering multiple risk factors. BMC Med Res Methodol 2009, 9:7.

21. Ro J, Wu C, Yue K: Some recent work on resampling methods for complex surveys. Survey Methodol 1992, 18:209–217.

22. SAS Institute Inc: SAS EG software, version 5.1Copyright © 2012, Cary, NC, USA: SAS Institute Inc.

23. World Health Organization, UNFPA, UNICEF, AMDD-Averting Maternal Death and Disability: Monitoring Emergency Obstetric Care: A Handbook. Geneva: WHO Press; 2009.

24. McDonald SD, Pullenayegum E, Taylor VH, Latus R, Bracken K, Good C, Hutton E, Sword W: Despite 2009 guidelines, few women report being counseled correctly about weight gain during pregnancy. Am J Obstet Gynecol 2011, 205:333.e1–6.

25. Public Health Agency of Canada (PHAC): What Mothers Say: The Canadian Maternity Experiences Survey. Ottawa: PHAC, 2009.

26. Shields M, Gorber S, Tremblay M: Effect of measurement on obesity and morbidity. Health Rep 2008, 19:77–84.

27. Brunner Huber L: Validity of self-reported height and weight in women of reproductive age. Matern Child Health J 2007, 11:137–144.

28. Liu S, Rusen ID, Joseph KS, Liston R, Kramer MS, Wen SW, Kinch R, for the Maternal Health Study Group of the Canadian Perinatal Surveillance System: Recent trends in caesarean delivery rates and indications for caesarean delivery in Canada. J Obstet Gynaecol Can 2004, 26:755–742.

29. Feise RJ: Do multiple outcome measures require p-value adjustment? BMC Med Res Methodol 2002, 2:8.