Weight Gain during Pregnancy: Importance for Maternal and Child Health

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Abstract
Gestational weight gain is a strong predictor of short- and long-term health outcomes for both childbearing women and their offspring. Epidemiologic studies have found that higher maternal gestational weight gains are associated with abnormalities in maternal prenatal glycemia, hypertensive disorders of pregnancy and delivery complications, along with an increased risk of postpartum weight retention, incident obesity and adverse cardiometabolic sequelae in mothers by midlife. Additionally, observational data have linked greater gestational weight gains to increased fetal growth and later childhood obesity. Associations of gestational weight gain with preterm birth and infant mortality may be \textit{U}-shaped, such that the risks are increased with both low and high gains. In an attempt to optimize both maternal and child outcomes, the Institute of Medicine revised gestational weight gain guidelines in 2009, recommending smaller gains for women with higher prepregnancy body mass indices, particularly for women entering pregnancy with a body mass index of at least 30. However, it is as of yet unclear if these new recommendations will lead to improvements in the proportions of women gaining recommended amounts, and in maternal and child health. As fewer than one third of mothers currently gain within the ranges recommended by the Institute of Medicine, interventions to help mothers achieve healthy gestational weight gains are of critical public health importance.

Introduction

Gestational weight gain is a strong predictor of infant outcomes at birth [1]. It is well established that gestational weight gain is directly associated with intrauterine growth, and thus, infants born to women who gain more weight during pregnancy are less likely to be born small for gestational age or at low birth weight [1, 2]. Both very low and very high gestational weight gains are associated with an increased risk of preterm birth and infant death...
In an attempt to improve neonatal outcomes, recommendations for weight gain during pregnancy have increased since the early part of the 20th century, from 7 kg in the 1930s to 11.5–16 kg for normal weight-women in 1990 [4]. Actual gestational weight gains have been increasing in excess of the guidelines [5], and in recent years, nearly half of women in the USA gained more than recommended [6].

However, more weight gain may not always be better. Recent studies have highlighted some of the negative health outcomes associated with greater gains during pregnancy [3], including delivery complications [7], childhood overweight [8–10] and higher postpartum weight retention, which predisposes to later risk of obesity in the mother [6, 11].

In an attempt to optimize both maternal and child outcomes, in 2009 the United States Institute of Medicine (IOM) revised gestational weight gain guidelines for the first time since 1990 (table 1) [1]. These guidelines recommend smaller gains for women with higher prepregnancy body mass indices (BMI), particularly for women entering pregnancy with a BMI of at least 30. Given these more stringent recommendations, the proportion of women gaining above the suggested levels is likely to increase, unless successful interventions can interrupt trends toward higher gains.

In this article we review the physiology and sociodemographic predictors of gestational weight gain. We summarize the evidence underlying the 2009 IOM gestational weight gain guidelines [1, 3], as well as more recent studies not incorporated into the guidelines. We discuss mechanisms by which maternal weight gain during pregnancy influences maternal and child health outcomes, incorporating data from human trials and animal studies. Finally, we discuss strategies to help mothers achieve healthy pregnancy weight gains.

### Components of Gestational Weight Gain

The weight gained in a normal pregnancy includes biologic processes designed to foster fetal growth [12]. Although women vary in the composition of the weight they gain during pregnancy, a general picture can be drawn. Approximately 25–30% of the weight gain resides in the fetus, 30–40% resides in maternal reproductive tissues, placenta, fluid and blood, and about 30% is made up of maternal fat stores [1]. In early pregnancy, normal-weight women (prepregnancy BMI <25) deposit fat in their hips, back and upper thighs, which is thought to be important as a caloric reserve for late pregnancy and lactation [12]. Insulin secretion and sensitivity rise, favoring increased lipogenesis and fat accumulation, in preparation for the increased energy needs of the growing fetus [13]. However, in obese women (prepregnancy BMI ≥30), peripheral insulin sensitivity declines, and little or no increased fat is accrued in early pregnancy, perhaps due to a reduced need for additional caloric reserves [14]. By late pregnancy, insulin resistance increases among all mothers (although it is more pronounced in obese women), a normal physiologic adaptation that shifts maternal energy metabolism from carbohydrate to lipid oxidation and thus spares glucose for the fetus [15].

The pattern of gestational weight gain is most commonly described as sigmoidal, with the majority of weight gained in the 2nd and early 3rd trimesters of pregnancy.
Who Is at the Greatest Risk of Under- or Over-Gain in Pregnancy?

A complex interplay among biological, psychological and social contextual factors influences the amount of weight a woman gains in pregnancy. Despite the consistent inverse relationship observed between total gestational weight gain and pregravid BMI category, overweight and obese women are nearly 2 times more likely to exceed 1990 IOM recommended gains compared to normal-weight women [16, 17]. Underweight women, on the other hand, are more likely to gain below 1990 IOM recommendations [16]. Additionally, multiparity, smoking during pregnancy, older age and being of low income, black or Hispanic race/ethnicity, unmarried status and limited education are associated with inadequate gain [1, 18, 19]. A number of the same sociodemographic characteristics have emerged as risk factors for gaining above the IOM recommendations. For example, among a sample of 622 predominately white women living in New York State, Olson et al. [20] found that those with household incomes <185% of the US federal poverty line were 2.5 times more likely to gain excessively in pregnancy than the women with higher incomes. Lederman et al. [21] found that over two thirds of low-income Black women in New York City gained more than recommended by the IOM, and 100% of the overweight and obese women experienced excessive gain.

However, some risk factors have been understudied. Although dietary intake, physical inactivity, television viewing and insufficient sleep are associated with weight gain in nonpregnant women and men [22–24], limited data exist on these factors during pregnancy. The contributions of specific genes and sequence variants to higher and lower gestational weight gains are also still unclear. A better understanding of the characteristics of women at the highest risk of inadequate and excessive weight gain is critical in order to aggressively target these mothers in interventions aimed at achieving healthy pregnancy weight gains, and thus lead to improvements in the maternal and child outcomes described in this review.

Gestational Weight Gain and Maternal Health Outcomes

Maternal Health Outcomes during Pregnancy

Glucose Metabolism

Gestational diabetes mellitus (GDM) is defined as glucose intolerance initially diagnosed during pregnancy. In about 7% of women, the acceleration of insulin resistance in late pregnancy is accompanied by insufficient pancreatic β-cell insulin secretion, and GDM ensues [15, 25]. Both GDM and more moderate states of abnormal glucose tolerance in pregnancy are associated with an increase in perinatal complications [26] and later development of type 2 diabetes in both mother and child [27, 28].

It is plausible that greater gestational weight gains would increase the risk of abnormal glucose tolerance in pregnancy. Weight gain and obesity promote incident diabetes in nonpregnant individuals, as excess adiposity results in insulin resistance and ultimately in pancreatic β-cell exhaustion [29, 30]. Maternal weight entering pregnancy is among the strongest identified predictors for the development of GDM [31, 32]. Furthermore, interpregnancy weight gain predicts the risk of GDM in a subsequent pregnancy [33].

Most early studies examining associations of gestational weight gain with risk of GDM were limited in that they assessed total gestational weight gain [3]. Diagnosis of GDM, which generally occurs when routine glycemic screening is administered at 24–28 weeks’ gestation, may influence subsequent weight gain. A few recent studies have examined associations of weight gain prior to glycemic screening with risk of abnormal glucose tolerance. In a study of women enrolled in the Pregnancy, Infancy and Nutrition cohort, Saldana et al. [34] found a 2-fold increased risk of impaired glucose tolerance (a moderate state of abnormal glucose tolerance in pregnancy) among overweight women who gained weight at a rate higher than recommended by the IOM prior to glycemic screening. However, this measure of gestational weight gain was not related to any increase in risk of GDM, and no associations were evident in normal-weight or obese mothers. We found similar results among women in the Project Viva cohort (fig. 1), although there was no interaction with prepregnancy BMI [35]. Another recent cohort study also revealed a direct relationship of weight gain prior to glycemic screening in excess of IOM guidelines with glucose intolerance, although these findings were limited to Hispanic women with a BMI of at least 35 [36].

Evidence that the association between higher gestational weight gain and hyperglycemia may be causal.
comes from a recent clinical trial. Among 50 obese Danish women enrolled in a dietary counseling intervention in early pregnancy, Wolff et al. [37] reported lower weight gain throughout pregnancy, a 20% reduction in serum insulin levels at 27 weeks’ gestation and an 8% reduction in fasting blood glucose at 36 weeks’ gestation compared with women who did not receive the intervention. The intervention women did not experience a reduction in risk of GDM, however, suggesting that changes in weight during pregnancy may have a greater impact on more moderate levels of glucose intolerance.

Overall, the available data suggest a direct relationship between gestational weight gain during the first 2 trimesters of pregnancy and moderate levels of abnormal glucose tolerance at glycemic screening. However, no convincing evidence indicates that lower weight gains are associated with lower risk of developing GDM. Whether the absence of a relationship between weight gain and GDM is related to other, unmeasured factors, such as β-cell exhaustion or pregnancy-specific alterations in insulin resistance [38, 39], that predispose women to GDM independent of weight-related changes, is still unclear. It is possible that the timing or pattern of metabolic changes responsible for frank GDM is different from those predicting moderate states of glucose intolerance in pregnancy [40, 41].

**Hypertensive Disorders**

Complicating 6–8% of pregnancies, hypertensive disorders are common medical problems encountered during pregnancy that remain a leading source of maternal and fetal morbidity [42]. Hypertensive disorders during pregnancy include gestational hypertension (new-onset, nonproteinuric hypertension first observed after 20 weeks’ gestation) and preeclampsia (new-onset hypertension with proteinuria and edema after 20 weeks of gestation) [42]. Most established risk factors for gestational hypertension or preeclampsia, including maternal age, race/ethnicity, parity, and previous hypertension or preeclampsia, are not modifiable [43]. During the past 2 de-

**Fig. 1.** Odds of developing impaired glucose tolerance (IGT) in pregnancy or GDM by quartile of gestational weight gained before glycemic screening, Project Viva, 1999–2002. Estimates adjusted for gestational age at glycemic screening, age, race/ethnicity, prepregnancy BMI category and history of gestational diabetes (from Herring et al. [35]).
cades, a number of studies have examined whether maternal weight gain in pregnancy might influence the risk of pregnancy-induced hypertension, given the strong association between weight gain and high blood pressure in nonpregnant adults [44].

The majority of epidemiologic studies have reported a direct relationship between greater weight gain in pregnancy and the onset of gestational hypertension and/or preeclampsia [45–54]. Additionally, weight gain within or below IOM-recommended ranges may be protective against the onset of hypertensive disorders during pregnancy. A large prospective cohort study from Sweden found that gains of <8 kg were associated with reduced odds of developing preeclampsia for women in all pregravid BMI categories, compared to a reference gain of 8–16 kg [47]. Similarly, Kiel et al. [48] found a decreased risk of preeclampsia among obese women gaining <7 kg. Since edema is one of the diagnostic criteria for preeclampsia, however, it is still unclear whether the observed association is truly related to excess gain in body fat or whether it is just a by-product of excess fluid retention.

Delivery Complications
Two systematic reviews that included data from >500,000 pregnancies in 21 studies have found a consistent dose-response relationship between pregnancy weight gain and cesarean delivery [3, 4]. Weight gains within or below IOM-recommended ranges may be protective against cesarean delivery [48]. In addition, recent data suggest that weight gains in excess of IOM recommendations lead to increased odds of other delivery complications, including failed induction and cephalopelvic disproportion, compared to gains within the recommended range, in women of all prepregnancy BMI categories [46, 47, 49].

Postpartum and Long-Term Maternal Health
Postpartum Weight Retention, Obesity Risk and Cardiometabolic Sequelae
In observational epidemiologic studies, gestational weight gain is the strongest predictor of maternal weight change from prepregnancy through 18 months postpartum, accounting for 20–35% of the variability in weight change [11, 55–59]. In addition to the total amount of weight gain, the pattern of gain may influence weight retention. Kleinman et al. [60] found that weight gains earlier in pregnancy were more predictive of weight retention at 6 months postpartum compared with the same amount of gain accrued later in pregnancy.

Postpartum weight retention appears particularly likely among Black women and those who enter pregnancy overweight or obese [11, 59, 61]. Among all women, postpartum weight retention is associated with short- and long-term risk of overweight. Approximately 6–14% of women develop overweight within 1 year after delivery [62]. Additionally, Linne et al. [63] reported that nearly 44% of women who were normal weight entering pregnancy but retained significant amounts of weight (approximately 4.8 kg) at 12 months postpartum became overweight 15 years later.

Compared with weight gain during other periods, excess weight gain associated with childbearing appears to be particularly harmful, as it is deposited in central rather than peripheral sites [64], it is associated with reductions in HDL cholesterol [65] and with an increased risk of metabolic syndrome by midlife [66]. One mechanism for the persistent cardiometabolic derangements of pregnancy may be increases in intra-abdominal (visceral) adiposity. A 5-year longitudinal study found a 40% increase in visceral fat from preconception to postpartum versus a 14% increase among nonparous women followed for the same amount of time [67]. Intra-abdominal adipose tissue is associated with obesity-related insulin resistance, production of adipocytokines that regulate insulin sensitivity and dyslipidemia [30, 68]. Whether this metabolic risk is minimized by achieving guideline-recommended gestational weight gains and postpartum weight loss, is still unclear; interventions are needed to test whether mothers’ short- and long-term metabolic status improves.

In summary, gestational weight gain is associated with several short- and longer-term maternal health outcomes. For all of these maternal outcomes, less gain is better. In contrast, as we review below, greater gestational weight gain is associated with improvements in some infant health outcomes, but increased risk for others.

Gestational Weight Gain and Child Health Outcomes
Gestational Weight Gain and Infant Health
Fetal Growth
The direct association between maternal gestational weight gain and infant weight at birth has been recognized for decades and was one of the primary drivers for the IOM to generate recommendations for higher weight gains in 1990 [69]. In a recent evidence review of publications from 1990 through 2007, Viswanathan et al. [3] found moderate to strong evidence suggesting an association of weight gain below IOM recommendations with
low birth weight and small for gestational age (SGA) births, and strong evidence for the relationship between weight gain above IOM recommendations and high birth weight, macrosomia and large for gestational age (LGA) births [70].

Most studies have examined weight, or weight for gestational age, as infant outcomes. However, weight tends to track with linear growth. Some studies have found similar associations between maternal weight gain and measures of infant weight adjusted for length [71]. In one study, weight gain in midpregnancy predicted infant length as well as weight at birth [72]. In addition, weight comprises both fat and lean mass. If higher weight gain promotes greater increase in lean body mass, that may be desirable, but if higher weight gain predicts only gain in fat mass, then that may be a less favorable result. Data regarding direct measures of adiposity are extremely limited [73].

Associations of gestational weight gain with higher infant weight at birth are generally independent of maternal prepregnancy BMI, although some evidence suggests that the associations may be particularly strong among women who are normal weight or underweight entering pregnancy. Among women who are obese, gestational weight gain is a less strong predictor of fetal growth [74]. Although some groups of mothers are at greater risk of having a SGA infant, such as mothers who are black, teenagers, of short stature or smoke during pregnancy, higher gains do not appear to equalize risks for these mothers [75].

Most evidence linking gestational weight gain with fetal growth comes from observational studies. As observational research cannot determine causality, it is possible that other factors underlie the relationship between greater maternal and infant weight gains. Most obviously, since the weight gained by the mother includes that gained by the infant, higher birth weight results in greater total gestational weight gain. However, associations persist in studies that have used net gestational weight gain (i.e. birth weight subtracted from total weight gain) as an exposure [76]. In addition, it is possible that shared genes underlie greater maternal and fetal weight gain. However, in a study of 90 pairs of siblings, greater gestational weight gain was associated with higher birth weight on a within-mother analysis [77]. Furthermore, mean birth weight among term infants increased during the second half of the 20th century in the USA, Canada and other countries, a trend not likely to be attributable to shifts in genes but that appeared to be caused by parallel increases in gestational weight gain and other maternal characteristics [78–80].

Thus, it is likely that associations of higher gestational weight gains with greater fetal growth are causal. Moderate gains are recommended to minimize the risk of the child being either small for gestational age or large for gestational age.

Preterm Birth and Infant Mortality

In their recent evidence review, Viswanathan et al. [3] found strong evidence suggesting that both low and high weight gains result in an increased risk of premature birth. Eight of 9 studies reported at least 1 significant association between low gestational weight gain and preterm birth; 4 of 5 studies focused on high gestational weight gain (as defined in each study) reported at least 1 significant association between gestational weight gain and preterm birth [3]. Overall, the majority of studies found a consistent effect of low gestational weight gain on preterm birth and a less consistent effect of high gestational weight gain on preterm birth. The association for low gestational weight gain holds whether total weight gain or rate of weight gain is used as the relevant exposure of interest.

Viswanathan et al. [3] summarized 3 studies that looked at the association between maternal weight gain and infant mortality. None of them was rated as good quality. Overall, these studies suggest a protective effect of gestational weight gain on perinatal mortality but not on stillbirth. In more recent publication data from the US National Maternal and Infant Health Survey, maternal prepregnancy obesity as well as very low and very high rates of weight gain were each associated with infant death. For example, compared with normal-weight women who gained 0.30–0.44 kg/week, obese women who gained <0.15 kg/week had an adjusted odds ratio of infant death of 1.75 (95% CI = 1.28–2.39), and obese women who gained ≥0.45 kg/week had an odds ratio of 2.87 (95% CI = 1.98–4.16).

Thus, gestational weight gain appears to have a U-shaped relationship with both preterm birth and infant death. Similar to the fetal growth outcomes, moderate gains are optimal.

Gestational Weight Gain and Longer-Term Child Health

Childhood Weight Status and Risk of Obesity

A number of observational epidemiologic studies have found that higher maternal gestational weight gain is associated with higher weight in childhood [8–10], adoles-
Outcomes of Maternal Weight Gain in Pregnancy

It is unclear whether associations of gestational weight gain with child weight vary by maternal prepregnancy weight. Some studies found stronger associations among overweight and obese mothers [8], some observed somewhat stronger relationships among underweight mothers [9, 88], one found an effect only among mothers currently normal weight but not overweight [89], and others reported no evidence for effect modification by maternal BMI [10, 82].

How might excess weight gain during pregnancy have a persistent influence on offspring weight and related cardiometabolic risk? Shared genes and behaviors certainly explain part of the risk. In addition, maternal overnutrition appears to have a direct influence on several aspects of offspring physiology, including appetite, metabolism and activity levels (fig. 2) [90]. Offspring of overfed rat dams have reduced energy expenditure [91, 92] and a greater taste for junk food [93], as do human children of...
obese mothers [94, 95]. Lambs of overfed ewes have changes in the central appetite regulatory system, altered gene expression in adipose tissue and increased expression of leptin [96–98]. Maternal overnutrition may result in increased fetal adipose tissue deposition [99]. Since adipocyte number appears to be set in the first years of life [100], excess fat formed in early life may result in lifelong excess adiposity. Maternal prenatal overnutrition may also influence the fetal epigenome, thereby affecting the expression of genes that direct the accumulation of body fat or related metabolism [101–103].

Other Child Outcomes
If higher gestational weight gains result in child obesity, it is plausible that they would also be associated with the adverse sequelae of obesity. We have found that children whose mothers gained excess weight during pregnancy had higher blood pressure [8] and poorer cognitive test scores [104] at age 3 years. To date, few studies have examined child outcomes other than weight or have information on offspring in later life.

Balancing the Risks and Benefits of Too Much or Too Little Gestational Weight Gain

Overall, too much or too little weight gain in pregnancy appears to have a profound impact on the health of mothers and their children. While higher amounts of weight gain generally seem to be harmful for both maternal short- and longer-term health outcomes after childbirth, the same is not true for infants. Determining optimal gestational weight gain is complicated by the fact that associations with outcomes may differ not only in strength and direction but also in seriousness. In 2009, we used data from the Project Viva cohort to determine the most favorable amount of weight gain considering 5 short- and longer-term outcomes: short for gestational age, large for gestational age, preterm delivery, substantial maternal postpartum weight retention and child obesity [74]. We found that lowest-risk gestational weight gains were within 1990 recommended ranges for women who were normal weight entering pregnancy but were lower than the recommendations for overweight and obese women [74]. In all models, the lowest predicted prevalence of adverse outcomes for obese women occurred with weight loss. Our data suggest that more research is needed to determine optimal gain in mothers, taking into account the risks and benefits of too little and too much gain, particularly for mothers who begin pregnancy overweight and obese. While the 2009 IOM guidelines recommend somewhat smaller weight gains for obese mothers compared with 1990 guidelines, it is still unclear whether even greater weight restriction among obese mothers, or no weight gain at all, will achieve the best maternal and child outcomes.

Strategies to Achieve Healthy Pregnancy Weight Gains

Despite continued debate over the optimal range of gestational weight gain for overweight and obese mothers, too few mothers of all pregravid BMI categories gain within the recommended ranges [6]. Thus, a big question remains: how can we help more mothers achieve recommended gestational weight gains? Because pregnant women have frequent interactions with the health care system, obstetric clinicians are uniquely positioned to address weight gain with their pregnant patients. In fact, data suggest that medically advised and actual pregnancy weight gains are strongly correlated [105, 106]. Several interventions to promote recommended gestational weight gain have included clinician advice as one component of the intervention [107–110]. However, these interventions have generally not been successful in improving the proportion of women gaining within recommended limits [107] or were successful only in a subset of women [108].

Many obstetric clinicians are not providing their patients with any guidance regarding the appropriate amount of gestational weight gain. In a national survey, only 58% of obstetrician-gynecologists reported counseling their pregnant patients about weight gain during pregnancy ‘most of the time’, and even fewer (35.7%) modified their recommendations based on their patients’ prepregnancy BMI [111]. Further, the obstetric providers who do advise their patients may not be recommending gestational weight gain ranges concordant with IOM guidelines. In a 2007–2008 survey of 58 obstetric providers in Massachusetts, we found that provider gestational weight gain recommendations were generally discordant with 1990 IOM guidelines [112]. Our data suggest a need for better dissemination of recommended gains to obstetric providers, to arm them with the correct information for advising their pregnant patients.

In addition to recommending the right amounts of gain, clinicians may also need to counsel women regarding how to achieve these recommended gains. The 2009 IOM report does not provide any detailed guidance con-
cerning specific components of diet or other behaviors to achieve healthy gains. Many clinicians indicate that they do not have sufficient time or knowledge to counsel women regarding weight-related behaviors [112]. Further, obstetricians may not be comfortable discussing weight-related behaviors with their patients or may feel that their advice does not influence their patients in making changes [112]. Specially trained ancillary staff, including dieticians, health coaches and public health nurses, may be helpful adjuncts in delivering nutrition and healthy weight gain messages to pregnant mothers [37, 113–115]. For example, in 2008, Wolff et al. [37] randomized 50 obese pregnant women in Denmark to either ten 1-hour dietary consultations with a trained dietician or to usual care. The women in the intervention group successfully limited their energy intake and restricted their total gestational weight gain to an average of 6.6 kg compared to 13.3 kg in the control group. However, the small sample size and different healthcare settings have limited the widespread adoption of these intervention strategies to date.

Few interventions have focused on minority mothers, who are at high risk of both undernutrition and overweight. Additionally, no studies have followed both mothers and their children into the postpartum period, to evaluate the effect of interventions on longer-term maternal and child health outcomes. More research is needed to help all women achieve healthy pregnancy weight and behaviors, assessing both short- and longer-term health outcomes.

In summary, efforts to help mothers gain within IOM-recommended ranges in pregnancy are critical to keeping mothers and their children healthy. These efforts are also likely to be economical, as a single intervention could benefit the mother, her child, future pregnancies and subsequent generations. Ongoing and planned research will provide greater guidance in the coming years regarding the best way to support women in achieving optimal gains.

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