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Maternal Weight after Childbirth versus Aging-Related Weight Changes

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Abstract

Background: Pregnancy weight gain is believed to contribute to female overweight and obesity. However, most studies do not account for the changes in body weight expected to occur as women age. We examined the long-term weight trajectory of childbearing women relative to weight progression that could be expected in the absence of pregnancy.
Methods: From the hospital records of 32,187 women with two births in Wisconsin during 2006 to 2013, we extracted the maternal weight at pregravid, delivery, and subsequent pregravid. We predicted the corresponding aging-progressed weights using a weight-for-age equation adjusted for sociodemographic variables. Nonparametric mixed effects models estimated the average maternal weight trajectory and the corresponding aging-related progression through 5 years after birth.
Results: The estimated aging-related progression predicted a gradual annual weight increase of 1.94 pounds (95% confidence interval 1.90–1.98), from 152.79 pounds at pregravid to 163.76 pounds by 5 years after birth. Actual maternal weight followed a sinusoidal pattern: increasing during gestation, decreasing during the first postbirth year, converging with the aging-related progression during the second postbirth year, and then increasing at 2.89 pounds (95% confidence

interval 2.23–3.55) annually and diverging upward from the aging-related progression to 168.03 pounds by 5 years after birth.
Conclusion: Pregnancy weight gain did not contribute to the aging-related trend, but lifestyle changes of parenthood may later exacerbate the long-term trend.

Pregnancy-related weight gain and retention have long been viewed as contributors to long-term weight increase and obesity among women of childbearing age (Bogaerts et al., 2013; Crawford & Senyak, 2016; Endres et al., 2015; Gore, Brown, & West, 2003; Gunderson, 2009; Gunderson & Abrams, 2000; Rossner, 1992; Rossner & Ohlin, 1995; Villamor & Cnattingius, 2006, 2016; Williamson, 1993; Williamson, Kahn, Remington, & Anda, 1990; Williamson et al., 1994). In a recent online survey of more than 7,000 U.S. women, 85% attributed their excess weight to prior pregnancy weight gain (Crawford & Senyak, 2016). Similar popular views were evident in other surveys both in the United States and internationally (Rossner, 1992; Rossner & Ohlin, 1995). The notion that the weight retained after pregnancy is a source of long-term maternal weight increase has support from numerous studies reporting that as many as one in five women experience a substantial postbirth weight increase (10 pounds or more) 1 year after giving birth relative to their pregravid weight (Gunderson, 2009). More recently, three population-level studies found an average increase of 3 to 6 pounds between two sequential births (Bogaerts et al., 2013; Villamor & Cnattingius, 2006, 2016), and a prospective cohort study of 775 primarily low-income women reported a more than 11-pound higher average maternal weight 1 year after pregnancy relative to preconception weight (Endres et al., 2015).

However, research on pregnancy weight retention largely overlooks the tendency of a woman's body weight to increase over time owing to physiological and lifestyle changes associated with aging, even in the absence of pregnancy (Gunderson, 2009; Gunderson & Abrams, 2000; Williamson, 1993; Williamson et al., 1990; Williamson et al., 1994). Studies report that from 1960s to 1990s, nulliparous women of reproductive age were gaining between 0.9 and 1.7 pounds per year, although these estimates have not been updated recently (Gunderson et al., 2004; Williamson, 1993; Williamson et al., 1990; Williamson et al., 1994). Not properly adjusting for weight changes that are expected in the absence of childbirth could lead to a false attribution of non–pregnancy-related weight gain to pregnancy weight retention. A handful of cohort studies of up to 3,000 U.S. women of childbearing age have included a comparison group of nulliparous women to account for aging-related weight changes (Gunderson et al., 2004; Rookus, Rokebrand, Burema, & Deurenberg, 1987; Smith et al., 1994; Williamson et al., 1994; Wolfe, Sobal, Olson, Frongillo, & Williamson, 1997). These studies found that women who gave birth gained 4 to 7 pounds more at the end of the 5- to 10-year follow-up periods than childless women. However, it was unclear whether the excess weight was attributable to retaining part of the weight gained during pregnancy, or to gaining weight after birth at a faster rate than nulliparous women, owing to potential lifestyle changes of parenthood (Gunderson, 2009; Gunderson

& Abrams, 2000). Analyses that examine a continuous trajectory of maternal weight changes during several years after childbirth, relative to aging-related weight progression over the same period, are lacking in the literature.

The specific aim of this study was to examine the long-term weight trajectory of childbearing women relative to weight progression that could be expected in the absence of pregnancy.

Materials and Methods

Data

Our data source, PeriData.Net, is a data platform developed in 2006 through the leadership of the Wisconsin Association for Perinatal Care, and it collects birth records data from 87 of 100 hospitals (92% of births). Thirty-one hospitals agreed to provide data for this research through limited data agreements, containing a total of 236,820 birth records, or 57% of all births between 2006 and 2013 in PeriData.Net. A key feature of these data is that each birth record contains a unique anonymized identification code for the mother, thus allowing us to link all births to the same woman in the order that they occurred. Institutional review board approval was obtained for the university institutional review board of the principal investigator (M.W.); institutional review board determinations were obtained from participating hospitals or deferred to the primary institutional review board.

Sample

From 230,466 births delivered between 24 and 42 weeks of gestation, linked to 172,835 women, we created our primary sample of sequential birth pairs from consecutive singleton pregnancies for estimating the maternal and the aging-related weight trajectories. We also used a sample of singleton births (with or without another birth) to primiparous women to generate a weight-for-age formula (Figure 1). We used the weight-for-age formula for predicting aging-progressed weight values that could be expected in the absence of pregnancy for the sample of birth pairs. We included live-born and fetal deaths and excluded births with missing data on maternal age, weight, and height. We also excluded, for generalizability purposes, observations where the mother had three or more prior births, for a primary sample of 32,187 birth pairs (17,159 were first/second births, 9,785 second/third births, and 5,243 third/fourth births) to 28,718 women. The sample of births to primiparous women included 64,835 singleton births with a record indicating no prior births (parity equals one), including the 17,159 sequential first/second births in the primary analysis sample and all other first births that either did not have a record of a subsequent birth during the study period or had a subsequent birth record with parity of greater than two, suggesting a missed birth record ($n = 1,414$).

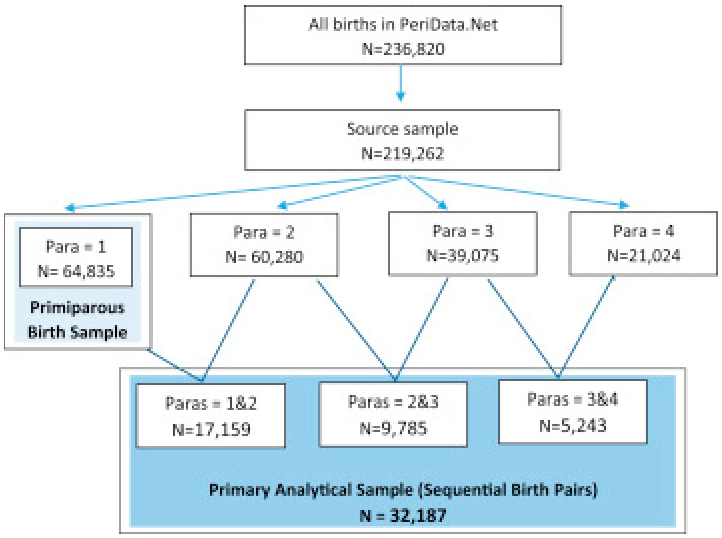

Figure 1. Sample selection flow-chart.

Measures

Our main outcome was maternal weight. Pregravid weight was recorded by hospitals at the time of admission in labor, based on a woman's weight at the first prenatal visit from the obstetrical providers' records. Maternal weight at delivery was measured either at admission in labor or at the last prenatal visit.

The main exposure variable was maternal age. Each birth record contained maternal age at delivery in years, rounded to three decimal points. We computed pregravid age as maternal age at delivery minus the length of gestation. The length of gestation was reported in weeks, rounded to two decimal points. The precise measurements of maternal age and gestational length allowed us to establish a precise timeline for maternal and aging-related weight estimation.

As control variables, we included maternal race and ethnicity (White non-Hispanic, Black non-Hispanic, other non-Hispanic, or Hispanic), marital status (married or other), education level (less than high school, completed high school, partial college, completed 4-year college, or graduate degree), type of health insurance (private, Medicaid or other public, self-pay or uninsured), and maternal height at delivery in inches.

Statistical Analyses

For each birth pair, we refer to the index pregnancy as "1" and the following pregnancy as "2." Summary statistics of the main analytic sample of birth pairs and for the sample of primiparous women were calculated and presented in a tabular form (Table 1).

Table 1. Descriptive Statistics of the Birth Pairs Sample and the Primiparous Births Sample

Variables	**Birth Pairs Sample, *n* (%)**	**Primiparous Births Sample, *n* (%)**
Number of observations	32,187	64,835
Age at delivery of pregnancy 1 (y)		
Mean (SD)	26.04 (5.20)	25.12 (5.00)
Race, ethnicity		
White, non-Hispanic	20,902 (70.1)	42,761 (66.0)
Black, non-Hispanic	5,792 (18.0)	10,752 (16.6)
Other, non-Hispanic	1,670 (5.2)	3,695 (5.7)
Hispanic	3,823 (11.9)	7,627 (11.8)
Marital status at delivery of pregnancy 1		
Not currently married	13,050 (40.5)	31,378 (48.4)
Currently married	19,137 (59.5)	33,457 (51.6)
Education level at delivery of pregnancy 1		
Less than high school	6,056 (18.8)	10,116 (15.6)
High school	7,481 (23.2)	16,468 (25.4)
Some college	7,286 (22.6)	16,010 (24.7)
4-year college graduate	7,882 (24.5)	15,264 (23.5)
Graduate degree	3,324 (10.3)	6,646 (10.3)
Missing	158 (0.5)	331 (0.5)
Pregravid BMI in pregnancy 1		
Mean (SD)	25.66 (6.08)	25.58 (6.13)
Pregravid BMI classification in pregnancy 1		
Underweight	1,433 (4.5)	3,846 (5.9)
Normal weight	16,667 (51.9)	33,484 (51.6)
Overweight	7,743 (24.1)	15,141 (23.4)
Obese	6,344 (19.7)	12,364 (19.1)
Pregravid weight in pregnancy 1 (lbs)		
Mean (SD)	152.79 (38.38)	152.00 (39.00)
Height in pregnancy 1 (in)		
Mean (SD)	64.64 (3.06)	64.64 (2.94)
Gestational age in pregnancy 1 (wk)		
Mean (SD)	38.99 (1.89)	39.05 (1.92)
Gestational weight gain in pregnancy 1 (lbs)		
Mean (SD)	32.38 (15.07)	33.57 (15.49)
Did not exceed recommendation*	10,109 (31.4)	24,252 (45.6)
Exceeded recommendation*	16,628 (51.66)	28,891 (54.4)
Pregravid weight change from pregnancy 1 to pregnancy 2 (lbs)		

Variables	Birth Pairs Sample, *n* (%)	Primiparous Births Sample, *n* (%)
Mean (SD)	6.30 (18.90)	6.26 (19.56)‡
Interpregnancy interval from delivery of pregnancy 1 to pregravid of pregnancy 2 (mos)		
Mean (SD)	19.88 (12.71)	20.61 (12.43)*

Abbreviations: BMI, body mass index; SD, standard deviation.
∗Did not exceed recommendations if gained less than 35/25/20 pounds for normal weight (including underweight), overweight, and obese, respectively; exceeded otherwise (Rasmussen & Yaktine, 2009).
†The average interpregnancy interval is based on a subsample with a record of another birth after the first birth.

We predicted how much each woman would have weighed at delivery of pregnancy 1 and pregravid of pregnancy 2, accounting only for aging-related progression of weight that would have been expected in the absence of pregnancy 1. To predict these aging-progressed weight values, we used a weight-for-age formula, which we derived by estimating a cross-sectional polynomial regression of pregravid weight on pregravid age with adjustment for the maternal control variables using the primiparous sample.

Both the maternal weight trajectory and the aging-related progression were initiated at the same starting point representing the average pregravid weight in pregnancy 1. From delivery of pregnancy 1 and throughout the 5-year postbirth period, we estimated a nonparametric longitudinal mixed effects regression model (Wu & Zhang, 2006), first regressing the actual maternal weight at delivery of pregnancy 1 and pregravid of pregnancy 2 on the maternal age at the corresponding points, and then repeating the estimation with the aging-progressed predicted weight values. Longitudinal mixed effects models are designed for modeling the types of data, where the longitudinal response variable (the actual maternal weight and the aging-progressed predicted weight) varies for each woman over time (Wu & Zhang, 2006). We modelled the maternal and aging-progressed longitudinal patterns as nonparametric fixed effects, and adjusted for the uniqueness of each woman using a maternal random effect. We clustered both sets of estimates at the individual woman level to account for instances of multiple pairs of births to the same mother. Intuitively, these models estimated the sample means and confidence intervals for the actual maternal weight values, and for the corresponding aging-progressed predictions, at a series of timepoints from delivery to 5 years after birth in quarter-year increments, each time using only the women whose pregnancy 2 started at that specific postbirth timepoint. To examine robustness of our aging-related progression to bias potentially resulting from using cross-sectional variation in ages and weights of primiparous women, we conducted sensitivity analyses for our weight-for-age estimations using the National Longitudinal Study of Adolescent to Adult Health (Harris, 2009) that contains repeatedly measured weight prior to first pregnancy, and several other external national databases. Details of the statistical analysis and the sensitivity analyses are described in Online Supplement A.

We compared the maternal weight trajectory with the aging-related weight progression at each postbirth timepoint, interpreting the inclusion of the aging-related weight within the 95% confidence bounds of the respective maternal weight, and a nonsignificant ($p > .05$) difference between the maternal weight and aging-related estimate, as evidence of convergence at that timepoint. We presented the maternal weight trajectory and the aging-related progression in Figure 2; we reported the full set of estimates with 95% confidence intervals and the significance testing results in Table 2.

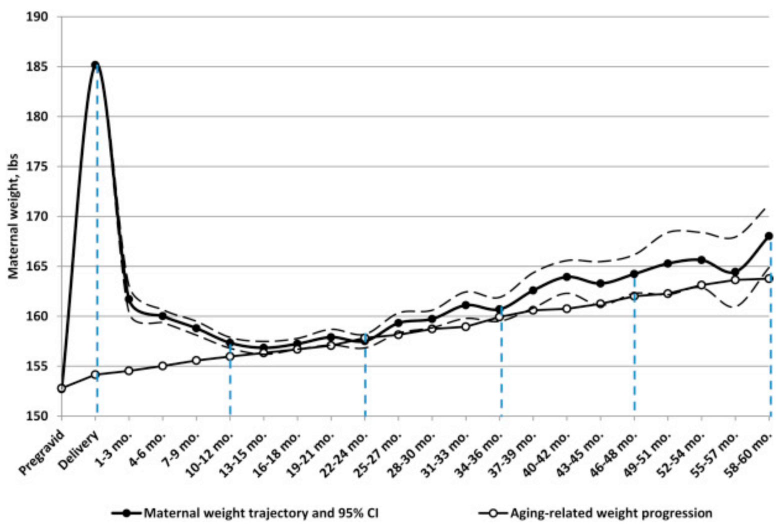

Figure 2. Maternal weight trajectory versus aging-related weight progression. Shown are the maternal weight trajectory (solid line with solid-filled markers) and the 95% confidence intervals (CI; dashed lines), alongside the corresponding aging related weight progression (solid line with hollow markers), from pregravid to 5 years after birth. The data points were obtained from the author's analyses of maternal weight for 32,187 birth pairs from the Peridata. Net data platform, Wisconsin, using longitudinal non-parametric mixed-effects models. The blue vertical dashed lines indicate 12-month postbirth intervals.

Table 2. Maternal Weight Trajectory versus Aging-Related Weight Progression, Full Sample ($n = 32,187$ Births)

Time Point	Number of Observations	Maternal Weight Trajectory (95% CI)	Aging-Related Weight Progression (95% CI)	Difference (p Value)
Pregravid	32,187	152.8 (152.8–152.8)		
Delivery	32,187	185.2 (185.0–185.3)	154.1 (154.1–154.2)	31.01 (<.001)**
		Year 1		
1–3 mo	917	161.7 (160.4–163.1)	154.5 (154.5–154.6)	7.185 (<.001)**
4–6 mo	2,899	160.0 (159.4–160.7)	155.0 (155.0–155.1)	4.993 (<.001)**
7–9 mo	2,478	158.8 (158.1–159.5)	155.6 (155.5–155.6)	3.229 (<.001)**
10–12 mo	4,364	157.3 (156.8–157.9)	156.0 (155.9–156.0)	1.370 (<.001)**
		Year 2		
13–15 mo	3,021	156.8 (156.2–157.5)	156.3 (156.2–156.4)	0.508 (.123)
16–18 mo	4,041	157.2 (156.7–157.8)	156.7 (156.6–156.8)	0.548 (.062)
19–21 mo	2,240	157.9 (157.1–158.7)	157.1 (156.9–157.2)	0.836 (.058)

Time Point	Number of Observations	Maternal Weight Trajectory (95% CI)	Aging-Related Weight Progression (95% CI)	Difference (p Value)
22–24 mo	2,897	157.5 (156.8–158.2)	157.8 (157.6–158.0)	−0.316 (.377)
		Year 3		
25–27 mo	1,512	159.3 (158.3–160.3)	158.1 (157.9–158.4)	1.169 (.025)*
28–30 mo	1,942	159.7 (158.9–160.6)	158.7 (158.5–159.0)	0.998 (.030)*
31–33 mo	1,015	161.1 (159.8–162.4)	158.9 (158.6–159.3)	2.160 (.002)**
34–36 mo	1,232	160.7 (159.5–161.9)	159.9 (159.6–160.3)	0.772 (.222)
		Year 4		
37–39 mo	643	162.6 (160.8–164.4)	160.6 (159.4–161.8)	1.991 (.066)
40–42 mo	850	163.9 (162.3–165.6)	160.7 (160.3–161.2)	3.187 (<.001)**
43–45 mo	438	163.3 (161.1–165.5)	161.2 (160.6–161.9)	2.039 (.076)
46–48 mo	523	164.2 (162.3–166.2)	162.0 (161.4–162.7)	2.217 (.029)*
		Year 5		
49–51 mo	288	165.3 (162.2–168.4)	162.3 (161.4–163.2)	3.009 (.064)
52–54 mo	328	165.6 (162.9–168.4)	163.1 (162.0–164.3)	2.503 (.096)
55–57 mo	168	164.4 (161.0–167.9)	163.6 (162.3–165.0)	0.799 (.679)
58–60 mo	176	168.0 (164.9–171.2)	163.8 (162.4–165.1)	4.266 (.018)*

$*\ p < .05$; $**\ p < .01$.

We conducted sensitivity analyses with respect to 1) pregravid body mass index (BMI) category (Centers for Disease Control and Prevention, 2016), 2) gestational age ("Definition of term pregnancy", 2013), 3) pregnancy weight gain relative to the recommended gestational weight gain limit for each BMI category (exceeded recommendations if >35/>25/>20 lbs for normal weight/overweight/obese; did not exceed otherwise; Rasmussen and Yaktine, 2009), and 4) parity order at pregnancy 1 (whether the birth pair represented first/second, second/third, or third/fourth gestations). We present these results in Online Supplement B.

Results

The descriptive statistics for 1) the primary analysis sample of paired births (first/second, second/third, third/fourth) and 2) the sample of births to primiparous women (first/second births plus all first births without a record of a second birth) are presented in Table 1. In the paired births sample, the average maternal age was 26.04 years (SD = 5.20). The average pregravid weight was 152.79 pounds (SD = 38.38) and the average pregravid BMI was 25.66 (SD = 6.08), which exceeds the normal BMI range (normal BMI, 18.5–24.9; Centers for Disease Control and Prevention, 2016). On average, women gained 32.38 pounds (SD = 15.07) during pregnancy and 52% (n = 16,628) gained more than clinically recommended for their BMI category (Mayo Clinic, 2014). The sample of births to primiparous women had similar descriptive statistics, although the women were about 1 year younger at delivery (25.12 years; SD = 5.00) and had slightly lower pregravid weight (152.00 pounds; SD = 39.00) and BMI (25.58 kg/m^2; SD = 6.13).

Figure 2 shows the estimated maternal weight trajectory and the estimated aging-related progression from pregravid to 5 years after birth. The material weight trajectory had a sinusoidal upward trending pattern: it was characterized by an initial weight increase from 152.79 pounds (95% confidence interval [CI] 152.76–152.82) at pregravid 1 to 185.16 pounds (95% CI 185.05–185.27) at delivery 1 (Table 2). Delivery was followed by a decrease to 157.34 pounds (95% CI 156.80–157.88) by 1 year after birth. During the second postbirth year, maternal weight was relatively stable at 156.83 pounds (95% CI 156.20–157.48) in the first quarter and 157.51 pounds (95% CI 156.82–158.19) in the last quarter, with a linear trend indicating a non-significant annual weight increase of 1.12 pounds (95% CI -0.09 to 2.34). During postbirth years 3 through 5, maternal weight increased gradually from 159.32 (95% CI 158.31–160.32) in the first quarter of postbirth year 3 to 168.03 (95% CI 164.87–171.18) in the last quarter of the postbirth year 5, with the linear trend indicating weight gain at the annual rate of 2.89 pounds (95% CI 2.23–3.55).

Aging-related weight progression had a monotone upward gradient: body weight increased progressively by an average of 1.94 pounds (95% CI 1.90–1.98) per year. Based on aging-related weight changes alone, the average weight for women in the sample was expected to increase from its pregravid level of 152.79 pounds to 155.97 pounds (95% CI 155.90–156.03) by the last quarter of postbirth year 1, to 157.83 pounds (95% CI 157.64–158.01) by the last quarter of postbirth year 2, and to 163.76 pounds (95% CI 162.44–165.08) by the end of postbirth year 5 (Table 2). In sensitivity analyses using external databases, we found even greater increases in weight with age, relative to which the weight-for-age estimates presented in this study are conservative (Online Supplement A).

The maternal weight trajectory and its 95% confidence bounds lay significantly above the aging-related weight progression during the first postbirth year. Maternal weight estimates during the second postbirth year were not different, containing the corresponding expected values from the aging-related weight progression within the respective 95% confidence bounds. During postbirth years 3 through 5, the maternal weight trajectory started to increase at a faster rate than the aging-related progression with 0.95 pounds additional weight gain annually above the aging-related progression (difference between 2.89 and 1.94; $p < .01$). In sensitivity analyses, the results were robust showing convergence of the maternal weight trajectory with the aging-related progression by the end of the second postbirth year across the gestational age categories, pregravid BMI categories, gestational weight gain categories, and parity orders (Online Supplement B).

Discussion

This study examined the popularly held notion that the weight gain experienced by many women during childbearing years is attributable to long-term retention of gestational weight gain. We estimated the maternal weight trajectory from pregravid through 5 years after birth using longitudinal data, and compared it with the aging-related weight progression in our sample. Our novel approach to estimating the convergence of pregnancy-related weight trajectory across 5 years after birth with the aging-related weight progression allowed us to determine whether long-term weight gain in childbearing women was related to pregnancy or to aging.

The weight increase of 4 to 5 pounds (1.8–2.3 kg) relative to pregravid weight, from 153 pounds (69.4 kg) at pregravid to 157 to 158 pounds (71.2–71.7 kg) at 1 to 2 years after birth, was consistent with earlier studies that also found a 3 to 6-pound (1.4–2.7 kg) maternal weight gain between subsequent births (Bogaerts et al., 2013; Villamor & Cnattingius, 2006, 2016). However, the aging-related weight progression also increased by about 2 pounds (0.9 kg) per year on average. In comparing the pregnancy-related trajectory and the aging-related weight progression, we found that maternal weight significantly exceeded the aging-related projection throughout the first postbirth year, with subsequent convergence of the maternal weight trajectory with the aging-related weight progression by second postbirth year. Although maternal weight stabilized during the second postbirth year at a level that was above the pregravid weight, the amount of weight increase was similar to what could be expected in the absence of pregnancy. In other words, by approximately 1 to 2 years after delivery, a woman's weight tends to be back in line with the expected weight trajectory for her age. Of note, sensitivity analyses using external databases suggested that aging-related changes in weight may in fact be more prominent than in our study data, thus strengthening our conclusion that long-term weight increases in women of childbearing age are unlikely to be attributable to the effects of pregnancy weight gain.

Understanding that changes in body weight are expected with age, even in the absence of pregnancy, is important for promoting positive and reasonable expectations for body weight and body image after pregnancy. With close to two out of every three pregnant women expecting their weight to return to the pregravid level by the end of the first postbirth year, the apparent misalignment of expectations with the reality of aging-related weight progression could be contributing to the worsened body image reported by 64% of women 1 to 2 years after giving birth (Crawford & Senyak, 2016). Women are usually advised to reduce caloric intake and increase physical activity during the postpartum year until return to the prepregnancy weight is achieved; however, evidence of these recommendations is mixed (Choi, Fukuoka, & Lee, 2013; Field et al., 2003; O'Toole, Sawicki, & Artal, 2003; Rossner, 1992). Additionally, several studies have suggested that short-term dieting to lose weight—in contrast with a longer term effort to engage in more healthful eating and physical activity—can actually lead to long-term weight gain, disordered eating, and depression (Field et al., 2003; Keel, Baxter, Heatherton, & Joiner, 2007). Accordingly, prenatal and postnatal visits present an opportunity for clinicians for reinforce reasonable postbirth weight loss expectations and promote healthy long-term management of both pregnancy-related and aging-related weight changes, with the goal of steering women toward a more healthful permanent lifestyle for both themselves and their children.

During postbirth years 3 to 5, maternal weight increased almost a pound-per-year faster than what could be expected in the absence of pregnancy, thus adding up to approximately 3 pounds (1.4 kg) of extra weight by the end of year 5. Because the excess maternal weight gain was accumulated after the second postbirth year, it is unlikely that it is attributable to retention of gestational weight gain. Mothers of young children often prioritize the caregiving needs of the child while being unaware of subtle changes in their own lifestyle, such as increased caloric intake, a less healthy diet, and reduced physical activity (Berge, Larson, Bauer, & Neumark-Sztainer, 2011). Over a period of time, however, the combined effect of these lifestyle changes could lead to excess weight accumulation. Accordingly, health care providers should counsel women regarding weight changes that are expected to occur with age and raise awareness of the ways that inconspicuous lifestyle changes of parenthood could be exacerbating this long-term trend, to decelerate the progression of weight over a woman's life course.

Short interpregnancy intervals may deserve special attention. Women who became pregnant within 1 year of a previous birth weighed more at the beginning of the second pregnancy relative to the corresponding aging-related projections, possibly increasing their risk of retaining and accumulating pregnancy weight with repeated pregnancies. Although short interpregnancy intervals have been linked previously to obstetrical complications and adverse maternal and infant outcomes (Ball, Pereira, Jacoby, de Klerk, & Stanley, 2014; Conde-Agudelo, Rosas-Bermudez, & Kafury-Goeta, 2006; Shachar & Lyell, 2012), our study is the first to point out the role of short interpregnancy intervals as a potential contributor to long-term maternal weight accumulation. Counselling about an adequate interpregnancy interval of at least 12 months is important for improving reproductive health outcomes and promoting life-long weight management.

Our study had several limitations. Our weight-for-age formula was derived from cross-sectional variation of pregravid weight with age for first-time mothers; longitudinal progression of weight with age before the onset of first pregnancy would be preferred but was not available in our data. However, sensitivity analyses using external longitudinal data supported our conclusions. Clinical estimates of gestational age are subject to error owing to reporting of the last menstrual period by the mother and error in ultrasound estimations; however, our findings are robust to gestational age. Our study examined population-based averages and did not specifically evaluate the subset of women in the upper-most or lower-most portions of the BMI and gestational weight gain distributions who may require active weight management plans to maintain a healthy weight throughout adulthood. Generalizability of the findings is limited by the characteristics of the study sample from a single state in the Midwestern United States. The average weight gain during pregnancy in our sample exceeded gestational weight recommendations and was consistent with previously reported gestational weight gain estimates in the United States, but higher than international samples (Bogaerts et al., 2013; Mayo Clinic, 2014; Villamor & Cnattingius, 2006, 2016; Weight Gain During Pregnancy: Reexamining the Guidelines, 2009). Last, there are several unmeasured variables that could account for postdelivery weight loss trajectories of the women in this study, such as breastfeeding, postpartum diet, and exercise. The role of these and other unmeasured lifestyle factors in shaping the woman's postpartum weight trajectory should be examined in future studies.

Conclusion

This study refutes the popularly held notion that accumulation of weight over the childbearing years is attributable to retained gestational weight gain for most women. Although the women in our study did not return to their pregravid body weight after birth, the amount of weight gain observed 1 to 2 years after birth was similar to what would have been expected in the absence of pregnancy, owing to aging-related progression of body weight. Thereafter, the weight trajectory diverged upward from the expected aging-related progression, suggesting the impact of family lifestyle factors as contributors to long-term weight increase.

Implications for Practice and/or Policy

Postnatal counseling should focus on setting realistic weight loss expectations to help promote a more positive body image after pregnancy. Weight gain that occurs with age in the absence of pregnancy and the potential exacerbating impact of lifestyle changes associated with parenthood should be clearly communicated to women. Encouraging women to adopt and maintain healthy eating and physical activity as a permanent lifestyle, as opposed to focusing on short-term dieting and exercise to achieve postpartum weight loss, can promote a healthy weight trajectory over the life course and help prevent overweight and obesity.

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Supplementary Data

Digital supplement A. Statistical analysis

Maternal weight trajectory

We modelled the post-birth segment of the maternal weight trajectory non-parametrically: instead of assuming a specific parametric form of maternal weight changes (e.g., segment-linear, polynomial, etc.), our non-parametric longitudinal mixed-effects model(Wu & Zhang, 2006) estimated sample means and confidence intervals of maternal weight (*m_wt*) at every time-point (*t*) from delivery to 5 years post-birth in quarter-year increments, using those women whose pregnancy 2 started at that specific time-point. We clustered the standard error at the maternal level using unique anonymized maternal identifiers (*SURROGATE_MOTHER_ID*). We set the data as a time-panel using the <*tsset SURROGATE_MOTHER_ID t*> command, and then estimated the non-parametric regression model by executing the following command <*xtreg m_wt i.t, cluster(SURROGATE_MOTHER_ID) fe*> in Stata.14.(Corp, 2015) The estimates are displayed in **Figure 1** and **Table 2** in the main manuscript.

Aging-related maternal weight progression

We conducted the estimation in three steps. First, to model the pattern of expected aging-related weight changes, we used the sample of primiparous women (*gravida=1*) with singleton pregnancies (*singleton=1*) who had not been treated for infertility (*invertility_treat=0*). We applied a cross-sectional non-parametric regression approach to estimate conditional means and 95% confidence intervals for pregravid weight (*pre_m_wt*) at every pregravid age in years (*pre_m_age*), using only women who became pregnant at that specific age. Because of potential cross-sectional correlation of maternal age at first pregnancy with maternal socioeconomic and demographic characteristics, we adjusted the estimation for the maternal control variables (marital status: *m_married*; educational level: *m_noHS*, *m_HS*, *m_someCol*, *m_BsBa*, *m_MsMaPlus*; race: *m_white*, *m_black*, *m_amerind*, *m_asian*, *m_other*, *m_hisp*; partner's race similarly defined with a prefix *h_*; insurance type: *m_private*, *m_Medicaid*, m_otherPubl, *m_selfpay*; height in inches: *m_height*). We used the command <*reg pre_m_wt i.pre_m_age m_married m_noHS m_HSm_someCol m_BsBa m_MsMaPlus m_white m_black m_amerind m_asian m_other m_hisp h_white h_black h_amerind h_asian h_other h_hisp m_private m_Medicaid m_otherPubl m_selfpay m_height if gravida==1&singleton==1&infertility_treat==0*> in Stata.14. We presented the non-parametric weight-for-age means with 95% CIs in **Figure A.1**.

Second, we fitted a series of polynomial regression equations of varying degrees (2nd through 10th degree) to the non-parametric weight-for-age predicted values, eliminating equations that did not fit within the corresponding non-parametric 95% confidence interval for one or more of the age groups. Of the remaining equations that fit within the confidence bounds for all age groups, we chose the smallest degree polynomial equation to avoid over-fitting. We graphed the final weight-for-age polynomial overlaying the weight-for-age means and 95% Cis in **Figure A.1**. We used the weight-for-age formula to calculate the expected aging-progressed weight (*a_wt*) at delivery 1 as $a\_wt = 0.0012*(del\_m\_age^4 - pre\_m\_age^4) - 0.0537*(del\_m\_age^3 - pre\_m\_age^3) + 0.7296*(del\_m\_age^2 - pre\_m\_age^2) - 1.382*(del\_m\_age - pre\_m\_age) + pre\_m\_wt$. We used a similar approach to calculate the predicted maternal weight at pregravid of pregnancy 2 by substituting maternal age at delivery for maternal age at pregravid of pregnancy 2.

Third, we estimated a non-parametric aging-related weight progression using the same approach that we used to estimate the maternal weight progression and the predicted aging-progressed maternal weight estimates (*a_wt*) at delivery and pregravid of pregnancy 2 from step 2. We set the aging-progressed data as a time-panel using the <*tsset SURROGATE_MOTHER_ID t*> command, and then estimated a non-parametric regression model <*xtreg a_wt i.t, cluster(SURROGATE_MOTHER_ID) fe*> in Stata.14. The estimates are presented in **Figure 1** and **Table 2** in the main manuscript.

Additional analyses

We also estimated the aging-related progression from several alternative data sources. We used three additional data sources: the National Vital Statistics data (NVS),("HAI Data and Statistics," 2016) the National Health and Nutrition Examination Survey (NHANES),("National Health and Nutrition Examination Survey Data," 2001-2014) and the National Longitudinal Study of Adolescent to Adult Health (Add Health).(Harris, 2009) The NVS data contain the full population of birth records from all U.S. states, and it has a similar structure to the WI birth records used in this study. We used the most recent NVS data for year 2015 and extracted a sample of singleton births 24-42 weeks gestation to primiparous women without a history of fertility treatment (n=1,062,891). For the NHANES data, we combined seven recent waves covering the period from 2001-2014 (n=14,519), and restricted the sample to nulliparous women with no missing records on marital status, education, race, height, weight. Using the NVS and NHANES samples, estimated two cross-sectional weight-for-age models using the approach described in step 1 above.

The Add Health study is a longitudinal survey of a nationally representative sample of approximately 12,000 U.S. 7-12th graders in 1994-1995, with follow-up surveys to 1996, 1994/5, 2001-2002, and 2007-2008. We restricted our Add Health sample to nulliparous women at the time of the 2007-2008 follow up, with no missing data on height and weight (n=3,466). Because the Add Health data are longitudinal, we estimated a non-parametric mixed-effects weight-for-age equation with individual-level random effects. We present the estimates from our Peridata.Net sample, alongside with the NVS, NHANES, and Add Health estimates, for maternal ages of 15-35 in **Figure A.2** (the Add Health data had insufficient numbers of women over the age of 32 for analysis).

The estimations of the aging-related weight progression using the Peridata.Net sample suggested that, in the absence of pregnancy, a woman's body weight increases by 1.94 pounds [1.90–1.98] per year. The estimated progressions from the other data sources had similar or greater annual increase estimates: 1.93 pounds [1.89-1.97] annual weight increase in the NVS data; 2.35 pounds [2.30–2.40] annual increase in the NHANES data, and 2.75 pounds [2.70-2.79] annual weight gain in the Add Health data. These findings were higher than the previously reported 0.9-1.7 pound annual weight increase in nulliparous women,(Gunderson et al., 2004; David F. Williamson, 1993; D. F. Williamson, Kahn, Remington, & Anda, 1990; D. F. Williamson et al., 1994) likely reflecting the growing trend of overweight and obesity over the recent decades.

Figure A.1. Weight-for-age relationship and polynomial approximation

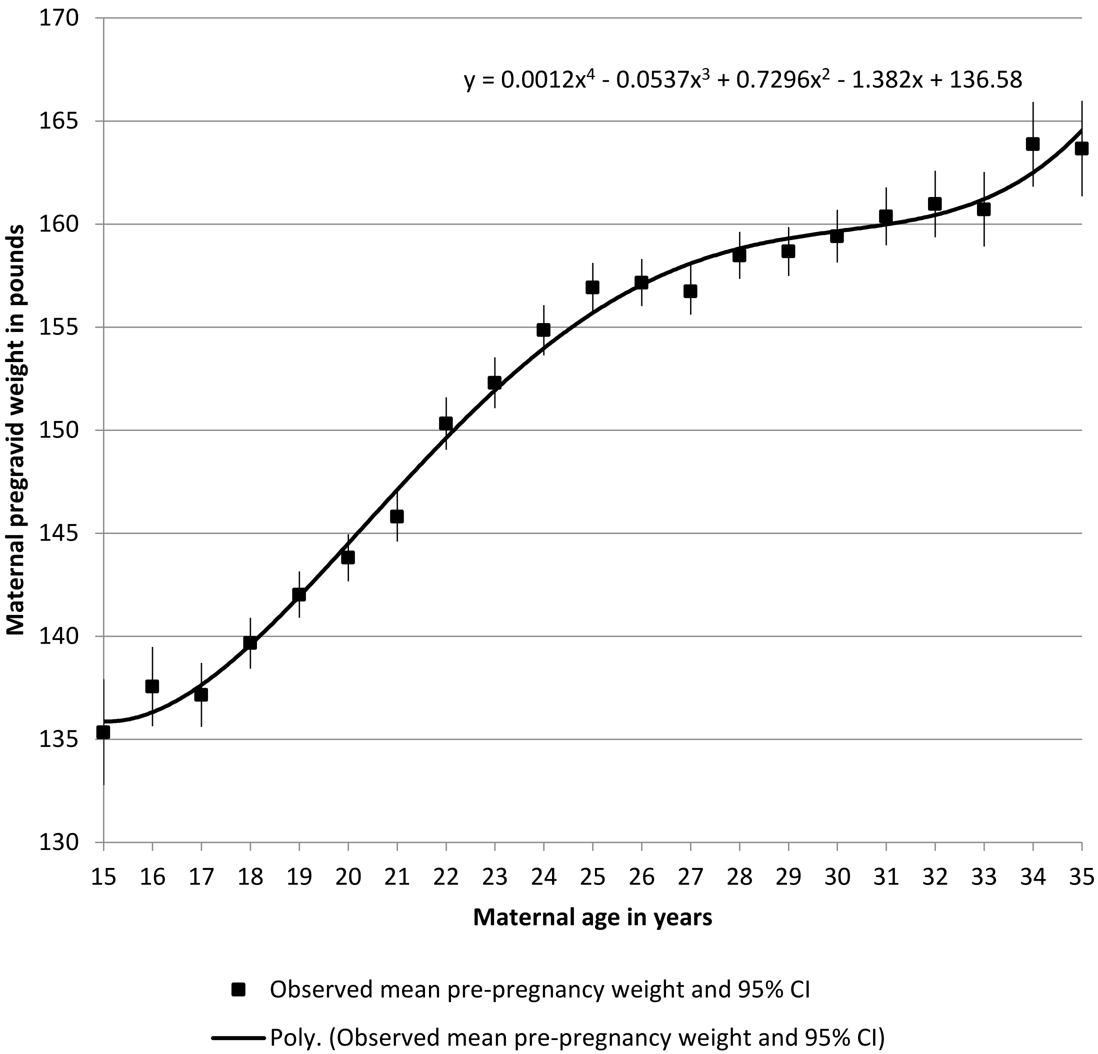
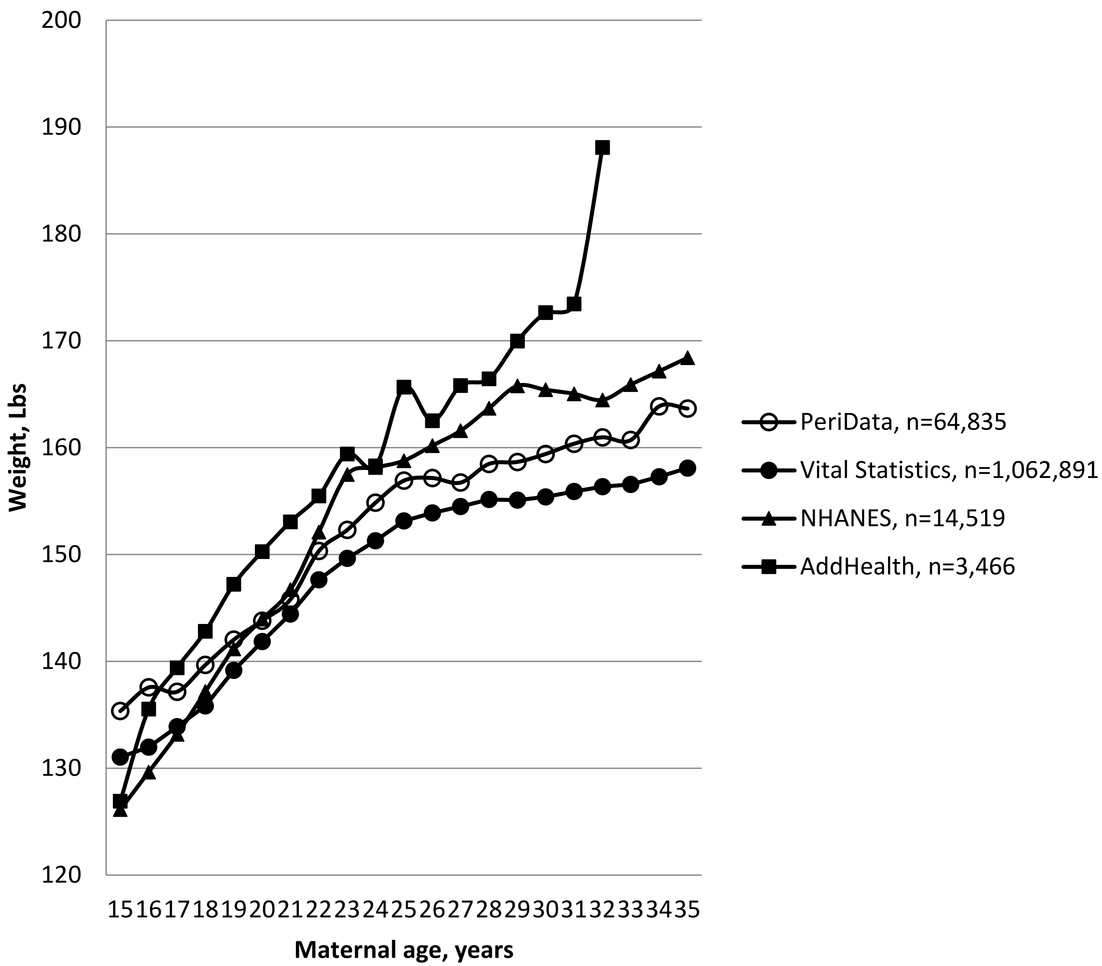


Figure A.2. Pre-gravid weight-by-age profile from PeriData, NVS, NHANES, and Add Health



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Digital Supplement B. Sensitivity Analyses by Maternal Body Mass Index, Gestational Weight Gain, Gestational Age, and Parity

Sensitivity analyses related to pregravid Body Mass Index (BMI) category("Body Mass Index (BMI)," 2016) (underweight or normal weight: BMI less than 25; overweight: BMI between 25 and 29.9; and obese: BMI of 30 and higher), gestational weight gain relative to the recommended gestational weight gain limit for each BMI category("Pregnancy weight gain: What's healthy?," 2014) (did not exceed recommendations/ exceeded the recommendations), and gestational age("Definition of term pregnancy. Committee Opinion No. 579. American College of Obstetricians and Gynecologists.," 2013) (preterm: 24-36 weeks; early term: 37-38 weeks; full term: 39-40 weeks; late term: 41-42 weeks) produced robust results. Descriptive statistics of the sample stratified by the pregravid BMI category are presented in **Table B.1**.

In sensitivity analyses by pregravid BMI (**Figure B.1**), the maternal weight trajectories and the corresponding aging-related weight progressions started at higher pregravid weight levels for women from higher BMI categories and displayed the expected upward-trending sinusoid patterns and. The maternal weight trajectories for underweight/normal and overweight BMI categories were characterized by a 34-35 pound gestational weight increase during pregnancy. In both of these BMI categories, maternal weight closely approximated the corresponding aging-related progressions from the later part of post-birth year 2 to the earlier part of post-birth year 3. Both trajectories showed subsequent divergence from the corresponding aging-related progressions during post-birth years 3 to 5, with the annual weight gain of 3.29 pounds [2.51 – 4.07] among the underweight/ normal weight women and 3.88 pounds [2.51 – 5.25] among the overweight women. The obese category had a gestational weight gain of close to 26.5 pounds and showed a convergence to the aging-related weight progression early during the first post-birth year, trending up at a gradual rate of 1.42 pounds annually

[0.46 – 2.38] but slightly below the aging-related progression, with little evidence of divergence throughout the entire post-birth period.

In further sensitivity analyses by gestational weight gain (**Figure B.2)**, convergence of the maternal weight trajectory with the aging-related weight progression was observed during second post-birth year in all gestational weight gain categories and BMI groups, with faster convergence among women who did not exceed weight gain recommendations for their BMI category relative to women who gained excessive gestational weight. Among obese women who met gestational weight recommendations, the post-birth segment of the maternal weight trajectory lay below the corresponding aging-related progression, suggesting a possible weight loss after birth relative to what could be expected in the absence of pregnancy.

While we did not find excessive gestational weight gain and high pregravid BMI to be risk factors for greater long-term retention of pregnancy weight, high BMI and excessive gestational weight gain are known risk factors for pregnancy complications (gestational diabetes, gestational hypertension, and Cesarean delivery) in current and subsequent pregnancies.(Bogaerts et al., 2013; Cedergren; Crane, White, Murphy, Burrage, & Hutchens, 2009; Kiel, Dodson, Artal, Boehmer, & Leet, 2007; E. Villamor & Cnattingius, 2006; Eduardo Villamor & Cnattingius, 2016; *Weight Gain During Pregnancy: Reexamining the Guidelines*, 2009) Additionally, strong associations with poor birth outcomes, including increased risk of preterm birth, still birth, and infant death, have also been reported.(Aune, Saugstad, Henriksen, & Tonstad, 2014; Bogaerts et al., 2013; Johansson et al., 2014; Nohr et al., 2008; Verma & Shrimali, 2012; E. Villamor & Cnattingius, 2006; Eduardo Villamor & Cnattingius, 2016; *Weight Gain During Pregnancy: Reexamining the Guidelines*, 2009) Therefore, high BMI and excessive gestational weight gain may impact a woman's and her baby's health in later life, even though the impact on long-term maternal weight may be minimal.

In sensitivity analyses by gestational age (**Figures B.3-B.6**), convergence of the maternal weight trajectory with the aging-related weight progression was also observed in all gestational age groups between one and two years post-birth. Subsequent divergence upward during the later post-birth years was also evident following an early-term and full-term pregnancy, but not in the pre-term and late-term gestational age groups; however the sample sizes in the pre-term and late-term groups were relatively small, therefore the findings should be interpreted with caution.

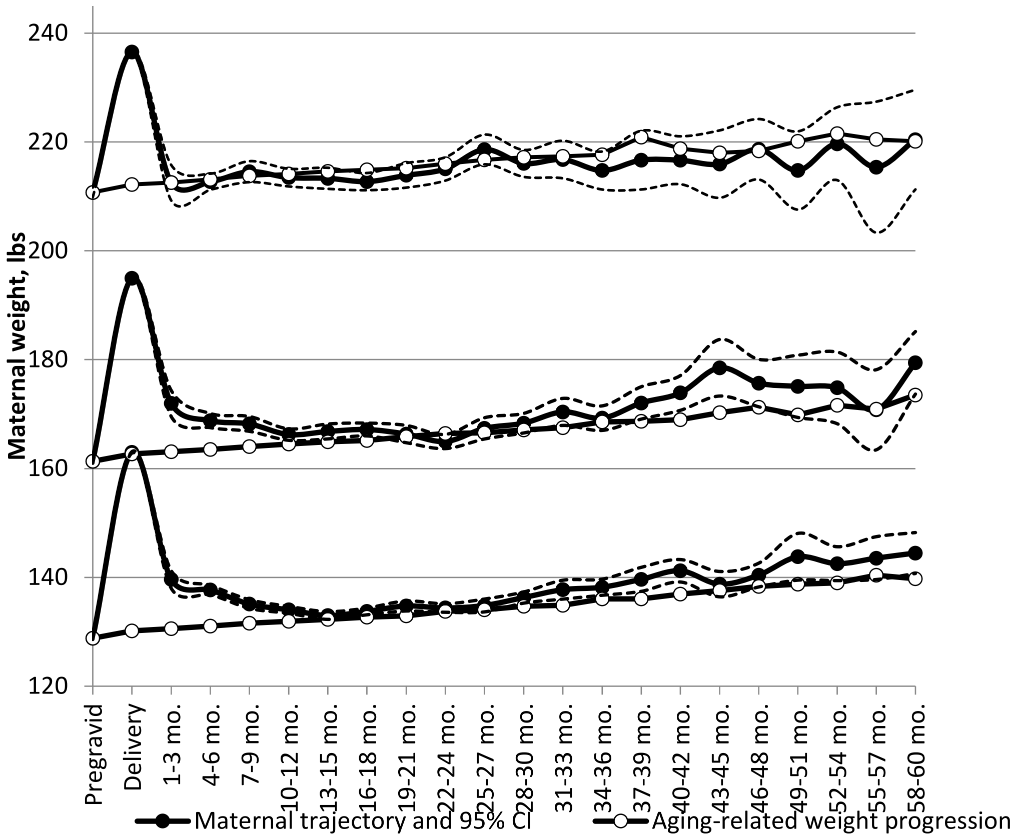
In sensitivity analyses by pregnancy number (Figure B.7), pregravid weight was about 150.6 points in the first pregnancy, 154.2 pounds in the second pregnancy, and 157.3 pounds in the third pregnancy. Average maternal age at delivery was 25.5 in the first pregnancy, 26.7 in the second pregnancy, and 27.8 in the third pregnancy. Gestational weight gain was about 34.2 pounds in first pregnancy, 31 pounds in the second pregnancy, and 29.7 pounds in the third pregnancy. Convergence of the maternal weight trajectories during and following the first, second, and third pregnancy with a common aging-related weight progression was observed by 12 months postpartum in all pregnancies.

Table B.1. Descriptive statistics of the sample by pregravid BMI classification

Variables	Sequential Birth Pairs			
	All	Normal weight and underweight (BM<24.9)	Overweight (BMI: 25-29.9)	Obese (BMI: 30+)
Number of observations	32,187	18,100	7,743	6,344
Age at delivery of pregnancy 1, years:				
Mean (SD)	26.04 (5.20)	25.92 (5.27)	26.15 (5.12)	26.25 (5.09)
Race, ethnicity:				
White, non-Hispanic	20,902 (70.1)	12,082 (66.8)	5,038 (65.1)	3,782 (59.6)
Black, non-Hispanic	5,792 (18.0)	2,847 (15.7)	1,392 (18.0)	1,553 (24.5)
Other, non-Hispanic	1,670 (5.2)	1,141 (6.3)	331 (4.3)	198 (3.1)
Hispanic	3,823 (11.9)	2,030 (11.2)	982 (12.7)	811 (12.8)
Marital status at delivery of pregnancy 1:				
Not currently married	13,050 (40.5)	7,036 (38.9)	3,064 (39.6)	2,950 (46.5)
Currently married	19,137 (59.5)	11,064 (61.1)	4,679 (60.4)	3,394 (53.5)
Education level at delivery of pregnancy 1:				
Less than high school	6,056 (18.8)	3,480 (19.2)	1,375 (17.8)	1,201 (18.9)
High school	7,481 (23.2)	3,828 (21.1)	1,875 (24.2)	1,778 (28.0)
Some college	7,286 (22.6)	3,668 (20.3)	1,846 (23.8)	1,772 (27.9)
4-year college graduate	7,882 (24.5)	4,838 (26.7)	1,883 (24.3)	1,161 (18.3)
Graduate degree	3,324 (10.3)	2,186 (12.1)	734 (9.5)	404 (6.4)
Missing	158 (0.5)	100 (0.6)	30 (0.4)	28 (0.4)
Pregravid BMI in pregnancy 1				

Mean (SD)	25.66 (6.08)	21.60 (2.13)	27.14 (1.45)	35.49 (5.10)
Pregravid weight in pregnancy 1, pounds:				
Mean (SD)	152.79 (38.38)	128.81 (16.19)	161.33 (16.52)	210.75 (36.11)
Height in pregnancy 1, inches:				
Mean (SD)	64.64 (3.06)	64.72 (3.16)	64.57 (2.89)	64.49 (2.92)
Gestational age in pregnancy 1, weeks:				
Mean (SD)	38.99 (1.89)	38.98 (1.87)	39.06 (1.82)	38.93 (2.04)
Gestational weight gain in pregnancy 1, pounds				
Mean (SD)	32.38 (15.07)	34.15 (13.10)	33.66 (15.21)	25.76 (18.08)
Did not exceed recommendation	10,109 (31.4)	10,857 (59.1)	2,250 (29.1)	2,453 (38.7)
Exceeded recommendation	16,628 (51.66)	7,273 (40.02)	5,493 (70.9)	3,891 (61.3)
Pregravid weight change from pregnancy 1 to pregnancy 2, pounds:				
Mean (SD)	6.30 (18.90)	6.93 (16.22)	6.94 (19.22)	3.73 (24.56)
Interpregnancy interval from delivery of pregnancy 1 to pregravid of pregnancy 2, months:				
Mean (SD)	19.88 (12.71)	19.97 (12.54)	19.94 (12.73)	19.53 (13.19)

Figure B.1. Maternal weight trajectory versus aging-related weight progression, by pregravid BMI catergory



Obese
n=6,344

Overweight
n=7,743

Normal/underweight
n=18,100

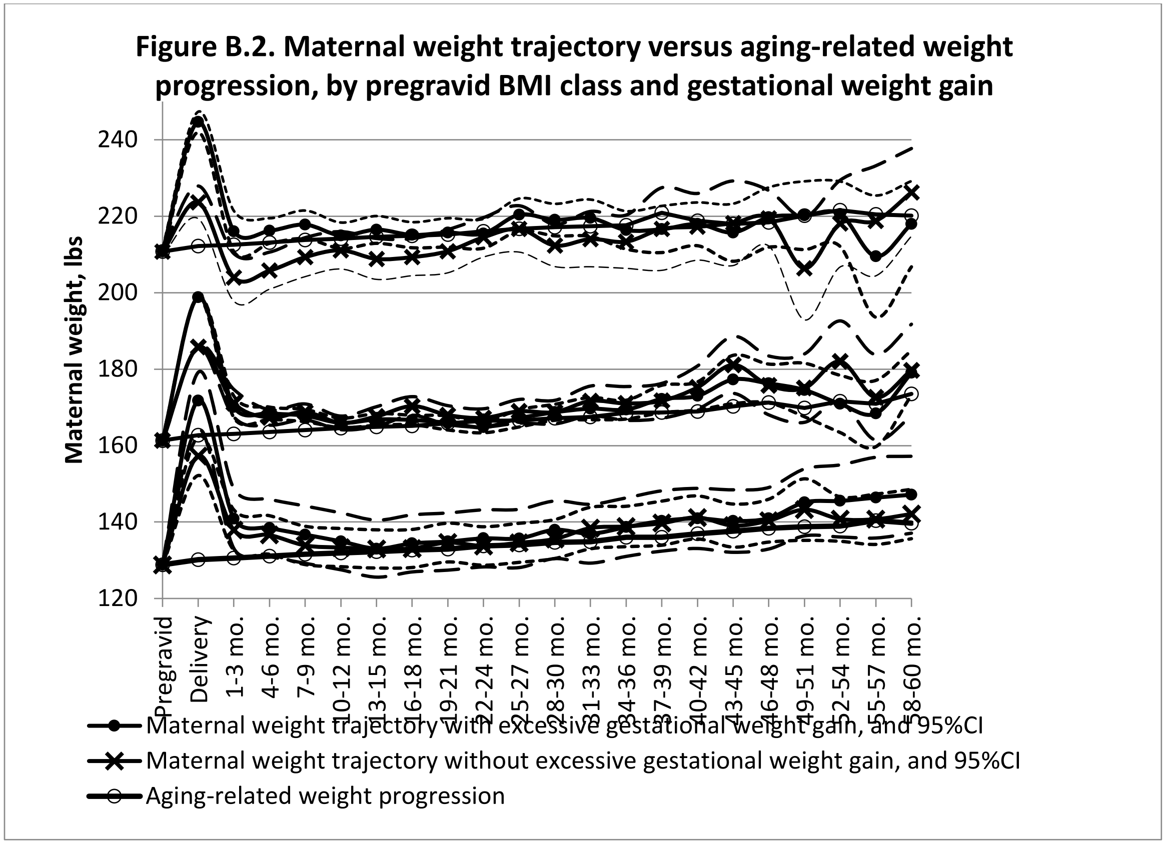


Figure B.2. Maternal weight trajectory versus aging-related weight progression, by pregravid BMI class and gestational weight gain
Maternal weight, lbs
240
220
200
180
160
140
120
Pregravid
Delivery
1-3 mo.
4-6 mo.
7-9 mo.
10-12 mo.
13-15 mo.
16-18 mo.
19-21 mo.
22-24 mo.
25-27 mo.
28-30 mo.
31-33 mo.
34-36 mo.
37-39 mo.
40-42 mo.
43-45 mo.
46-48 mo.
49-51 mo.
52-54 mo.
55-57 mo.
58-60 mo.
Maternal weight trajectory with excessive gestational weight gain, and 95%CI
Maternal weight trajectory without excessive gestational weight gain, and 95%CI
Aging-related weight progression

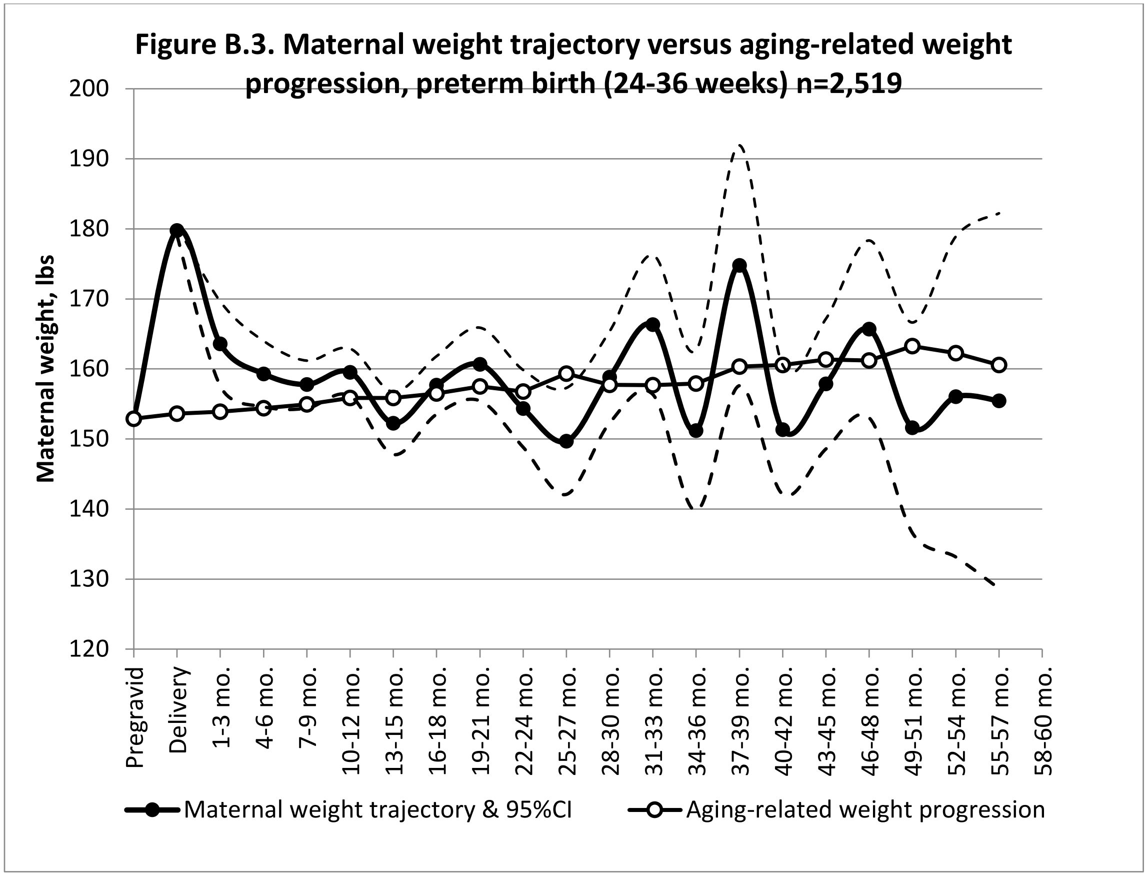
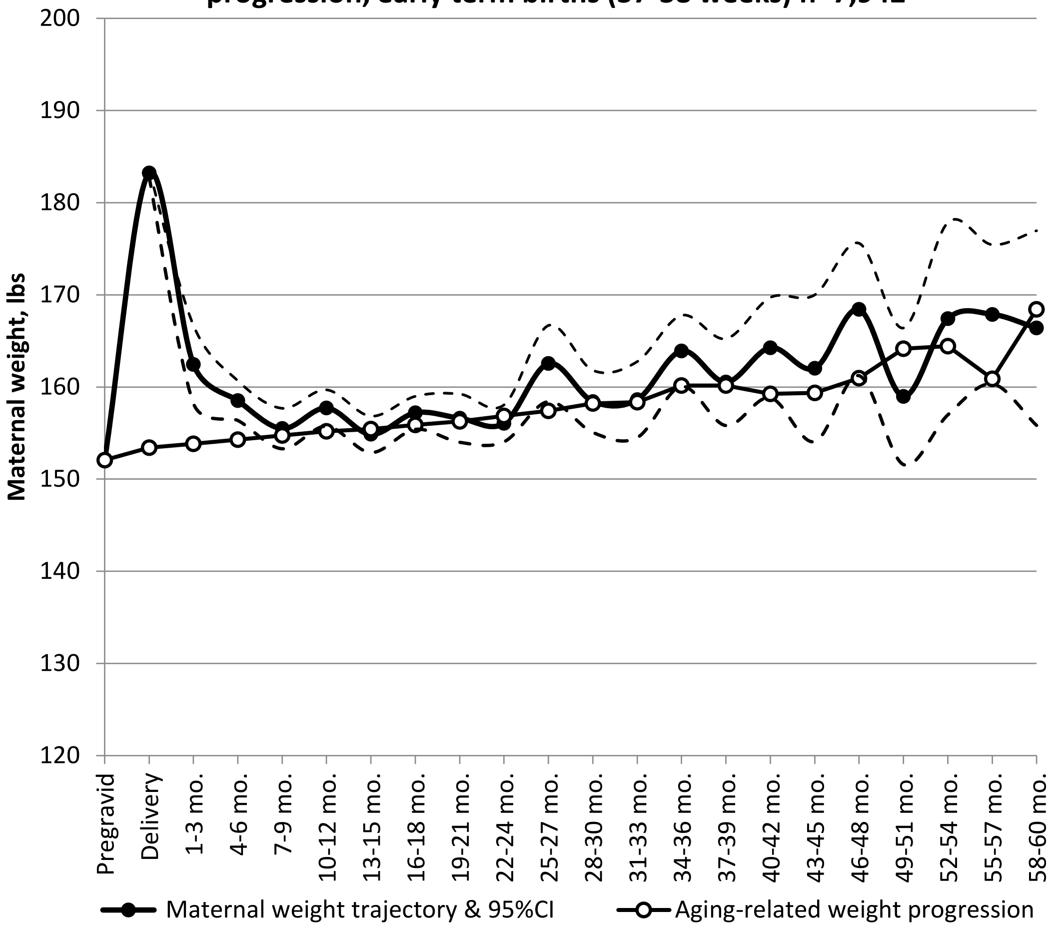


Figure B.3. Maternal weight trajectory versus aging-related weight progression, preterm birth (24-36 weeks) n=2,519
Maternal weight, lbs
200
190
180
170
160
150
140
130
120
Pregravid
Delivery
1-3 mo.
4-6 mo.
7-9 mo.
10-12 mo.
13-15 mo.
16-18 mo.
19-21 mo.
22-24 mo.
25-27 mo.
28-30 mo.
31-33 mo.
34-36 mo.
37-39 mo.
40-42 mo.
43-45 mo.
46-48 mo.
49-51 mo.
52-54 mo.
55-57 mo.
58-60 mo.
Maternal weight trajectory & 95%CI
Aging-related weight progression

Figure B.4. Maternal weight trajectory versus aging-related weight progression, early term births (37-38 weeks) n=7,942



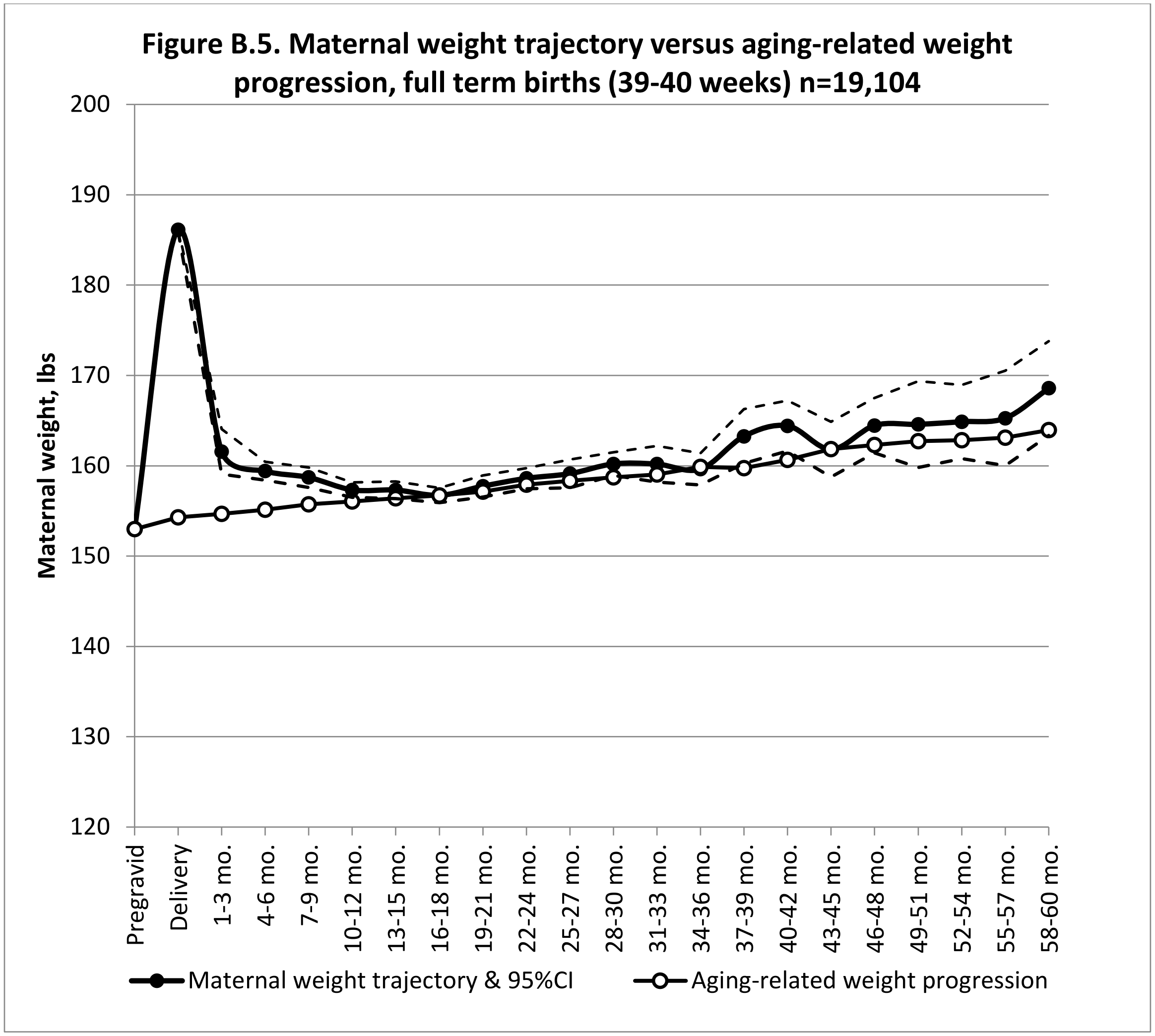


Figure B.5. Maternal weight trajectory versus aging-related weight progression, full term births (39-40 weeks) n=19,104
Maternal weight, lbs
200
190
180
170
160
150
140
130
120
Pregravid
Delivery
1-3 mo.
4-6 mo.
7-9 mo.
10-12 mo.
13-15 mo.
16-18 mo.
19-21 mo.
22-24 mo.
25-27 mo.
28-30 mo.
31-33 mo.
34-36 mo.
37-39 mo.
40-42 mo.
43-45 mo.
46-48 mo.
49-51 mo.
52-54 mo.
55-57 mo.
58-60 mo.
Maternal weight trajectory & 95%CI
Aging-related weight progression

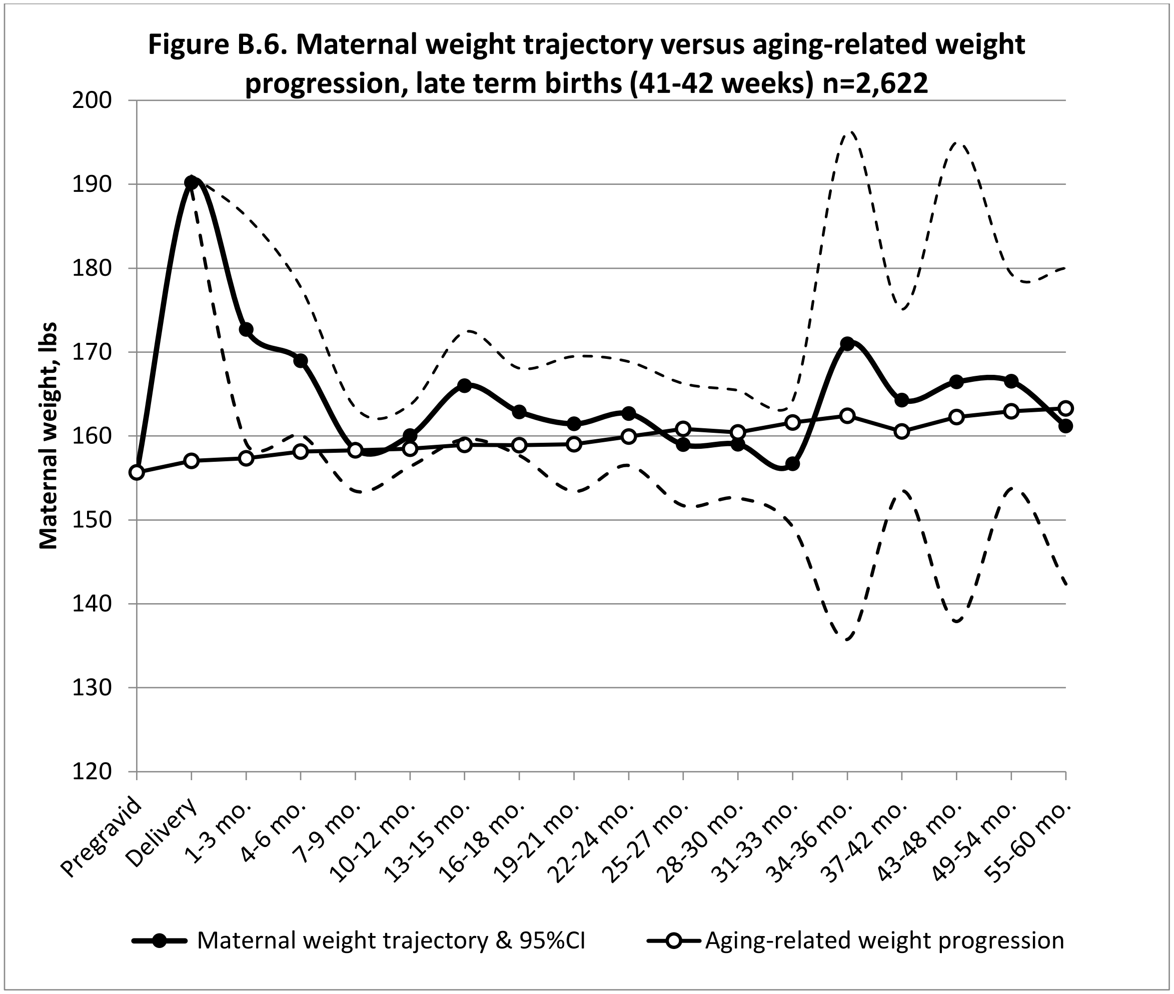
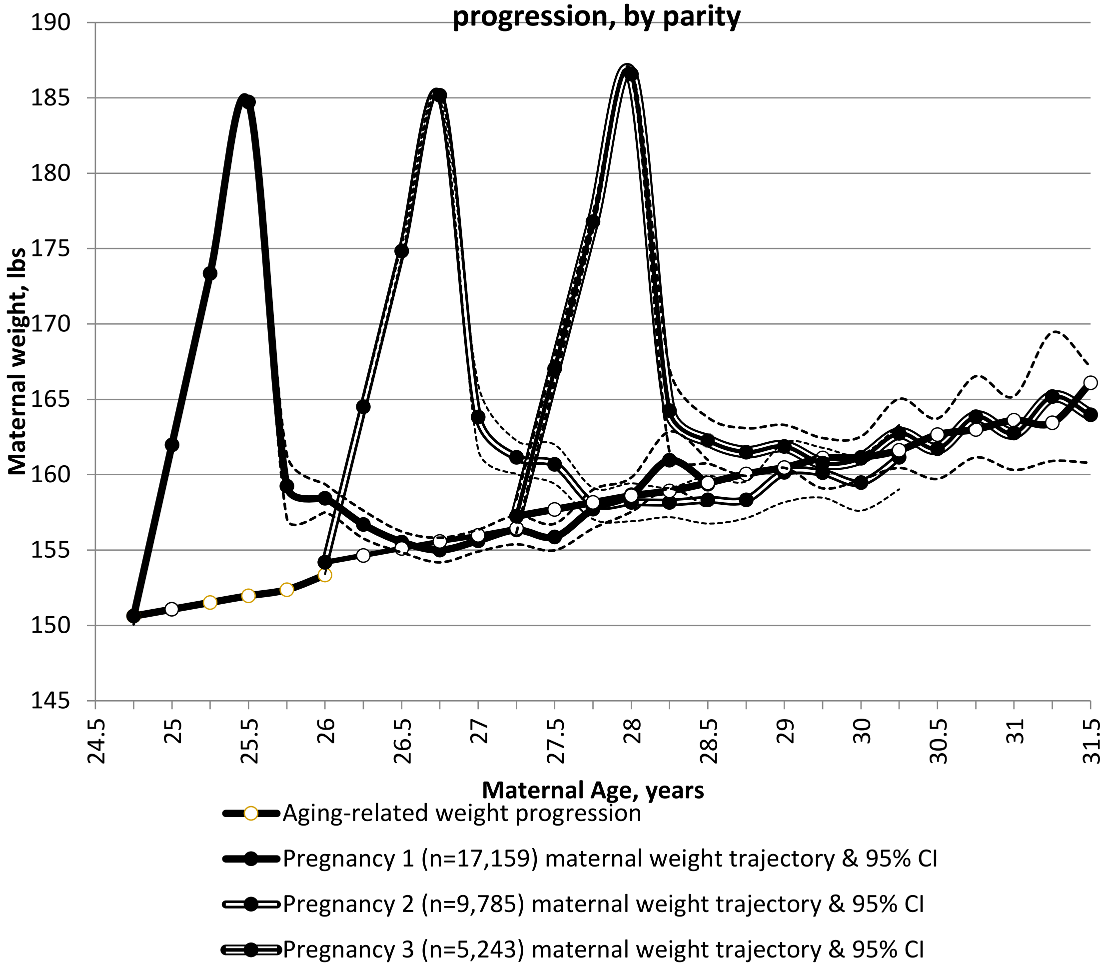


Figure B.6. Maternal weight trajectory versus aging-related weight progression, late term births (41-42 weeks) n=2,622
Maternal weight, lbs
200
190
180
170
160
150
140
130
120
Pregravid
Delivery
1-3 mo.
4-6 mo.
7-9 mo.
10-12 mo.
13-15 mo.
16-18 mo.
19-21 mo.
22-24 mo.
25-27 mo.
28-30 mo.
31-33 mo.
34-36 mo.
37-42 mo.
43-48 mo.
49-54 mo.
55-60 mo.
Maternal weight trajectory & 95%CI
Aging-related weight progression

Figure B.7. Maternal weight trajectory versus aging-related weight progression, by parity



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