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Nicholas Perseus Deputy Date

Examining Gestational Weight Gain Using Two Surveillance Systems:

Prevalence, Determinants and Quality of Maternal Weight Data

By

Nicholas Perseus Deputy, M.P.H

Doctor of Philosophy

Nutrition and Health Sciences

_____	_____
Usha Ramakrishnan, Ph.D. Advisor	Andrea J. Sharma, Ph.D., M.P.H. Advisor
_____	_____
Timothy L. Lash, Sc.D., M.P.H. Committee Member	Laura A. Schieve, Ph.D. Committee Member
_____	
Aryeh D. Stein, M.P.H., Ph.D. Committee Member	

Accepted:

_____

Lisa A. Tedesco, Ph.D.
Dean of the James T. Laney School of Graduate Studies

_____

Date

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Nicholas Perseus Deputy

B.S. Boston University, 2008

M.P.H. Boston University School of Public Health, 2009

Advisor: Usha Ramakrishnan, Ph.D.

Advisor: Andrea J. Sharma, Ph.D., M.P.H.

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ABSTRACT

Examining Gestational Weight Gain Using Two Surveillance Systems: Prevalence, Determinants and Quality of Maternal Weight Data

By Nicholas Perseus Deputy

Gestational weight gain is associated with important health consequences for mothers and infants. In 2009, the Institute of Medicine (IOM) revised gestational weight gain recommendations, which are specific to a mother's pre-pregnancy body mass index (BMI). Despite health outcomes associated with gestational weight gain, surveillance data are lacking in the United States and little is known about factors influencing weight gain outside recommendations.

To examine the prevalence of gestational weight gain below, within or above the 2009 recommendations (referred to as inadequate, appropriate and excessive, respectively), we combined 2013 birth certificate data from 43 jurisdictions with 2012 data from five states participating in the Pregnancy Risk Assessment Monitoring System (PRAMS). Among women delivering full-term, singleton infants, 48% had excessive gain, whereas 20% had inadequate and 32% had appropriate. Weight gain varied by jurisdiction: 21 had a prevalence of inadequate gain ≥20%, whereas 17 had a prevalence of excessive gain ≥50%.

Next, we examined maternal characteristics associated with gestational weight gain using data from 28 PRAMS states. Notably, pre-pregnancy BMI was strongly associated with excessive gain: overweight and obese women had nearly three-times the odds of excessive gain compared with normal weight. Among four PRAMS states, we examined healthcare provider advice about gestational weight gain and found 26% of women reported receiving advice consistent with 2009 IOM recommendations. Compared with women who reported receiving consistent advice, those receiving advice below or above recommendations were more likely to have inadequate or excessive gain, respectively.

Finally, we compared pre-pregnancy BMI and gestational weight gain variables from the birth certificate or PRAMS to variables from medical records to evaluate data quality. Overall, 87% and 84% of women were categorized into the same pre-pregnancy BMI category by the birth certificate or PRAMS compared with medical record; 70% were categorized into the same gestational weight gain category by the birth certificate compared with medical record.

Our results signal a need for interventions that promote appropriate gestational weight gain and, importantly, strategies may need to focus beyond mothers to include healthcare providers. Ongoing, national surveillance of gestational weight gain will be needed to evaluate future intervention efforts.

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Chapter 1 - Introduction

During pregnancy, adequate energy and nutrient consumption is essential to nourish the developing fetus and to support the physiological demands of pregnancy, parturition and lactation (1, 2). For most women, nutrient requirements are higher than at any other stage in the life cycle (1). The weight a woman gains during pregnancy, known as gestational weight gain, broadly reflects the additional calories consumed during this period. As the nutrient status of a mother is difficult to directly ascertain, gestational weight gain is an important clinical and public health proxy for maternal nutritional status and growth of an infant.

Gestational weight gain has important short- and long-term health implications for mothers and infants (2, 3). There is a well-established, linear relationship between gestational weight gain and fetal growth (operationalized as total infant birth weight or infant birth weight-for-gestational age), such that low and high weight gains are associated with infants born small-for-gestational age (SGA; birthweight $<10^{th}$ percentile for gestational age) and large-for-gestational age (LGA; birthweight $>90^{th}$ percentile for gestational age), respectively (2-4). This association is stronger among mothers entering pregnancy underweight (pre-pregnancy body mass index [BMI; kilograms/meters^2] <18.5), and weaker among mothers entering pregnancy overweight or obese ($25.0 \leq$ BMI <30.0 and BMI ≥ 30.0, respectively) (2-4).

Beyond the perinatal period, higher gestational weight gain has been associated with the development of obesity in childhood, although this relationship may be modified by pre-

pregnancy BMI (2, 5); higher gains may also be associated with obesity in adolescence (6) and adulthood (7). For mothers, high weight gains are associated with increased postpartum weight retention, which may contribute to the development of obesity later in life (8).

In the United States (US), the Institute of Medicine (IOM) provides gestational weight gain recommendations that balance the risks associated with too little or too much weight gain in order to promote optimal health. In 1990, the IOM developed weight gain ranges that balanced the risks of delivering SGA or LGA infants (4). The recommendations acknowledged that women entering pregnancy with a higher BMI generally gain less than those with a lower BMI, and that the association between gestational weight gain and infant birth weight was modified by pre-pregnancy BMI category; thus, recommendations were specific to a woman's pre-pregnancy BMI. Of note, at the time of these recommendations, BMI cut-off values were based on the Metropolitan Life Insurance Table cut-off values. Furthermore, data on obese women were limited and precluded the IOM Committee from developing a recommended upper limit of weight gain. The 1990 IOM recommendations (along with definitions for BMI cut-off values) are presented in Table 1.

In response to changing characteristics of women entering pregnancy – including an increase in the prevalence of pre-pregnancy obesity – the IOM revised gestational weight gain recommendations in 2009 (2). Unlike previous recommendations, current recommendations were developed to balance the risks of adverse health outcomes for

infants and mothers alike. These recommendations were updated to reflect pre-pregnancy BMI category cut-off values established by the World Health Organization, which had also been adopted by the National Heart, Lung, and Blood Institute and many public health practitioners and clinicians in the US (9). Notably, the adoption of these cut-off values classify more women overweight and fewer women as underweight or obese. Finally, the committee was able to develop a defined, narrow range of weight gain for obese women. The current, 2009 IOM recommendations are presented in Table 2.

Despite the important short- and long-term health outcomes for both mothers and infants, surveillance data on gestational weight gain are lacking in the United States. Indeed, since the release of the 1990 recommendations, the IOM has called for routine monitoring of gestational weight gain using representative samples of women (2). Furthermore, while the IOM considered a wealth of available evidence that examined adverse health outcomes associated with gestational weight gain, less research has focused on factors that may influence weight gain outside of recommended ranges. Characteristics associated with gestational weight gain may be useful in identifying women that need additional clinical attention to achieve appropriate weight gain or may be used to identify behaviors potentially amenable to clinical or public health intervention. Finally, in evaluating available evidence, the IOM recognized that future research should be conducted in large, population-based samples that more closely reflect the diversity of women giving birth in the US.

The overall objective of this dissertation was to further knowledge around prevalence and determinants of gestational weight gain, with the goal of providing relevant information to clinicians or program planners that may be used to promote appropriate gestational weight gain. To achieve our objectives, we undertook several analyses using two representative surveillance systems: National Vital Statistics System (NVSS) birth data (i.e. data from the birth certificate), a census of all live births in the US (10), and the Pregnancy Risk Assessment Monitoring Systems (PRAMS), an ongoing multistate surveillance system (11). In our first analysis, we examined the prevalence of gestational weight gain below, within and above the 2009 IOM recommendations; we examined prevalences stratified by pre-pregnancy BMI category and also assessed state-specific prevalences. To produce the most comprehensive prevalence estimates possible, we combined 2013 birth certificate data from 43 jurisdictions that had pre-pregnancy BMI and gestational weight gain data available with 2012 data from an additional five states participating in PRAMS. In our second analysis, we utilized PRAMS data to examine the influence of maternal demographic, behavioral, psychosocial and medical characteristics, which had been previously identified by the IOM, on weight gain outside recommendations. As the IOM recommendations have been adopted by clinical organizations – specifically, the American College of Obstetrician and Gynecologist (12) – our third analysis estimated the proportion of women receiving advice from a healthcare provider that was consistent with the IOM recommendations; we further examined how inconsistent healthcare provider advice influenced women's actual weight gain during pregnancy. In recognizing the utility of birth certificate and PRAMS data in studying pre-pregnancy BMI and gestational weight gain, our fourth and final analysis

examined the quality of maternal height and weight variables from these data sources by comparing them to information abstracted from medical records.

The subsequent chapters in this dissertation are organized as follows: Chapter 2 summarizes relevant background literature related to the analyses mentioned above. In Chapter 3, we provide detailed information about the NVSS birth data and the PRAMS. Chapters 4-7 report the main findings of this dissertation, and are presented as standalone manuscripts suitable for publication in scientific journals; these chapters correspond with the four analyses mentioned above. Finally, Chapter 8 serves to conclude this dissertation by summarizing results, highlight strengths and limitations and commenting on public health implications.

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Table 1-1: 1990 Institute of Medicine Gestational Weight Gain Recommendations for Full-Term, Singleton Pregnancies

Pre-pregnancy BMI Category	BMI Definition (kg/m^2)	1990 IOM GWG Recommendations (lbs)
Underweight	BMI < 19.8	28-40
Normal weight	19.8 ≤ BMI < 26.0	25-35
Overweight	26.0 ≤ BMI < 29	15-25
Obese	BMI ≥ 29.0	> 15

Table 1-2: 2009 Institute of Medicine Gestational Weight Gain Recommendations for Full-Term, Singleton Pregnancies

Pre-pregnancy BMI Category	BMI Definition (kg/m^2)	2009 IOM GWG Recommendations (lbs)
Underweight	BMI < 18.5	28-40
Normal weight	18.5 ≤ BMI < 25.0	25-35
Overweight	25.0 ≤ BMI < 30.0	15-25
Obese	BMI ≥ 30.0	11-20

Chapter 2 - Literature Review

In this dissertation, our goal was to further knowledge around prevalence and determinants of gestational weight gain. We undertook several analyses using large, representative datasets to achieve this goal. Specifically, we used representative data to: 1) estimate the proportion of women with gestational weight gain below, within or above the 2009 Institute of Medicine (IOM) gestational weight gain recommendations; 2) examine the influence of maternal demographic, behavioral, psychosocial and medical characteristics on gestational weight gain; and healthcare provider advice on gestational weight gain outside recommendations; 3) examine the influence of healthcare provider advice about gestational weight gain on women's actual weight gain during pregnancy and 4) examine the quality of maternal height and weight data from the birth certificate or Pregnancy Risk Assessment Monitoring System (PRAMS) questionnaire compared with medical record information. Each aim is addressed in subsequent chapters and is formatted as a standalone manuscript suitable for publication in scientific journals.

In this chapter, we provide relevant background information for each aim described above. We start with a brief overview of gestational weight gain, and follow with relevant information about prevalence estimates. The next section focuses on determinants of gestational weight gain, which for the purposes of this dissertation broadly includes maternal characteristics and healthcare provider advice. Finally, we conclude with a summary of relevant information on quality of maternal height and weight data.

Overview of Gestational Weight Gain

During pregnancy, a woman's body is in an anabolic state and requires an increase in calories, macronutrients, and micronutrients to provide energy and substrate for the growth of new maternal and fetal tissue (1, 2). Gestational weight gain results from the accretion of fluid, protein and fat to meet these demands of pregnancy. For most women, approximately 35% of weight gained is attributed to the products of conception, i.e. the placenta, fetus and amniotic fluid; the remaining weight is attributed to maternal blood volume expansion, extracellular fluid expansion, and accretion of mammary, uterine and adipose tissue. The pattern of weight gain during pregnancy is thought to follow a sigmoidal pattern, with limited gain in the first trimester of pregnancy followed by a relatively linear rate of gain in the second and third trimester (1).

As previously mentioned, for most women, gestational weight gain is inversely associated with pre-pregnancy BMI, such that women with higher BMI tend to gain less weight during pregnancy (1, 3). This may be partly explained by the fact that pre-pregnancy BMI broadly reflects maternal energy stores in the preconception period and these available energy stores may be used to meet the metabolic demands of pregnancy (1, 3). Of note, women entering pregnancy with obesity have been found to have an increased risk for adverse pregnancy outcomes, including the development of diabetic or hypertensive disorders, preterm delivery, and pregnancy complications (e.g. cesarean delivery, excessive blood loss) (4, 5). Infants of obese mothers also face health risks that include congenital anomalies, fetal macrosomia, the development of obesity in childhood (4), and potentially lower cognition or developmental delays later in life (6-9). The

proportion of women entering pregnancy with obesity has increased in recent years, from 17.6% in 2003 to 20.5% in 2009 (10).

Overview of Gestational Weight Gain Recommendations

As previously mentioned, the Institute of Medicine (IOM) provides gestational weight gain recommendations that balance risks associated with too little or too much weight gain during pregnancy. The earliest IOM recommendations were released in 1970 as a response to concerns about high infant mortality rates in the United States (US) compared to other developed countries; these recommendations consisted of a single weight gain range of 20-25 pounds for all women. In 1990, the first BMI-specific recommendations were released and focused on short-term health outcomes – specifically, optimizing fetal growth. Importantly, the 1990 recommendations used BMI cut-off values from the Metropolitan Life Insurance Company weight-for-height standards and, due to limited available evidence, these recommendations did not include an advised weight gain range for obese women. In 2009, the IOM revised recommendations by considering short- and long-term health outcomes for both mothers and infants, adopting World Health Organization body mass index (BMI) cut-off values, and developing a defined recommended weight gain range for obese women (1).

The 2009 recommendations were based on the best available evidence at the time and included commissioned analyses and a comprehensive review of outcomes associated with gestational weight gain (1, 11). The IOM noted that research studies examining gestational weight gain often shared common limitations, including the use of self-

reported weight values to calculate pre-pregnancy weight and/or delivery weight and a lack of control for relevant confounding factors. To address these limitations, the IOM made several recommendations for future research and public health activities using data sources or methods that could overcome these shortcomings.

Aside from limitations recognized by the IOM, aspects of the revised recommendations were called into question after being published. Some researchers and clinicians (not involved with IOM) raised concern about the recommended weight gain range for obese women – specifically, that the recommendation is too high (12). It has been argued that among obese women, fetal growth restriction should not be weighed as heavily as an adverse outcome compared with the development of hypertensive or diabetic conditions because ultrasound technology allows for early and accurate detection of restricted growth. Furthermore, in developing the recommendations, the IOM was hesitant to draft recommended weight gain ranges that might induce ketonemia during pregnancy (which may occur as a result of fasting to achieve low or no weight gain), as this had been found to adversely influence cognitive developments in offspring; however, it has been argued that studies examining ketonemia and cognition may have been limited by not controlling for important confounders, such as maternal cognition (12).

To address these concerns, the IOM asserted that the recommendations were based on the best available evidence at the time and were developed using a guiding principle of “first, do no harm”, which precluded the development of lower weight gain ranges for obese women due to the potential for long-term, adverse cognitive outcomes (1, 13). The IOM

reiterated a need for additional research on many aspects of gestational weight gain, including outcomes among obese women. Moreover, the IOM emphasized good clinical judgement as a cornerstone for providing optimal care for obese women (1, 13). Indeed, the American College of Obstetricians and Gynecologists agreed with this position and further suggested that clinicians may not need to encourage weight gain for obese women with inadequate weight gains so long as the fetus appears to be growing healthily (14). Taken together, the 2009 IOM gestational weight gain recommendations represent an effort to synthesize available evidence in order to promote optimal maternal and infant health. In spite of advances to the scientific literature since 1990, the current recommendations call for additional research that can be used to strengthen future recommendations. In the 2009 report, the IOM outlined several research priorities, including: surveillance of gestational weight gain, potential determinants of gestational weight gain, and quality of maternal weight variables commonly used to study gestational weight gain.

Prevalence of Gestational Weight Gain

Overview of Prevalence Estimates

Despite the important health outcomes associated with gestational weight gain, prevalence and trend estimates relative to the IOM recommendations have been hampered due to a lack of ongoing, representative data sources that capture both pre-pregnancy BMI and gestational weight gain (1). Two data sources have primarily been used to monitor gestational weight gain: the National Center for Health Statistics' (NCHS) National Vital Statistics System (NVSS) birth data (15), which are captured via

the US Standard Certificate of Live Birth (referred to as birth certificate data), and the Pregnancy Risk Assessment Monitoring System (PRAMS) (16). Below we provide a brief description of these data sources as changes in format (especially for birth certificate data) have influenced surveillance activities. As these data sources were also used in this dissertation, we provide a more in-depth description in Chapter 3.

The remainder of this section provides relevant background information about prevalence estimates from the birth certificate and PRAMS. We focus our review on data from 1990 onward, which is when the previous IOM recommendations were released (differences between the 1990 and 2009 IOM recommendations are noted in Chapter 1). Importantly, no study mentioned below used data from births occurring after the 2009 IOM recommendations were released; however, some studies categorized gestational weight gain relative to the 2009 IOM recommendations. Hereafter, we refer to gestational weight gain below, within and above the recommendations as inadequate, appropriate and excessive gestational weight gain, respectively.

Birth Certificate Data

From 1989 through 2016, two versions of the birth certificate were in use: the 1989 version and the 2003 revision. Both versions captured information on gestational weight gain, however, only the 2003 revision captured information on pre-pregnancy BMI category and gestational weight gain, which allows for gestational weight gain to be examined in relation to the IOM recommendations (15). As the 2003 revision of the birth certificate was adopted on a state-by-state basis, data fields specific to the 2003 revision

were not immediately reported by the NCHS or released for public use. Specifically, pre-pregnancy BMI data (and other fields specific to the 2003 revision) were not released until 2013; at this time, birth data from 2009 – 2012 were re-released with these new data fields.

Nearly national prevalence of gestational weight gain has been monitored by NCHS through published National Vital Statistics Reports (California did not report gestational weight gain prior to 2006) (17). As pre-pregnancy BMI was not collected on most birth certificates at this time, the reports estimate the proportion of women gaining below the minimum recommendations, regardless of BMI (i.e. 16 pounds for obese women) and the proportion of women gaining above the maximum recommendation, regardless of pre-pregnancy BMI (i.e. 40 pounds for underweight women). From 1990 through 2005, these reports indicated the proportion of women delivering full-term, singleton infants with weight gain below 16 pounds increased from 8.3% to 12.2% and the proportion with weight gain above 40 pounds increased from 16.0% to 20.6% (17). Subsequent reports indicated that from 2009 to 2013 the proportions of women with gestational weight gain below 11 and above 40 pounds (representing the minimum proportion of women with gestational weight gain outside the 2009 IOM recommendations) continued to increase: the proportion of women with full-term, singleton infants and had weight gain below 11 pounds increased from 7.5% to 8.1% and the proportion above 40 increased from 20.8% to 21.6% (18).

Recent studies have reported the prevalence of inadequate, appropriate and excessive gestational weight gain relative to the 2009 IOM recommendations using revised birth certificate data from select states. Two studies from South Carolina examined singleton pregnancies between 2004 and 2008 and found most women had excessive gain (46%-49%, depending on study), whereas appropriate gain was least common (23%-26%, depending on study) (19, 20). Importantly, preterm delivery was handled differently in each study. Another study examining Florida birth certificate data from 2004-2007 found similar results: among women delivering full-term, singleton infants, 51% had excessive, 29% had appropriate and 20% had inadequate gestational weight gain (21).

PRAMS Data

PRAMS is an ongoing, state-specific surveillance system jointly administered by the Centers for Disease Control and Prevention (CDC) and state governments or jurisdictions (16). PRAMS participants are sampled from infant birth certificates in each participating state. PRAMS combines birth certificate information (e.g. gestational weight gain) with questionnaire information (e.g. height and pre-pregnancy weight, from which pre-pregnancy BMI can be calculated) self-reported by mothers approximately 4 months postpartum. The combination of birth certificate and PRAMS questionnaire data allows for examination of gestational weight gain relative to IOM recommendations, regardless of whether the 1989 or 2003 birth certificate version is in use.

In preparing the 2009 IOM recommendations, PRAMS data from women delivering full-term, singleton infants in eight states were analyzed to describe trends in gestational

weight gain relative to the 1990 IOM recommendations during the time period between 1993-1994 and 2002-2003 (1). The IOM committee noted that trends over this 10-year period varied by pre-pregnancy BMI category. Among underweight women, appropriate weight gain increased from 45% to 50%, whereas among normal weight women, appropriate gain remained stable at approximately 41%. Among overweight and obese women, appropriate gain decreased from 31% to 27% and 32% to 30%, respectively. Of note, in 2002-2003, overweight women had the highest prevalence of excessive gain at 63%.

To extend the findings presented in the IOM report, Johnson and colleagues examined trends in gestational weight gain from 2000-2001 to 2008-2009 among women delivering full-term, singleton infants giving birth in 14 PRAMS states (22). In their report, the authors found the average gestational weight gain was 31 pounds over the 10-year period and did not significantly change over time. During the study period, the proportion of women with inadequate gestational weight gain (relative to the 1990 recommendations) remained stable, whereas the proportion with appropriate weight gain decreased by 3.3 percentage points ($p<0.01$) and the proportion with excessive gain increased by 3.0 percentage points ($p<0.01$). In 2008-2009, the proportion of women with inadequate, appropriate, and excessive gain was 20%, 34% and 46%, respectively.

Potential Determinants of Gestational Weight Gain

Overview of Potential Determinants

Potential determinants of gestational weight gain have been extensively reviewed by the IOM in their 2009 report to revise the weight gain recommendations. The conceptual framework used the IOM broadly reflects a socio-ecologic model and considers five levels of potential determinants: 1) the social-institutional level, which considers the influence of media, culture and health services on gestational weight gain; 2) the environmental level, which considers determinants specific to the natural environment, including altitude and other (non-nutritional) environmental exposures; 3) the community level, which refers to characteristics of the community in which a woman lives and includes access to healthy foods and opportunities for physical activity; 4) the interpersonal-level, which includes marital status and social support; and 5) the maternal level, which includes characteristics of the mother, such as age, dietary habits, and medical conditions (1, 3). In subsequent sections and chapters, we discuss interpersonal and maternal conditions together and collectively refer to these potential determinants as 'maternal' characteristics.

The next section provides background information on maternal characteristics associated with gestational weight gain, and considers four domains: demographic (e.g. age, race-ethnicity), behavioral (e.g. physical activity, smoking during pregnancy), psychosocial (e.g. depression, stress) and medical (e.g. hypertensive or diabetic conditions). The section after provides relevant information about healthcare provider advice about gestational weight gain. To our knowledge, no studies have examined a broad range of

determinants (either maternal characteristics or healthcare provider advice) and gestational weight gain relative to the 2009 IOM recommendations using multistate, representative data.

Maternal Characteristics

Demographic Characteristics

In their 2009 report, the IOM recognized that the demographic characteristics of women entering pregnancy has changed since previous gestational weight gain recommendations had been released (1). Furthermore, the IOM recognized that some subgroups of women had a disproportionate burden of adverse pregnancy outcomes. For example, the proportion of women 35 years or older entering pregnancy increased from 8.9% in 1990 to 14.5% in 2009 (23) and both teenagers (≤ 19 years) and older women (≥ 35 years) entering pregnancy are at increased risk for delivering infants preterm or small-for-gestational age (1). The IOM found evidence that teenagers were more likely to have a higher total weight gain (>40 lbs) compared with 25-30 year old counterparts (1). It is hypothesized that adolescents entering pregnancy may require higher weight gains to support the growth of their body in addition to the growth and development of the fetus (1). In contrast, the IOM noted that older women more often had less total weight gain compared with younger counterparts. Importantly, several studies cited by the IOM were unable to control for pre-pregnancy BMI and recent studies controlling for pre-pregnancy BMI and other covariates have found no association between age and gestational weight gain (24-26); however, the primary purpose of these studies was not to examine the age specifically.

The racial composition of women entering pregnancy has also changed from 1990 through 2009, with the proportion of non-Hispanic white mothers decreasing, while non-Hispanic black mothers have remained relatively stable and Hispanic mothers have increased (27). Furthermore, racial-ethnic minorities, particularly non-Hispanic black mothers, are known to have an increased burden of adverse pregnancy outcomes (1, 27). The IOM report and others have found lower total weight gains among non-Hispanic black, Hispanic and Asian women compared with non-Hispanic white (1, 27). After controlling for relevant covariates, non-Hispanic black women continue to have an increased risk of inadequate weight gain compared to weight counterparts (24, 28). Unfortunately, fewer studies have examined the influence of Hispanic or Asian race-ethnicity on gestational weight gain.

Behavioral Characteristics

Behavioral characteristics associated with gestational weight gain are useful for identifying targets for intervention activities. Among the most important behaviors linked to gestational weight gain are physical activity and diet. Evidence from observational studies consistently indicates women with higher levels of physical activity during pregnancy are less likely to have excessive gestational weight gain, although the duration and intensity of activity has been variably defined (29). Results from individual randomized trials testing physical activity interventions on gestational weight gain have yielded conflicting results; however, meta-analyses support the association between increased physical activity and reduced gestational weight gain (29, 30). Under most

circumstances, physical activity during pregnancy is considered safe (31, 32), although most women – particularly those less active before pregnancy – tend to decrease their activity levels as pregnancy progresses (33).

The association between dietary behaviors during pregnancy and gestational weight gain is less understood because dietary assessment methods have varied widely between studies (30). Findings from some observational studies indicate diets lower in total energy and vegetarian diets are associated with reduced weight gain (1, 30, 34). Additionally, interventions prescribing certain diets (such as low glycemic load) also have been found to reduce excessive gestational weight gain (35). Of note, very few representative studies are available that assess dietary or physical activity behaviors during pregnancy.

Another modifiable behavior during pregnancy that has been associated with gestational weight gain is cigarette smoking. Cigarette smoking during pregnancy is associated with several adverse pregnancy outcomes, including preterm birth, poor fetal growth, and damage to fetal lung and brain development (36, 37). While the proportion of women smoking during the last 3 months of pregnancy has decreased from 2000 to 2011, from 13.2% to 11.6% (38), smoking cessation during pregnancy is an important public health priority and has been shown to reduce adverse pregnancy outcomes (39). Observational studies suggest women who stop smoking during pregnancy are more likely to have higher total gestational weight gains and to exceed weight gain recommendations (40, 41). Furthermore, some studies suggest that timing of smoking cessation may be

important, with at least one study suggesting quitting in the first half of pregnancy, but not the second, is associated with increased weight gain (41). While the adverse health outcomes associated with smoking during pregnancy may present a greater danger to the fetus than gaining excessive weight, weight gain during pregnancy may be a barrier to smoking cessation (42); thus women attempting smoking cessation during pregnancy may need additional support to achieve appropriate weight gains.

Psychosocial Characteristics

Psychosocial characteristics were considered potential determinants of gestational weight gain through the influence these characteristics may have on eating behaviors; for example, the IOM noted that changes in weight and appetite are included as diagnostic factors for major depression (1). Prenatal depression is thought to complicate approximately 9%-11% of pregnancies (1, 43). Studies examining the association between diagnosed depression or self-reported depressive symptoms during pregnancy have found inconsistent results, with some studies finding an increased likelihood of both inadequate and excessive weight gain (1). A recent study examined the influence of pre-pregnancy obesity, antenatal depression, and dietary patterns during pregnancy on gestational weight gain and found obesity was related to depression, but depression was not related to diet or weight gain (44). Similarly, studies examining stressful life events during pregnancy have mostly yielded null results (1, 25, 26, 45, 46); importantly, many of these studies examined stress as a single variable among a larger range of other determinants of gestational weight gain. Finally, a recent systematic review concluded that negative affective states during pregnancy, including stress and depression, were not

associated with gestational weight gain, although, meta-analysis was not performed because of a variety of definitions used to define these variables (47).

Medical Characteristics

Medical characteristics associated with gestational weight gain include hypertensive conditions (e.g. pregnancy-induced hypertension, preeclampsia) or diabetic conditions (e.g. impaired glucose tolerance, gestational diabetes) that develop during pregnancy. Importantly, it is unclear whether these characteristics are causes or consequences of gestational weight gain. Specifically, hypertensive conditions may increase vascular permeability and decrease plasma oncotic pressure, which may result in increased swelling of peripheral tissue (i.e. edema) and increased gestational weight gain (1, 48). It is also possible that increased weight gain during pregnancy may cause hypertensive conditions through metabolic or hormonal disturbances, as found in non-pregnant populations (49). Unfortunately, few studies have been detailed enough to consider timing of weight gain in relation to onset of hypertensive, which precludes studies from determining the direction of association. Similarly, for diabetic conditions, dietary changes or medications meant to control glucose levels may also influence weight gain; conversely, excessive weight gain may cause metabolic disturbances that exacerbate glucose intolerance thus causing gestational diabetes (1). Taken together, the lack of defined temporality in these associations suggests that these hypertensive and gestational conditions are correlates rather than determinants of gestational weight gain.

Healthcare Provider Advice

Healthcare providers play an important role in counseling patients on appropriate behaviors that promote health and prevent disease. The American College of Obstetricians and Gynecologists (ACOG) has adopted gestational weight gain recommendations provided by the IOM (both the 1990 and 2009 recommendations). Studies from mostly small, clinic-based samples before the revised recommendations were released suggest the proportion of women receiving healthcare provider advice about gestational weight gain varies widely, ranging from 42-81% (50-56). More importantly, the proportion of women receiving advice that is consistent with the IOM recommendations (i.e. within a range recommended by the IOM) is lower, ranging from 12-49% (50, 52-56). While these findings are based on women's self-report, studies of Obstetricians-Gynecologists have yielded similar results: One study from 2005 found 85% of physicians reported providing weight gain counseling "most of the time" or "often", and 64% used patients' pre-pregnancy BMI to modify recommendations (57). In a subsequent study in 2010, 65% of physicians reported "always" counseling patients and only 41% "always" modified recommendations according to pre-pregnancy BMI (58).

Of the studies mentioned above, few have examined the influence of healthcare provider advice on women's actual weight gain during pregnancy. One study compared women receiving any healthcare provider advice (regardless of whether advice was consistent with guidelines) with receiving no advice and found no association between receiving advice and gaining weight within the 1990 or 2009 IOM recommendations (51). Other studies have more closely examined how much weight was advised. For example, a

study of mostly white women participating in a consumer mail panel and delivering in 1993 found that advice below the 1990 recommendations was associated with an increased likelihood of weight gain below recommendations (adjusted OR=3.6, 95% CI= 2.3 – 5.5), whereas advice above recommendations was associated with increased likelihood of weight gain above recommendations (adjusted OR=2.0, 95% CI= 1.5, 2.7) (50). Importantly, studies examining healthcare provider advice have mostly been comprised of non-representative samples of women or have examined the previous, 1990 IOM recommendations. Furthermore, none have examined whether associations vary by pre-pregnancy BMI category.

Quality of Maternal Height and Weight Data

The quality of recalled height and weight data has been studied extensively in non-pregnant populations and studies have generally concluded women overestimate height and underestimate weight compared with measured values (59-61). Fewer studies have evaluated the quality of maternal height and weight data on the revised birth certificate. A study examined birth certificate data from one Pennsylvania hospital and compared maternal height and pre-pregnancy weight variables to first-trimester, self-reported values from medical records (62). The study found pre-pregnancy weight from the birth certificate was within 5 pounds of the medical record for 41% to 67% of women, depending on pre-pregnancy BMI. Agreement in pre-pregnancy BMI category ranged from 52% to 100%, depending on pre-pregnancy BMI category, race and gestational age; gestational weight gain-for-gestational age categories also ranged from 51% to 83%, depending on maternal characteristics. A study examining Women Infants and Children

participants found pre-pregnancy weight was under-reported by 4.3 pounds on the birth certificate compared to measured first trimester values; between the two sources, there was 76% agreement in pre-pregnancy BMI category (63). Finally, one study found gestational weight gain from the birth certificate was within 10 pounds of medical record values for 48% of women (64).

We are unaware of research that has examined the validity of pre-pregnancy weight and height reported in the post-partum period, which is most applicable to weight self-reported on the PRAMS questionnaire. The accuracy of recalled pre-pregnancy weight may decrease as the length of time increases between conception and when weight is recalled; however, one study compared pre-pregnancy weight recalled 30-35 years postpartum to weight recorded in the Collaborative Perinatal Project and found a mean difference of approximately 1.5 pounds between the two sources (65). Notably, there was large variation in the mean difference between sources (standard deviation ~ 8 pounds) and the Collaborative Perinatal Project recruited women in the 1960s, when demographics of women entering pregnancy were very different than in recent years.

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Chapter 3 - Extended Methods

As previously mentioned, our dissertation aims were to use representative data to: 1) estimate the proportion of women with gestational weight gain below, within or above the 2009 Institute of Medicine (IOM) gestational weight gain recommendations; 2) examine the influence of maternal demographic, behavioral, psychosocial and medical characteristics on gestational weight gain; and healthcare provider advice on gestational weight gain outside recommendations; 3) examine the influence of healthcare provider advice about gestational weight gain on women's actual weight gain during pregnancy and 4) examine the quality of maternal height and weight data.

In this chapter, we present an extended description of the data sources used in this dissertation: National Vital Statistics System (NVSS) birth data (referred to as birth certificate data), the Pregnancy Risk Assessment Monitoring System (PRAMS) and the PRAMS Data Quality Study. We begin with a description of the birth certificate because birth certificates provide the sampling frame from which PRAMS respondents are sampled and certain data elements from the birth certificate are incorporated into the PRAMS dataset. Next, we describe PRAMS and provide an overview of analytic methodologies required to account for the complex sampling design utilized by this surveillance system. Finally, we describe the PRAMS Data Quality Study.

The National Vital Statistics System Birth Data

The NVSS is an inter-governmental data coordinating system that shares vital event data (e.g. birth, death, marriage data) collected by states or jurisdictions (in the cases of New

York City and the District of Columbia) with the National Center for Health Statistics (NCHS) for the purpose of compiling and disseminating vital statistics for the United States (US) (1, 2). The US Standard Certificate of Live Birth (birth certificate) is a document developed by the NCHS with state and other stakeholder input and may be used as a model for collecting birth data. Birth certificates serve as legal registration of live birth but also collect a wealth of information on maternal, paternal and infant demographic and health characteristics. Birth certificate information is used for many purposes, for example: providing legal documentation for individual identification and citizenship; monitoring population growth; planning and evaluating state program needs; and monitoring and studying the health status of mothers and infants at local, state and national levels (1, 2).

The US Standard Certificate of Live Birth is periodically revised by NCHS in cooperation with states and stakeholders. The revision process develops data fields to be added to the birth certificate and identifies existing fields to be modified or removed. The current version of the birth certificate was developed in the late-1990s and implemented on a state-by-state basis beginning in 2003, with national adoption completed by 2016 (1, 3). In addition to revising the birth certificate, NCHS developed standard instructions for completing the birth certificate, including preferred and alternate sources for data fields (4).

Key Variables

While many data fields were added or revised on the 2003 revision of the birth certificate, three data fields are of note to this dissertation: maternal height, pre-pregnancy weight and gestational weight gain. A description of these variables is provided in relevant chapters later in this dissertation, but are also presented here.

Height, Pre-pregnancy Weight, and Pre-Pregnancy BMI

Maternal height and pre-pregnancy weight are new data fields to the 2003 revision of the birth certificate. As indicated by NCHS, the preferred source for these variables is mothers' self-report around the time of delivery; alternatively, data may be abstracted from prenatal care records (4). Pre-pregnancy BMI is calculated on the 2003 revision of the birth certificate from maternal height and pre-pregnancy weight. Pre-pregnancy BMI is calculated as (weight [kilograms]) / (height [meters])^2 and is categorized as in Table 1.

Delivery Weight and Gestational Weight Gain

Delivery weight is another new field on the 2003 revision of the birth certificate. The preferred source for delivery weight is abstraction from labor and delivery medical records, which may be measured upon hospital admission, self-reported around delivery, or abstracted from the last measured weight during prenatal care (4). Gestational weight gain is calculated as the difference between delivery weight and pre-pregnancy weight (both of which are reported on the birth certificate). Of note, gestational weight gain was also captured on the 1989 version of the birth certificate as a single field. Per US Department of Health and Human Services guidelines, information on gestational weight

gain should have been obtained from the medical record, a physician or the mother herself (5).

Gestational Weight Gain Adequacy

Taken together, pre-pregnancy BMI and gestational weight gain captured on the 2003 revision of the birth certificate allow gestational weight gain to be examined in relation to the 2009 Institute of Medicine (IOM) gestational weight gain recommendations. The previous 1989 version of the birth certificate did not capture maternal height or pre-pregnancy weight and gestational weight gain was captured as a single field; thus, the 1989 version of the birth certificate could not be used to examine gestational weight gain relative to IOM recommendations.

Of note, we refer to gestational weight gain below, within and above the IOM recommendations as inadequate, adequate/appropriate, or excessive gestational weight gain (6). Furthermore, as the IOM recommendations were developed for full-term singleton infants, all analyses presented in this dissertation are restricted to women who gave birth after 37 weeks completed gestation. The 2009 IOM recommendations are presented in Table 1.

The Pregnancy Risk Assessment Monitoring System

PRAMS is an ongoing, state-specific surveillance system jointly administered by the Centers for Disease Control and Prevention and state governments or jurisdictions (7).

PRAMS was initiated in 1987 to better understand causes of infant morbidity (8, 9). To achieve this goal, PRAMS combines demographic and medical data from the birth certificate with questionnaire data administered to mothers approximately four months after delivery. The PRAMS questionnaire ascertains information on maternal behaviors and experiences before, during and shortly after pregnancy. PRAMS data are used by public health practitioners, policy makers, and researchers at the state and national level to monitor the health status of new mothers, identify women and infants at-risk for adverse health outcomes, examine relationships between health behaviors and adverse health outcomes, and measure progress toward meeting public health goals (8). Currently, 47 states (including New York state), New York City and Washington, D.C. participate in PRAMS, which represents approximately 83% of all US live births.

PRAMS Sample Selection and Related Statistical Considerations

In each participating PRAMS jurisdiction, a sample of approximately 100-250 mothers are selected each month from a frame of eligible birth certificates. Samples are commonly stratified by birthweight (low birth weight [<2,500g] vs not), but may be stratified by geographic region, maternal race/ethnicity, or a combination of factors (10). The stratified sampling strategy allows subpopulations of interest to be oversampled, thereby improving precision of risk estimates within subgroups that would normally have few cases. To account for the unequal probability of selection, sampling weights are calculated for all women as the inverse of the selection probability (7).

In addition to selection weights, separate weights are generated to account for survey nonresponse and non-coverage. Survey nonresponse weighting assumes that respondents and non-respondents who share similar demographic characteristics (e.g. age, education) would, on average, respond similarly to survey questions. Survey nonresponse weights are calculated as the inverse of the response rate for a group of women with similar characteristics within the sampling frame. The use of the birth certificate as the sampling frame allows demographic characteristics between respondents and non-respondents to be analyzed and weights to be derived. Noncoverage weights are used to account for the possibility that the sampling frame does not represent the target population of interest (i.e. women giving birth to live born infants in a particular state in a particular year). Noncoverage weights are calculated by comparing totals from the sample to the complete birth file for a given state in a given year. In PRAMS, noncoverage typically occurs due to late processing of birth records, and is evenly scattered throughout the state and the year; thus, the magnitude of noncoverage is usually small. The final analysis weight is calculated as the product of the sampling, nonresponse and noncoverage weights and allows inferences to be made about all women delivering a live-born infant in a particular state and at a given year (7).

The complex sample design employed by PRAMS requires special analytic attention. Specifically, the sampling, noncoverage and nonresponse weights must be incorporated into analyses to produce unbiased estimates of population parameters. The complex survey design features (i.e. stratification) influence variance estimates, which cannot be estimated as simple linear functions of the observed data; thus, Taylor series linearization

is used to approximate parameter estimates of interest and their associated variance (7, 11). For this dissertation, the analysis weights and complex sample design features are accounted for by using SAS-callable SUDAAN and specifying these features in each statistical procedure.

The PRAMS Questionnaire

The PRAMS questionnaire consists of two parts: a set of 'core' questions that are common to all states participating in PRAMS and a set of state-specific questions (7). Core questions have been identified, developed and pretested by CDC and participating PRAMS states and assess a comprehensive set of experiences and behaviors in the perinatal period, including: breastfeeding practices, contraceptive use, knowledge of pregnancy-related health issues, nutritional status (e.g. height and pre-pregnancy weight) and reproductive history. State-specific questions may be selected either from a set of questions developed and pretested by CDC with input by PRAMS states (referred to as 'standard' questions), or may be developed independently by states; these questions provide additional information on topics addressed by core questions (e.g. specific information about counseling received during prenatal care) or provide information on new topics. By combining core and state-specific questions, the PRAMS questionnaire provides standardized information on a variety of health topics while also providing additional information of particular interest to a state or local jurisdiction (7).

Key Variables

Data from the PRAMS questionnaire are combined with demographic and medical information captured on the birth certificate. Birth certificate and PRAMS questionnaire variables that are relevant to this dissertation are described below, and are also described later in relevant chapters.

Maternal Height and Pre-Pregnancy Weight

Maternal height and pre-pregnancy weight are obtained by self-report on the PRAMS questionnaire approximately 4 months postpartum. The two core PRAMS questions used to ascertain height and pre-pregnancy weight are as follows: *"Just before you got pregnant with your new baby, how much did you weigh?*" and "*How tall are you without shoes*?"

It is important to note that for states that had not yet adopted the 2003 revised birth certificate, PRAMS datasets for those given years do not include height and pre-pregnancy weight captured on the birth certificate – only height and pre-pregnancy weight self-reported on the questionnaire.

Gestational Weight Gain

Gestational weight gain is a birth certificate variable included in the PRAMS dataset. For states utilizing the 1989 version of the birth certificate, gestational weight gain is captured as a single data field, as described above. For states adopting the 2003 birth certificate, gestational weight gain is calculated as the difference between pre-pregnancy

weight and delivery weight, as described above and only the total gestational weight gain is reported in the PRAMS dataset. Of note, this variable is bottom-coded at 0, which reflects zero weight gain or weight loss, and is top-coded at 99, which reflects weight gain ≥ 99 pounds. Gestational weight gain relative to the 2009 IOM recommendations (i.e. below, within or above recommendations), may be determined using gestational weight gain (from either the 1989 birth certificate or 2003 birth certificate) and self-reported pre-pregnancy BMI reported from the PRAMS questionnaire.

Healthcare Provider Advice about Gestational Weight Gain

Healthcare provider advice about gestational weight gain is a standard, state-specific question on the PRAMS questionnaire. This question was asked on the Phase 6 (2009-2011) PRAMS questionnaire by Colorado, Georgia, Maine and Utah. The question is asked in two parts: First, women were asked whether any healthcare provider (i.e., a doctor, nurse, or other clinician) discussed how much weight to gain during pregnancy. Women who indicated receiving advice from a healthcare provider were prompted to report the advised amount of weight gain (recorded as start- and end-values of a range or an exact amount), or to indicate advice was not remembered. The exact question text for these items is as follows:

"<u>During any of your prenatal care visits</u>, did a doctor, nurse, or other health care worker talk with you about how much weight you should gain during your pregnancy?"

*"How much weight did your doctor, nurse, or other health care worker tell you to gain during your most recent pregnancy? Please check **one** answer and fill in the blanks(s) next to the checked box.*

□ *Between _____ Pounds and _____ Pounds*

□ *Between _____ Kilos and _____ Kilos*

□ *Exactly _____ Pounds OR _____ Kilos*

□ *I don't remember"*

Notably, mothers' report of healthcare provider advice can be used to categorize provider advice relative to the 2009 IOM recommendations; thus, in Chapter 6, we categorized healthcare provider advice in the following way: Using the start- and end-values (or exact amount) of the advised weight gain range, we created a five-level variable to describe healthcare provider advice relative to women's BMI-specific 2009 IOM gestational weight gain recommendation, as illustrated in Figure 1: advised weight gain range started below the recommendation; advised weight gain range started and ended within the recommendation (referred to as IOM-consistent); advised weight gain range ended above the recommendation; advised weight gain range was not remembered or not indicated; no weight gain advice was received. Women with an advised weight gain range that started below and ended above recommendations were excluded due to insufficient sample sizes.

The PRAMS Data Quality Study

The final data source used in this dissertation is the PRAMS Data Quality Study, a CDC-funded study to validate PRAMS questionnaire and birth certificate items against information recorded in the medical record (12, 13). Two PRAMS sites, New York City and Vermont, were selected to conduct the study through a proposal submission process. In New York City, all PRAMS respondents who delivered infants from January 1 through June 4, 2009 were included in the DQS (603 respondents, weighted to represent 65,843 women). In Vermont, all PRAMS respondents who delivered from January 1 through August 31, 2009 were included in the DQS subsample (664 respondents, weighted to represent 3,700 women). The weighted PRAMS response rate was 67.3% for New York City and 82% for Vermont, for each respective time-frame.

Key Variables

The purpose of the Data Quality Study was to compared PRAMS questionnaire and birth certificate data to information abstracted from the medical record. Medical record data were abstracted from all 41 hospitals that perform deliveries in New York City and 12 hospitals in Vermont that perform deliveries, in addition to one central New Hampshire hospital on Vermont's border. Medical record data abstractors were trained to use a standardized abstraction form, which included detailed instructions about where data elements were located. Data quality of abstracted medical information was assessed by CDC personnel at each site; errors in abstracted variables were estimated to be less than 3% (13).

For our particular study, we examined the quality of maternal height, pre-pregnancy weight and delivery weight data from the birth certificate and PRAMS questionnaire. Height, pre-pregnancy weight and delivery weight variables from the birth certificate and/or the PRAMS questionnaire have previously been described; thus, we present below brief description of these variables from the DQS.

Maternal Height and Pre-Pregnancy Weight

From the medical record, height was abstracted from measured or self-reported values in prenatal care or labor and delivery records. Pre-pregnancy weight was abstracted from self-reported values in prenatal care or labor and delivery records; if self-reported values were unavailable, the earliest measured weight recorded in prenatal records within eight weeks of pregnancy was used as a proxy for pre-pregnancy weight (n=72).

Delivery Weight

Delivery weight was abstracted from labor and delivery records; if values were unavailable, the last weight measured weight recorded in prenatal records within two weeks of delivery was used as a proxy for delivery weight (n=75). Gestational weight gain was calculated as the difference between delivery weight and pre-pregnancy weight.

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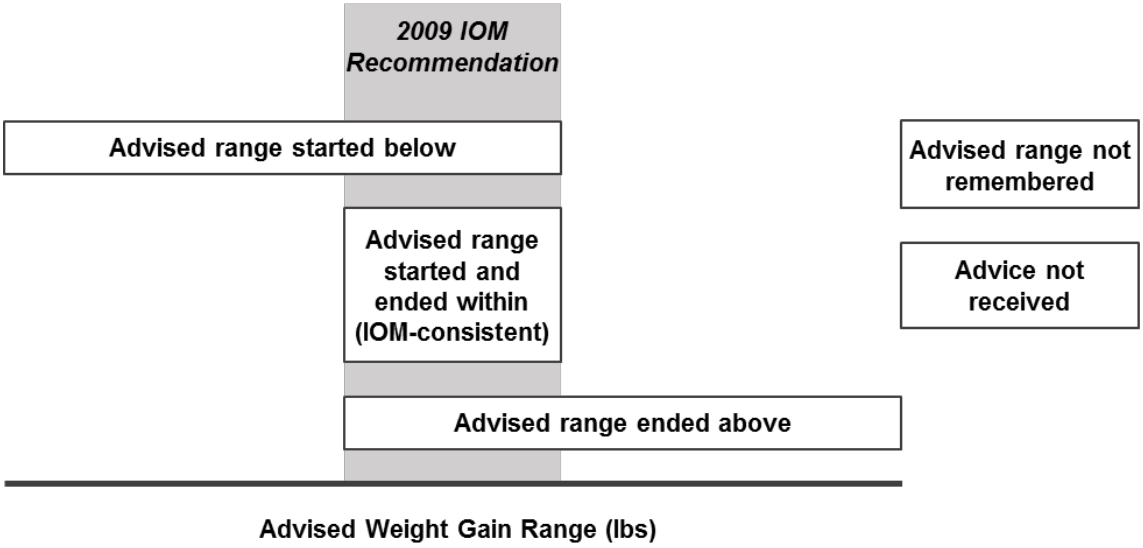
Table 3-1: 2009 Institute of Medicine Gestational Weight Gain Recommendations for Full-Term, Singleton Pregnancies

Pre-pregnancy BMI Category	BMI Definition (kg/m^2)	2009 IOM GWG Recommendations (lbs)
Underweight	BMI < 18.5	28-40
Normal weight	18.5 ≤ BMI < 25.0	25-35
Overweight	25.0 ≤ BMI < 30.0	15-25
Obese	BMI ≥ 30.0	11-20

Figure 3-1: Categorization Scheme for Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations

Figure 1: Categorization Scheme for Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations



Chapter 4 - Gestational Weight Gain — 46 States, New York City and District of Columbia, 2012 and 2013

Nicholas P. Deputy, MPH[1,2], Andrea J. Sharma, PhD MPH[1,3], Shin Y. Kim, MPH[1]

[1]Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, CDC; [2]Nutrition and Health Sciences Program, Laney Graduate School, Emory University, Atlanta, GA; [3]U.S. Public Health Service Commissioned Corps (Corresponding author: Andrea J. Sharma, AJSharma@cdc.gov, 770-488-5957)

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Chapter 5 - Prevalence and Characteristics Associated With Gestational Weight Gain Adequacy

Nicholas P. Deputy, MPH; Andrea J. Sharma, PhD, MPH; Shin Y. Kim, MPH; Stefanie N. Hinkle, PhD

Nutrition and Health Sciences Program, Laney Graduate School, Emory University, Atlanta, GA; Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA; U.S. Public Health Service Commissioned Corps, Atlanta, GA; Epidemiology Branch, Division of Intramural Population Health Research, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development, National Institutes of Health, Bethesda, MD

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Chapter 6 - Achieving Appropriate Gestational Weight Gain: the Role of Healthcare Provider Advice

Authors: Nicholas P. DEPUTY, MPH; Andrea J. SHARMA, PhD, MPH; Shin Y. KIM, MPH; Christine K. OLSON, MD, MPH

Affiliations: Nutrition and Health Sciences Program, Laney Graduate School, Emory University, Atlanta, GA (Mr. Deputy and Dr. Sharma); Maternal and Infant Health Branch, Division of Reproductive Health, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA (Mr. Deputy, Dr. Sharma, Ms. Kim, and Dr. Olson); U.S. Public Health Service Commissioned Corps, Atlanta, GA (Dr. Sharma and Dr. Olson)

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Abstract

Background: In 2009, the Institute of Medicine (IOM) revised gestational weight gain recommendations, which balance risks of too little and too much weight gain to promote optimal maternal and infant health. The American College of Obstetrics and Gynecology recommends healthcare providers assess pre-pregnancy BMI at the initial prenatal care visit and discuss appropriate weight gain throughout pregnancy. Few studies have examined the influence of healthcare provider advice on gestational weight gain; furthermore, studies examining current recommendations in representative, population-based samples are lacking. **Objective:** Using representative, population-based data, we sought to estimate the proportion of women receiving healthcare provider advice about gestational weight gain that was consistent with 2009 IOM recommended ranges and examine associations between provider advice and inadequate or excessive gestational weight gain, stratified by pre-pregnancy body mass index (BMI) category. **Study Design:** We analyzed cross-sectional data from women in Colorado, Georgia, Maine and Utah who participated in the Pregnancy Risk Assessment Monitoring System in 2010 or 2011 and delivered full-term (≥37 weeks gestation), singleton infants (unweighted n=7,101). Women reported the amount of weight advised by their healthcare provider (recorded as start- and end-values of a range or an exact amount); we described whether advice fell within IOM recommended ranges by categorizing advice as: starting below recommendations, starting and ending within recommendations (IOM-consistent), ending above recommendations, advice not remembered, or advice not received. We then examined associations between healthcare provider advice and inadequate or excessive gestational weight gain, compared with appropriate gain, using adjusted prevalence ratios

(aPR) and 95% confidence intervals (CI). **Results:** Overall, 26.4% of women received IOM-consistent healthcare provider advice; 15.6% received advice starting below recommendations, 18.1% received advice ending above recommendations, 13.9% did not remember advice and 26.1% received no advice. Compared with IOM-consistent advice, advice starting below recommendations was associated with higher likelihood of inadequate weight gain among underweight (aPR 2.22, CI 1.29-3.82) and normal weight women (aPR 1.57, CI 1.23-2.02); advice ending above recommendations was associated with higher likelihood of excessive weight gain among all but underweight women (aPR range 1.34, CI 1.06-1.70 to aPR 1.42, CI 1.19-1.71). Not remembering or not receiving advice was associated with both inadequate and excessive weight gain, but associations varied by pre-pregnancy BMI. **Conclusions:** Few women reported receiving IOM-consistent advice; not receiving IOM-consistent advice put women at-risk for weight gain outside recommendations. Strategies that raise awareness of IOM recommendations and address barriers to providing advice are needed.

Key words: advice, counseling, gestational weight gain, healthcare provider advice, nutrition, pregnancy, Pregnancy Risk Assessment Monitoring System, prenatal care, weight

Introduction

Recent studies indicate less than one-third of women had gestational weight gain within 2009 Institute of Medicine (IOM) recommendations, whereas one-fifth gained below and nearly half gained above recommendations.[1,2] The IOM recommendations, which are specific to a woman's pre-pregnancy body mass index (BMI) (Table 1), balance risks associated with too little and too much weight gain to promote optimal maternal and infant health.[3] Weight gain below recommendations is associated with small-for-gestational age infants, whereas weight gain above recommendations is associated with large-for-gestational age infants, possibly childhood obesity, and maternal postpartum weight retention, which may contribute to developing or worsening obesity.[3,4]

The American College of Obstetricians and Gynecologists (the College) has adopted the 2009 IOM recommendations; further, the College recommends healthcare providers assess pre-pregnancy BMI at the initial prenatal care visit and discuss appropriate weight gain and dietary and physical activity behaviors throughout pregnancy.[5] Despite this guidance, studies indicate 42-81% of women report receiving any advice from a healthcare provider about gestational weight gain[6-12] and 12-49% report receiving advice consistent with IOM recommendations.[6,8-12] Healthcare provider advice about gestational weight gain has been found to influence weight gain during pregnancy.[6,8] Importantly, these earlier studies examined previous IOM recommendations[6-10], which lacked clear recommendations for women with obesity, or used data from small, clinic-based samples[11,12], which limits generalizability to broader populations.

Our objective was to estimate the proportion of women receiving healthcare provider advice about gestational weight gain consistent with 2009 IOM recommendations using representative, population-based data. We also assessed the relationship between healthcare provider advice and gestational weight gain, stratified by pre-pregnancy BMI category.

Materials and Methods

Data are from the Pregnancy Risk Assessment Monitoring System (PRAMS), a cross-sectional surveillance system administered by the Centers for Disease Control and Prevention (CDC) and state governments.[13] Each month, participating states systematically sample 100-250 mothers approximately 4 months postpartum using birth records as a sampling frame. Sampled mothers complete a questionnaire or telephone interview that assesses behaviors and experiences before, during and after pregnancy; these data are linked to select information from the birth certificate. Data are weighted to account for survey design, noncoverage, and nonresponse to provide representative estimates of the female population delivering a live birth in each state. The PRAMS protocol has been reviewed and approved by the CDC institutional review board, and participating states approved this analysis.

The PRAMS questionnaire is updated periodically and consists of questions common to all states and optional questions that individual states may choose to include. For this analysis, we used Phase 6 (2009-2011) data from Colorado, Georgia, Maine and Utah because these states included optional questions on healthcare provider advice about

gestational weight gain. We examined data from 2010-2011 because the IOM recommendations were revised in 2009. Women were asked whether any healthcare provider (i.e., a doctor, nurse, or other clinician) discussed how much weight to gain during pregnancy. Women who indicated receiving advice from a healthcare provider were prompted to report the advised amount of weight gain (recorded as start- and end-values of a range or an exact amount), or to indicate advice was not remembered. Using the start- and end-values (or exact amount) of the advised weight gain range, we created a five-level variable to describe healthcare provider advice relative to women's BMI-specific 2009 IOM gestational weight gain recommendation, as illustrated in Figure 1: advised weight gain range started below the recommendation; advised weight gain range started and ended within the recommendation (referred to as IOM-consistent); advised weight gain range ended above the recommendation; advised weight gain range was not remembered or not indicated; no weight gain advice was received. Women with an advised weight gain range that started below and ended above recommendations were excluded due to insufficient sample sizes (n=91). Because we observed terminal digit preference[14] in women's report of advised weight gain (i.e., "0" or "5" was the most frequently reported terminal digit for advised weight gain values, regardless of pre-pregnancy BMI category), we considered an advised weight gain range of 25-40 pounds for underweight women and 10-20 pounds for obese women to be consistent with the IOM recommendations.

Our outcome of interest was women's gestational weight gain below, within, or above the BMI-specific 2009 IOM recommendations (Table 1).[3] Gestational weight gain was

considered inadequate, appropriate or excessive if a woman gained below, within or above recommendations, respectively. Total gestational weight gain was obtained from the birth certificate. Pre-pregnancy BMI was calculated using self-reported height and pre-pregnancy weight from the PRAMS questionnaire; height and pre-pregnancy weight from the birth certificate were not available in PRAMS during this time.

Covariates included maternal age, race-ethnicity, education, parity and marital status, which were obtained from the birth certificate, and first trimester entrance into prenatal care, which was obtained from the PRAMS questionnaire. We obtained information for additional variables based on positive indication on either the birth certificate or questionnaire: enrollment in the Special Supplemental Nutrition Program for Women, Infants and Children; smoking status (defined as nonsmokers [no smoking before or during pregnancy], quitters [smoking before pregnancy, but not in the third trimester], or smokers [smoking in the third trimester]); indication of a hypertensive condition (i.e., pre-pregnancy hypertension, gestational hypertension, or pre-eclampsia); and indication of a diabetic condition (i.e., chronic or gestational diabetes).

Women were eligible for this analysis if they delivered a full-term (≥37 weeks gestation, based on clinical estimate), singleton infant (n=8,600). We excluded women with missing gestational weight gain values (n=527), missing or implausible pre-pregnancy weight (less than 75 pounds or more than 450 pounds; n=194), missing or implausible height (less than 48 inches or more than 78 inches; n=238), or missing healthcare provider advice (n=119). We also excluded women with healthcare provider advice that

ended above 50 pounds (n=29) because this advice is 10 pounds greater than the maximum IOM recommendation for singleton pregnancies (28-40 pounds for underweight women) and may represent implausible advice. As previously described, women with advice starting below and ending above the IOM recommendation were excluded due to insufficient sample sizes (n=91). Additionally, we excluded women with missing values on covariates (n=301). Our final sample size was 83% of our eligible population (unweighted n=7,101), which represents approximately 80% of births in Colorado, Georgia, Maine and Utah in 2010 and 2011.

We used Wald Chi-Square tests to identify significant differences in proportions of women receiving healthcare provider advice by maternal characteristics. To examine the association between healthcare provider advice and inadequate or excessive gestational weight gain, compared with appropriate weight gain, we estimated unadjusted prevalence ratios (PRs) and 95% confidence intervals (CIs) using predicted marginal proportions from multinomial logistic regression models;[15] IOM-consistent healthcare provider advice was considered the referent for all models. We also adjusted PRs for all covariates previously mentioned, which were identified as confounders *a priori* using directed acyclic graphs and stratified models by pre-pregnancy BMI category because gestational weight gain recommendations are specific to a woman's pre-pregnancy BMI.[3]

To explore the dose-response relationship between healthcare provider advice and gestational weight gain, we expanded our exposure variable to seven levels. Our expanded variable distinguished advice that started and ended below recommendations

from advice that started below but ended within recommendations, and distinguished advice that started within and ended above recommendations from advice that started and ended above recommendations (Supplemental Figure 1). The levels are: advised weight gain range started and ended below the recommendations; advised weight gain range started below and ended within the recommendations; advised weight gain range started and ended within the recommendation (i.e. IOM-consistent); advised weight gain range started within and ended above the recommendation; advised weight gain range started above and ended above the recommendation; advised weight gain range was not indicated or not remembered; no weight gain advice received. Using this variable, we estimated PRs and 95% CI, adjusting for all covariates, to examine the relationship between healthcare provider advice and gestational weight gain outside recommendations. Due to limited sample sizes within some levels, we were unable to stratify by pre-pregnancy BMI; thus, we present results from an un-stratified model that included pre-pregnancy BMI category as a confounder.

We conducted two sensitivity analyses. First, we assessed effect modification by state by testing an interaction term between state and healthcare provider advice in an un-stratified model. Second, we excluded women with hypertensive or diabetic conditions before or during pregnancy as these may influence healthcare provider advice and/or gestational weight gain. Specifically, women with hypertensive conditions may gain weight related to edema[3], while women with diabetic conditions likely receive additional nutritional advice to control glucose levels, which may influence weight gain.[16] Analyses were conducted using SAS 9.3 with SAS-callable SUDAAN 11 to account for the

complex sample design and weights utilized in the PRAMS. We considered statistical significance at $P<0.05$.

Results

Compared with women included in this analysis, a significantly smaller proportion of excluded women reported receiving healthcare provider advice that was IOM-consistent (17.2% vs. 26.4%), whereas a higher proportion reported not receiving advice (41.1% vs. 26.1%). Included and excluded women did not differ significantly in gestational weight gain or pre-pregnancy BMI; however, excluded and included women differed in several other characteristics (Table 2).

Overall, 26.4% of women reported receiving healthcare provider advice that was consistent with the 2009 IOM recommendations, whereas 15.6% received advice that started below recommendations, 18.1% received advice that ended above recommendations, 13.9% did not remember advice, and 26.1% did not receive advice (Table 3). The proportion of women receiving IOM-consistent advice varied by all maternal characteristics considered ($P<0.05$), except for diabetic disease (Table 3). Notably, compared with women in other pre-pregnancy BMI categories, more underweight and normal weight women received advice that started below recommendations whereas more overweight women received advice ending above recommendations; underweight women had the highest proportion of IOM-consistent advice. The most commonly advised weight gain range was 25-35 pounds for underweight, normal weight and overweight women; 15-20 pounds was most commonly advised for obese women (data not shown).

Figure 2 illustrates the bivariate association between women's report of healthcare provider advice and inadequate, appropriate or excessive gestational weight gain. Overall, 31.5% of women had appropriate weight gain, whereas 22.7% had inadequate and 45.8% had excessive gain. Inadequate weight gain was highest among women who received advice that started below recommendations (33.5%), whereas excessive weight gain was highest among those who received advice that ended above recommendations (65.0%). Among women who received IOM-consistent advice, 42.2% had appropriate gestational weight gain.

Unadjusted associations between women's report of healthcare provider advice and gestational weight gain (Supplemental Digital Content Tables 1 and 2) were not notably different than adjusted associations; thus, results of adjusted analyses are presented below.

Adjusted associations between women's report of healthcare provider advice and gestational weight gain, stratified by pre-pregnancy BMI category, are presented in Table 4; IOM-consistent advice was the referent for all associations. Underweight and normal weight women who received healthcare provider advice that started below recommendations were more likely to have inadequate gestational weight gain (PR 2.22, 95% CI 1.29-3.82 and PR 1.57, 95% CI 1.23-2.02, respectively). Normal weight, overweight and obese women who received advice that ended above recommendations were more likely to have excessive weight gain (normal weight: PR 1.34, 95% CI 1.06-

1.70; overweight: PR 1.42, 95% CI 1.19-1.71; obese: PR 1.38, 95% CI 1.09-1.74). Underweight and normal weight women who did not remember advice were more likely to have inadequate weight gain (PR 1.87, 95% CI 1.03-3.41 and PR 1.50, 95% CI 1.08-2.07, respectively), whereas overweight women who did not remember advice were more likely to have excessive gain (PR 1.29, 95% CI 1.04-1.61). Underweight and overweight women who did not receive advice were more likely to have both inadequate (PR 1.99, 95% CI 1.11-3.57 and PR 2.03, 95% CI 1.12-3.68, respectively) and excessive weight gain (PR 2.08, 95% CI 1.01-4.28 and PR 1.23, 95% CI 1.01-1.50, respectively); obese women who did not receive advice were also more likely to have excessive weight gain (PR 1.28, 95% CI 1.01-1.62).

We used our expanded healthcare provider advice variable to explore the dose-response relationship between women's report of healthcare provider advice and gestational weight gain among women in all pre-pregnancy BMI categories (Table 5); IOM-consistent advice was the referent for all associations. Women who received advice that started and ended below recommendations had a higher likelihood of inadequate gestational weight gain than women who received advice that started below, but ended within recommendations (PR 1.81, CI 1.28-2.56 vs PR 1.49, CI 1.19-1.88). Similarly, women who received advice that started and ended above recommendations had a higher likelihood of excessive weight gain than women who received advice that started within, but ended above recommendations (PR 1.50, CI 1.21-1.86 vs PR 1.36, CI 1.19-1.55).

Results of our sensitivity analyses revealed no meaningful differences in associations between healthcare provider advice and gestational weight gain when testing for effect modification by state or when excluding women with hypertensive or diabetic conditions (data not shown).

Comment

Using representative, population-based data, we found only 26.4% of women reported receiving healthcare provider advice consistent with 2009 IOM gestational weight gain recommendations. Similar to studies examining previous IOM recommendations,[6,8] healthcare provider advice below or above recommendations was associated with inadequate or excessive gestational weight gain, respectively; we extend previous findings by noting some associations varied by pre-pregnancy BMI category. Furthermore, we found the risk of inadequate or excessive weight gain increased as provider advice deviated further from recommendations, suggesting a dose-response relationship. Our findings underscore the importance of IOM-consistent healthcare provider advice to promote appropriate gestational weight gain.

Our finding that only 1 in 4 women reported receiving IOM-consistent advice suggests improved awareness of the 2009 IOM recommendations is needed among healthcare providers. A recent study found 6% of Obstetrics/Gynecology and Family Medicine residents correctly identified IOM-consistent gestational weight gain ranges.[17] Clinician surveys indicate pre-pregnancy BMI is not routinely used to guide weight gain advice;[18,19] indeed, we found healthcare providers most frequently advised a weight gain

range of 25-35 pounds for all but obese women. Moreover, healthcare providers may experience barriers to counseling about gestational weight gain, such as insufficient training and knowledge, sensitivity around weight-related topics, and perceptions that counseling is ineffective; addressing barriers may allow providers to feel more prepared to provide IOM-consistent advice.[20]

Notably, among women who reported receiving IOM-consistent advice, only 42% had appropriate gestational weight gain; thus, additional strategies may be needed to help women achieve appropriate weight gain. Specifically, healthcare providers can discuss appropriate weight gain throughout pregnancy[5] and encourage women to self-monitor and compare weight gain to recommended ranges using BMI-specific weight gain trackers, which are available online[21]. Routine self-monitoring of weight gain beginning early in pregnancy allows for detection of inadequate or excessive gain when small, corrective changes can be made.[22] Providers can also encourage dietary and physical activity behaviors that promote appropriate weight gain. Most women require no additional calories in the first trimester and an additional 340 and 450 calories a day in the second and third trimester, respectively, to support the metabolic demands of pregnancy;[3] women can use the USDA SuperTracker to identify foods that meet calorie needs.[23] Most pregnant women are recommended to achieve 150 minutes per week of moderate-intensity physical activity, such as brisk walking.[24,25] In primary care settings, physical activity prescriptions that include details of frequency, duration and intensity have been found to promote physical activity.[26]

Aside from patient-centered strategies, public health campaigns that address social norms and raise awareness about benefits of appropriate gestational weight gain are needed.[26] Social norms around gestational weight gain and the culture of "eating for two" may encourage excessive weight gain by overshadowing messages from healthcare providers about appropriate dietary, physical activity and weight gain behaviors.[27] Furthermore, raising awareness about weight gain recommendations may encourage women to initiate conversations with healthcare providers about strategies to achieve appropriate weight gain.

Our study was strengthened by the use of a large, population-based dataset representative of 4 states that allowed us to stratify analyses by pre-pregnancy BMI category and explore a dose-response relationship. We are limited by women's postpartum report of healthcare provider advice, which may result in recall bias; however, provider advice and weight gain information were ascertained separately, which may limit the influence of a woman's weight gain on her report of provider advice. Indeed, only 20% of women reported an advised weight gain range that included their actual gestational weight gain (data not shown); if recall bias were present, we would expect this proportion to be higher. Healthcare provider advice reported by women may not reflect actual advice from a healthcare provider, but information that women internalize and recall may be most important for influencing behavior.[11] We were unable to distinguish advice from a physician, nurse, or combination of clinicians, nor were we able to assess timing or frequency of provider advice during pregnancy because these details were not collected. Furthermore, examining healthcare provider advice 1-2 years after the 2009 IOM

recommendations were released may not have allowed sufficient time for recommendations to translate into practice; however, current and previous recommendations differ only for obese women.[28] Self-reported height and pre-pregnancy weight may result in misclassification of pre-pregnancy BMI category and gestational weight gain. Studies suggest 76%-84% of women are classified into correct BMI categories using self-reported height and pre-pregnancy weight,[29,30] whereas 50%-83% are classified into correct gestational weight gain categories, depending on pre-pregnancy BMI category.[31] Finally, studies have found that the prevalence of appropriate gestational weight gain varies by state, which may be related to social or environmental factors, including secular trends in healthcare provider advice.[1] While we found no evidence that state modified the association between provider advice and gestational weight gain, our findings may not be generalizable to women in all states.

In summary, our results suggest healthcare provider advice influences women's gestational weight gain; however, only one-quarter of women report receiving IOM-consistent advice and one-quarter report receiving no advice about gestational weight gain. Strategies that raise awareness of the 2009 IOM recommendations, address barriers to providing advice, and address social norms around gestational weight gain are needed to ensure women receive IOM-consistent advice.

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Tables and Figures

Table 6-1: 2009 Institute of Medicine Gestational Weight Gain Recommendations for Full-Term, Singleton Pregnancies

Table 1: 2009 Institute of Medicine Gestational Weight Gain Recommendations for Full-Term, Singleton Pregnancies

Pre-pregnancy BMI Category (BMI Range)	Recommended Total Weight Gain
Underweight (<18.5 kg/m^2)	28 – 40 lbs.
Normal weight (18.5 – 24.9 kg/m^2)	25 – 35 lbs.
Overweight (25.0 – 29.9 kg/m^2)	15 – 25 lbs.
Obese (≥ 30.0 kg/m^2)	11 – 20 lbs.

Table 6-2: Comparison of Characteristics among Women Excluded and Included From Analysis

Table 2: Comparison of Characteristics among Women Excluded and Included From Analysis

	Excluded (n=1,499[a])		Included (n=7,101[a])		
Characteristic	**N[a]**	**% (SE)[b]**	**N[a]**	**% (SE)[b]**	***P***
Gestational Weight Gain	555				
Inadequate	151	31.0 (4.0)	1,703	22.7 (0.9)	0.140
Appropriate	162	27.0 (3.5)	2,405	31.5 (1.0)	
Excessive	242	42.0 (3.9)	2,993	45.8 (1.1)	
Healthcare Provider Advice	1,073				
Advice started below recommendation	78	6.6 (1.3)	1,009	15.6 (0.8)	<0.001
IOM-consistent	178	17.2 (2.1)	1,967	26.4 (0.9)	
Advice ended above recommendation	147	11.9 (1.8)	1,286	18.1 (0.8)	
Advice not remembered	277	23.2 (2.3)	949	13.9 (0.8)	
Advice not received	393	41.1 (2.7)	1,890	26.1 (0.9)	
Pre-Pregnancy BMI	1,012				
Underweight	53	3.7 (1.0)	339	3.9 (0.4)	0.974
Normal Weight	533	52.9 (2.9)	3,741	51.9 (1.1)	
Overweight	226	22.9 (2.4)	1,708	24.1 (0.9)	
Obese	200	20.4 (2.4)	1,313	20.1 (0.9)	
Age (y)	1,498				
Younger than 19	259	10.8 (1.3)	768	8.1 (0.5)	0.257
20-24	352	22.5 (2.0)	1,684	23.8 (0.9)	
25-29	392	29.3 (2.2)	2,166	30.8 (1.0)	
30 or older	495	37.4 (2.3)	2,483	37.3 (1.0)	
Race-ethnicity	1,499				
Non-Hispanic white	718	39.9 (2.3)	5,126	65.4 (1.1)	<0.001
Non-Hispanic black	252	22.8 (2.2)	653	14.5 (0.9)	
Hispanic	433	29.6 (2.1)	1,010	14.7 (0.7)	
Other	96	7.6 (1.3)	312	5.4 (0.5)	
Education (y)	1,327				
Less than 12	429	27.9 (2.2)	1,087	13.8 (0.7)	<0.001
12	369	29.7 (2.4)	1,758	24.4 (0.9)	
More than 12	529	42.4 (2.5)	4,256	61.8 (1.0)	
Parity	1,457				
0	618	37.5 (2.3)	3,050	39.1 (1.0)	0.544
1 or more	839	62.5 (2.3)	4,051	60.9 (1.0)	
WIC Enrollment	1,491				
Yes	916	61.5 (2.3)	3,165	46.5 (1.1)	<0.001
No	575	38.5 (2.3)	3,936	53.5 (1.1)	
Smoking status during pregnancy	1,409				
Nonsmoker	1,163	85.7 (1.7)	5,482	79.0 (0.9)	0.001
Quitter	114	8.4 (1.3)	818	11.3 (0.7)	
Smoker	132	5.9 (1.1)	801	9.7 (0.7)	

First trimester prenatal care	1,360				
Yes	1,034	77.2 (2.1)	6,022	86.4 (0.7)	<0.001
No	326	22.9 (2.1)	1,079	13.6 (0.7)	
Marital status	1,483				
Married	841	57.4 (2.4)	4,872	68.0 (1.1)	<0.001
Nonmarried	642	42.6 (2.4)	2,229	32.1 (1.1)	
Hypertensive conditions	1,499				
Yes	186	13.2 (1.7)	951	11.5 (0.7)	0.354
No	1,313	86.8 (1.7)	6,150	88.5 (0.7)	
Diabetic disease	1,499				
Yes	179	10.7 (1.4)	645	8.8 (0.6)	0.211
No	1,320	89.3 (1.4)	6,456	91.2 (0.6)	

[a]Based on nonweighted data
[b]Based on weighted data

Table 6-3: Proportion of Women Receiving Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations by Maternal Demographic Characteristics

Table 3: Proportion of Women Receiving Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations by Maternal Demographic Characteristics

	Advice Started Below Recommendation	IOM-Consistent	Advice Ended Above Recommendation	Advice Not Remembered	Advice Not Received	
Characteristic	**% (SE)[a]**	**% (SE)[a]**	**% (SE)[a]**	**% (SE)[a]**	**% (SE)[a]**	***P***
Total	15.6 (0.8)	26.4 (0.9)	18.1 (0.8)	13.9 (0.8)	26.1 (0.9)	
Pre-Pregnancy BMI						
Underweight	22.3 (4.0)	37.9 (4.4)	1.9 (0.8)	13.9 (3.0)	24.1 (4.4)	<0.001
Normal Weight	24.1 (1.3)	29.1 (1.2)	8.6 (0.8)	12.9 (1.0)	25.4 (1.2)	
Overweight	4.9 (1.1)	18.2 (1.6)	33.9 (2.1)	14.9 (1.6)	28.2 (2.0)	
Obese	5.2 (1.2)	26.9 (2.2)	26.8 (2.2)	15.4 (2.0)	25.6 (2.2)	
Age (y)						
Younger than 19	20.8 (3.0)	21.8 (2.5)	22.3 (3.2)	16.1 (2.2)	19.1 (2.4)	0.047
20-24	16.1 (1.8)	23.6 (1.8)	19.2 (1.8)	13.5 (1.6)	27.6 (2.2)	
25-29	15.9 (1.5)	27.2 (1.5)	17.5 (1.4)	14.8 (1.5)	24.6 (1.6)	
30 or older	13.9 (1.2)	28.4 (1.5)	16.9 (1.3)	13.0 (1.3)	27.8 (1.5)	
Race-ethnicity						
Non-Hispanic White	15.4 (1.0)	28.4 (1.0)	17.7 (0.9)	11.1 (0.8)	27.4 (1.1)	0.001
Non-Hispanic Black	15.6 (2.8)	18.7 (3.0)	22.2 (3.2)	19.3 (2.9)	24.2 (3.2)	
Hispanic	16.3 (1.9)	26.9 (2.0)	16.3 (1.8)	18.8 (2.1)	21.7 (2.0)	
Other	15.8 (3.5)	20.8 (3.3)	16 (3.2)	20.4 (4.0)	27.0 (4.3)	
Education (y)						
Less than 12	14.1 (2.1)	20.1 (1.9)	16.8 (2.3)	22.7 (2.6)	26.3 (2.7)	<0.001
12	16.0 (1.8)	21.5 (1.7)	17.3 (1.7)	15.9 (1.7)	29.4 (2.2)	
More than 12	15.8 (1.0)	29.6 (1.1)	18.7 (1.0)	11.2 (0.9)	24.7 (1.1)	
Parity						
0	16.7 (1.4)	29.5 (1.4)	22.2 (1.4)	11.9 (1.1)	19.7 (1.3)	<0.001
1 or more	14.9 (1.0)	24.4 (1.1)	15.4 (1.0)	15.2 (1.1)	30.2 (1.3)	
WIC Enrollment						
Yes	16.3 (1.3)	23.2 (1.3)	18.0 (1.3)	17.8 (1.4)	24.7 (1.5)	<0.001
No	15.0 (1.0)	29.1 (1.1)	18.1 (1.0)	10.5 (0.8)	27.3 (1.1)	
Smoking status during pregnancy						
Nonsmoker	15.2 (0.9)	26.8 (1.0)	17.2 (0.9)	14.5 (0.9)	26.4 (1.0)	0.001
Quitter	16.5 (2.7)	29.4 (2.8)	24.7 (2.9)	12.5 (2.2)	17.0 (2.3)	
Smoker	17.4 (2.9)	19.6 (2.6)	17.8 (2.7)	11.1 (2.3)	34.1 (3.7)	
First trimester prenatal care						
Yes	15.8 (0.9)	27.4 (1.0)	18.2 (0.9)	13.2 (0.8)	25.4 (1.0)	0.003
No	14.1 (1.9)	19.8 (1.9)	17.2 (2.2)	18.2 (2.3)	30.7 (2.5)	
Marital status						
Married	14.6 (0.9)	28.6 (1.0)	18.4 (0.9)	11.9 (0.8)	26.6 (1.0)	<0.001

Nonmarried	17.7 (1.7)	21.7 (1.6)	17.5 (1.6)	18.2 (1.7)	25.0 (1.9)	
Hypertensive conditions						
Yes	10.2 (2.0)	27.2 (2.8)	20.4 (2.5)	18.5 (2.8)	23.9 (2.7)	0.031
No	16.3 (0.9)	26.3 (0.9)	17.8 (0.9)	13.3 (0.8)	26.4 (1.0)	
Diabetic disease						
Yes	13.5 (2.5)	21.8 (2.9)	18.7 (3.0)	17.9 (3.0)	28.2 (3.6)	0.334
No	15.8 (0.9)	26.8 (0.9)	18.0 (0.8)	13.5 (0.8)	25.9 (1.0)	

[a] Based on weighted data

Table 6-4: Adjusted Associations Between Healthcare Provider Advice Relative to 2009 IOM Recommendations and Gestational Weight Gain Below or Above Recommendations, Stratified by Pre-Pregnancy BMI Category

Table 4: Adjusted Associations Between Healthcare Provider Advice Relative to 2009 IOM Recommendations and Gestational Weight Gain Below or Above Recommendations, Stratified by Pre-Pregnancy BMI Category

	Underweight (n=339, [a] 3.9% [b])		Normal Weight (n=3,741, [a] 51.9% [b])		Overweight (n=1,708, [a] 24.1% [b])		Obese (n=1,313, [a] 20.1% [b])	
	Inadequate Weight Gain	Excessive Weight Gain	Inadequate Weight Gain	Excessive Weight Gain	Inadequate Weight Gain	Excessive Weight Gain	Inadequate Weight Gain	Excessive Weight Gain
Healthcare Provider Advice	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**
Advice started below recommendation	**2.22 (1.29–3.82)**	-- [c]	**1.57 (1.23–2.02)**	0.90 (0.71–1.13)	1.88 (0.87–4.05)	**1.32 (1.01–1.74)**	1.54 (0.86–2.74)	0.69 (0.35–1.39)
IOM-consistent	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*
Advice ended above recommendation	-- [c]	-- [c]	0.85 (0.52–1.36)	**1.34 (1.06–1.70)**	0.58 (0.28–1.20)	**1.42 (1.19–1.71)**	**0.49 (0.27–0.89)**	**1.38 (1.09–1.74)**
Advice not remembered	**1.87 (1.03–3.41)**	-- [c]	**1.50 (1.08–2.07)**	1.19 (0.94–1.51)	1.26 (0.58–2.73)	**1.29 (1.04–1.61)**	1.01 (0.59–1.72)	1.18 (0.86–1.62)
Advice not received	**1.99 (1.11–3.57)**	**2.08 (1.01–4.28)**	1.30 (0.99–1.70)	1.09 (0.90–1.31)	**2.03 (1.12–3.68)**	**1.23 (1.01–1.50)**	0.76 (0.49–1.18)	**1.28 (1.01–1.62)**

PR, prevalence ratio; CI, confidence interval.
Results are adjusted for covariates listed in Table 2.
Bold indicates statistically significant associations.
[a] Based on nonweighted data
[b] Based on weighted data
[c] Unable to estimate due to small sample sizes.

Table 6-5: Adjusted Associations Between Healthcare Provider Advice Relative to 2009 IOM Recommendations and Actual Gestational Weight Gain Below or Above Recommendations

Table 5: Adjusted Associations Between Healthcare Provider Advice Relative to 2009 IOM Recommendations and Actual Gestational Weight Gain Below or Above Recommendations

	Inadequate Weight Gain	Excessive Weight Gain
Healthcare Provider Advice	**PR (95% CI)**	**PR (95% CI)**
Starts below, ends below recommendations	**1.81 (1.28 – 2.56)**	0.94 (0.67 – 1.33)
Starts below, ends within recommendations	**1.49 (1.19 – 1.88)**	0.96 (0.81 – 1.15)
IOM-consistent	*Referent*	*Referent*
Starts within, ends above recommendations	0.69 (0.48 – 1.00)	**1.36 (1.19 – 1.55)**
Starts above, ends above recommendations	0.67 (0.34 – 1.35)	**1.50 (1.21 – 1.86)**
Advice not remembered	**1.32 (1.02 – 1.70)**	**1.21 (1.05 – 1.41)**
Advice not received	**1.26 (1.03 – 1.56)**	**1.17 (1.04 – 1.32)**

PR, prevalence ratio; CI, confidence interval.
Results are adjusted for covariates listed in Table 2.
Bold indicates statistically significant associations.

Figure 6-1: Categorization Scheme for Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations

Figure 1: Categorization Scheme for Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations

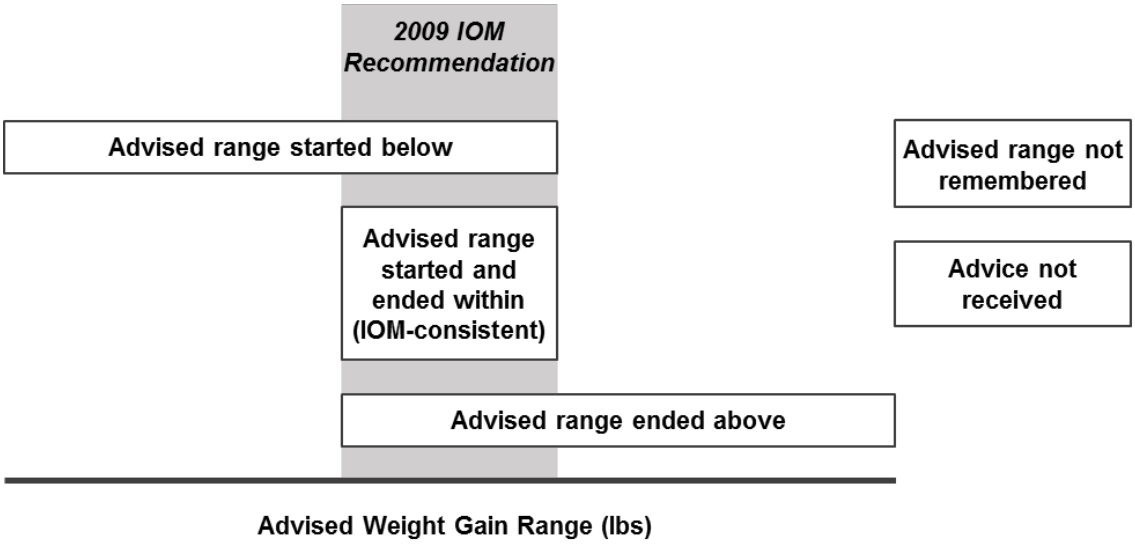
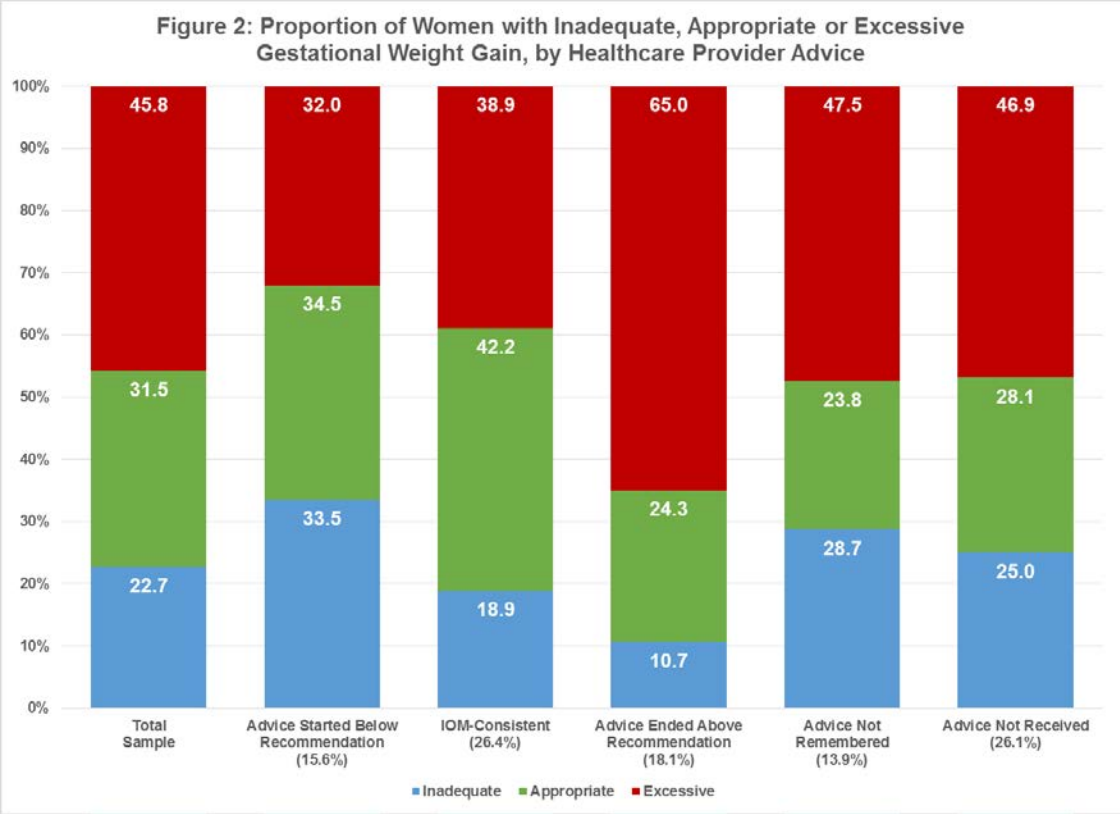


Figure 6-2: Proportion of Women with Inadequate, Appropriate or Excessive Gestational Weight Gain, by Healthcare Provider Advice



Supplementary Tables and Figures

Supplemental Digital Content, Table 1: Unadjusted Associations Between Healthcare Provider Advice Relative to 2009 IOM Recommendations and Gestational Weight Gain Below or Above Recommendations, Stratified by Pre-Pregnancy BMI Category

	Underweight (n=339[a], 3.9%[b])		**Normal Weight (n=3,741[a],51.9%[b])**		**Overweight (n=1,708[a], 24.1%[b])**		**Obese (n=1,313[a], 20.1%[b])**	
	Inadequate Weight Gain	**Excessive Weight Gain**	**Inadequate Weight Gain**	**Excessive Weight Gain**	**Inadequate Weight Gain**	**Excessive Weight Gain**	**Inadequate Weight Gain**	**Excessive Weight Gain**
Healthcare Provider Advice	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**	**PR (95% CI)**
Advice started below recomm-endation	**2.67 (1.49–4.78)**	**--[c]**	**1.82 (1.39 – 2.39)**	0.86 (0.68 – 1.09)	1.68 (0.71– 3.98)	**1.37 (1.03–1.81)**	1.50 (0.79 – 2.82)	0.68 (0.33 – 1.39)
IOM-consistent	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*	*Referent*
Advice ended above recomm-endation	**--[c]**	**--[c]**	0.94 (0.58–1.52)	**1.32 (1.05–1.66)**	0.50 (0.22–1.10)	**1.50 (1.24–1.82)**	**0.49 (0.26–0.91)**	**1.34 (1.06 – 1.71)**
Advice not remembered	**2.14 (1.09 – 4.18)**	**--[c]**	**1.96 (1.44 – 2.66)**	1.07 (0.84 – 1.38)	1.26 (0.54 – 2.95)	**1.31 (1.03– 1.65)**	1.08 (0.62 – 1.86)	1.12 (0.81 – 1.55)
Advice not received	**2.19 (1.11 – 4.30)**	2.26 (0.87 – 5.89)	**1.49 (1.13 – 1.96)**	1.04 (0.86 – 1.26)	**2.03 (1.01 – 4.08)**	1.20 (0.96 – 1.50)	0.79 (0.49 – 1.26)	1.23 (0.96 – 1.58)

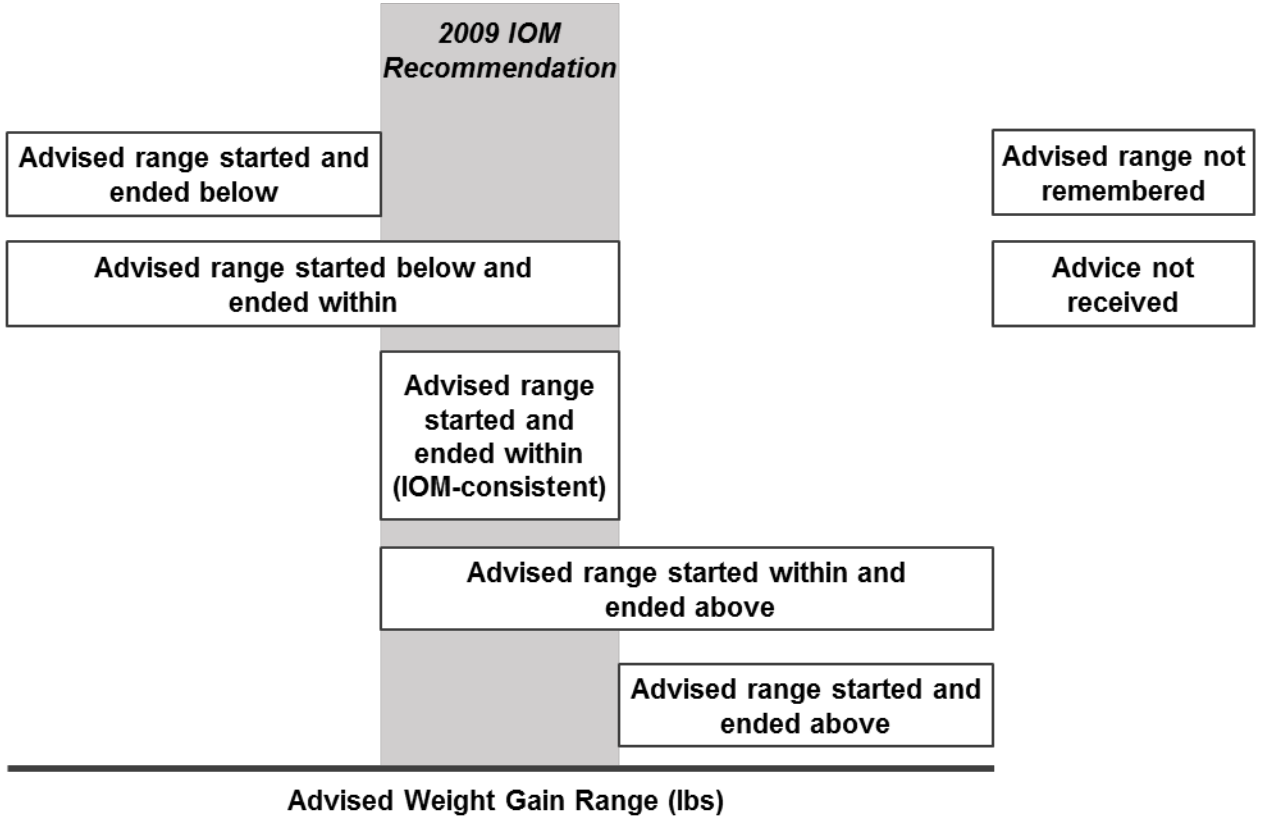
PR, prevalence ratio; CI, confidence interval.
Bold indicates statistically significant associations.
[a] Based on nonweighted data
[b] Based on weighted data
[c] Unable to estimate due to small sample sizes.

Supplemental Digital Content, Table 2: Unadjusted Associations Between Healthcare Provider Advice Relative to 2009 IOM Recommendations and Actual Gestational Weight Gain Below or Above Recommendations

	Inadequate Weight Gain	**Excessive Weight Gain**
Healthcare Provider Advice	**PR (95% CI)**	**PR (95% CI)**
Starts below, ends below recommendations	**2.36 (1.69 – 3.28)**	0.74 (0.48 – 1.13)
Starts below, ends within recommendations	**1.58 (1.24 – 2.02)**	0.85 (0.69 – 1.05)
IOM-consistent	*Referent*	*Referent*
Starts within, ends above recommendations	**0.55 (0.38 – 0.80)**	**1.63 (1.44 – 1.84)**
Starts above, ends above recommendations	0.61 (0.31 – 1.21)	**1.81 (1.52 – 2.16)**
Advice not remembered	**1.52 (1.18 – 1.95)**	**1.22 (1.04 – 1.42)**
Advice not received	**1.33 (1.07 – 1.65)**	**1.20 (1.06 – 1.37)**

PR, prevalence ratio; CI, confidence interval.
Bold indicates statistically significant associations.

Supplemental Figure 1: Categorization Scheme for Healthcare Provider Advice Relative to 2009 Institute of Medicine Recommendations: Expanded, 7-Level Variable



Chapter 7 - Pre-Pregnancy Body Mass Index and Gestational Weight Gain: How Well do the Birth Certificate and Pregnancy Risk Assessment Monitoring System Agree with the Medical Record?

Authors: Nicholas P. Deputy, Andrea J. Sharma, Jennifer Bombard, Timothy L. Lash, Laura Schieve, Usha Ramakrishnan, Aryeh D. Stein, Michael Nyland-Funke

Affiliations: Nutrition and Health Sciences Program, Laney Graduate School, Emory University, Atlanta, GA (Mr. Deputy, Dr. Sharma, Dr. Ramakrishnan, Dr. Stein); Department of Epidemiology, Rollins School of Public Health, Emory University, Atlanta, GA (Dr. Lash); National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, GA (Mr. Deputy, Dr. Sharma, Ms. Bombard); National Center for Birth Defects and Developmental Disabilities, Centers for Disease Control and Prevention, Atlanta, GA (Dr. Schieve); U.S. Public Health Service Commissioned Corps, Atlanta, GA (Dr. Sharma); Vermont Department of Public Health (Mr. Nyland-Funke).

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Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the CDC.

Abstract

Background: The 2003 birth certificate and Pregnancy Risk Assessment Monitoring System (PRAMS) are important for surveillance and research. To evaluate data quality, we compared pre-pregnancy body mass index (BMI), gestational weight gain and component variables from these sources to medical record data, considered the standard.

Methods: For 1,267 New York City and Vermont PRAMS respondents in 2009, we compared height, pre-pregnancy weight and delivery weight from the birth certificate, and height and pre-pregnancy weight from PRAMS to medical record. We calculated mean and distribution of differences. We calculated agreement and the κ statistic for pre-pregnancy BMI categories from the birth certificate or PRAMS compared to medical record, and for gestational weight gain categories from the birth certificate compared to medical record. We also evaluated data quality by maternal and infant characteristics.

Results: Pre-pregnancy weight from the birth certificate and PRAMS were within 2.3 kg (5 lb) of the medical record for 75% and 68% of women, respectively. Delivery weight and gestational weight gain from the birth certificate were within 2.3 kg of the medical record for 80% of and 64% of women, respectively. Compared to the medical record, agreement in pre-pregnancy BMI categories from the birth certificate and PRAMS was 87% (κ=0.79) and 84% (κ=0.73), respectively; agreement in gestational weight gain categories from the birth certificate was 70% (κ=0.54). Data quality varied by characteristics. **Conclusions:** Pre-pregnancy BMI and gestational weight gain from the birth certificate and PRAMS are subject to misclassification. Our results can inform approaches to adjust for misclassification.

Introduction

Pre-pregnancy weight and gestational weight gain have important health implications for mothers and infants. Pre-pregnancy obesity (body mass index (BMI) $\geq$ 30 kg/m^2) is a risk-factor for adverse pregnancy and developmental outcomes.[1] Gestational weight gain outside Institute of Medicine (IOM) recommendations, also carries risk. Gaining below recommendations is associated with infants born small-for-gestational age while gaining above recommendations is associated with infants born large-for-gestational age, maternal postpartum weight retention and other outcomes.[2,3]

It is a national priority to monitor trends in pre-pregnancy BMI and gestational weight gain and to research determinants and health outcomes associated with maternal weight in large, diverse populations.[3,4] The 2003 revision of the US certificate of live birth (revised birth certificate) and the Pregnancy Risk Assessment Monitoring System (PRAMS) are data systems frequently used to address these needs. The revised birth certificate collects data on maternal height, pre-pregnancy weight and delivery weight; the previous (1989) birth certificate version collected only total gestational weight gain, which precluded assessment of pre-pregnancy obesity or gestational weight gain relative to IOM recommendations.[5] The revised birth certificate was adopted by 27 states by 2008 and national adoption was completed in 2016. PRAMS is a multistate surveillance system developed in 1987 that combines select birth certificate data with questionnaire data; the questionnaire assesses many pregnancy-related behaviors and characteristics, including height and pre-pregnancy weight.[6] PRAMS is essential for examining pre-

pregnancy obesity and gestational weight gain relative to recommendations in states that had not yet adopted the revised birth certificate.

Our objective was to assess data quality of pre-pregnancy BMI and gestational weight gain, and component variables, recorded on the revised birth certificate or PRAMS questionnaire by comparing these data to information abstracted from medical records, which we considered the standard. Data quality was also assessed by maternal and infant characteristics.

Methods

Study population

Data for this analysis are from a PRAMS data quality study. The PRAMS is a multistate surveillance system jointly administered by the Centers for Disease Control and Prevention (CDC) and state or local governments.[6] Mothers are sampled monthly through stratified random sampling of infants' birth certificates and are asked to complete a questionnaire or telephone interview approximately four months postpartum. Questionnaire data are linked to birth certificate items. Data from PRAMS are weighted to provide representative estimates of women delivering a live birth in each jurisdiction.

Details of the PRAMS data quality study have been previously reported.[7,8] Briefly, two PRAMS sites, New York City and Vermont, were funded to conduct the study. Medical record data were abstracted from 41 hospitals in New York City for PRAMS respondents who delivered infants from January 1 through June 4, 2009 (603 respondents, weighted to

represent 65,843 women; weighted response rate 67.3%). Medical record data were abstracted from 12 hospitals in Vermont and one in central New Hampshire along Vermont's border for PRAMS respondents who delivered from January 1 through August 31, 2009 (664 respondents, weighted to represent 3,700 women; weighted response rate 82%). Data abstraction was completed by trained abstractors using standardized forms. Errors in abstracted medical record variables were estimated to be less than 3%. The data quality study was deemed exempt from review by Institutional Review Boards in both New York City and Vermont because each state's public health agency has authority to review medical records for public health surveillance purposes.

Variables of interest

Both New York City and Vermont had adopted the revised birth certificate by 2009; thus, from the birth certificate, we assessed data quality of variables needed to compute pre-pregnancy BMI and gestational weight gain. The National Center for Health Statistics (NCHS) provides standard instructions for completing the revised birth certificate, including preferred and alternate sources for data items.[9] The preferred source for height and pre-pregnancy weight is mothers' self-report around the time of delivery; alternatively, data may be abstracted from prenatal care records. The preferred source for delivery weight is abstraction from labor and delivery medical records, which may be measured upon hospital admission, self-reported around delivery, or abstracted from the last measured weight during prenatal care.

From the PRAMS questionnaire, we assessed maternal height and pre-pregnancy weight variables used to compute pre-pregnancy BMI. The PRAMS questionnaire does not ascertain delivery weight.

We assessed quality of maternal height and weight data from the birth certificate and PRAMS questionnaire by comparing these data to information abstracted from medical records. From the medical record, height was abstracted from measured or self-reported values recorded in prenatal care or labor and delivery records. Pre-pregnancy weight was abstracted from self-reported values in prenatal care or labor and delivery records; if self-reported values were unavailable, the earliest measured weight recorded in prenatal records within eight weeks of pregnancy was used as a proxy for pre-pregnancy weight (n=72). Delivery weight was abstracted from labor and delivery records; if values were unavailable, the last weight measured weight recorded in prenatal records within two weeks of delivery was used as a proxy for delivery weight (n=75).

For each data source, we computed pre-pregnancy BMI (pre-pregnancy weight [kg]/height[m]^2) and categorized women as underweight (BMI< 18.5), normal weight (BMI 18.5 to <25.0), overweight (BMI 25.0 to <30.0), or obese (BMI $\geq$ 30.0).[10] For the birth certificate and medical record, we calculated gestational weight gain (delivery weight – pre-pregnancy weight) and categorized weight gain as below, within or above the 2009 IOM recommendations: 12.5-18.0 kg for underweight women, 11.5-16.0 kg for normal-weight women, 7.0-11.5 kg for overweight women, and 5.0-9.0 kg for obese women.[3]

Maternal and infant characteristics came from the birth certificate, unless otherwise specified.

Statistical analysis

We compared characteristics of PRAMS respondents included in the data quality study to respondents not included (i.e. women who delivered infants after June 4 or September 1, 2009, for New York City and Vermont, respectively).

For all variables, we calculated mean differences and corresponding 95% confidence intervals (CIs) between sources (birth certificate – medical record or PRAMS questionnaire – medical record) and categorized differences as underreporting, reporting within or over-reporting by 2.5 cm (1 in), 2.3 kg (5 lbs), or 1 BMI unit. For weight variables reported on the birth certificate, we further calculated the proportion of women reporting within 1.1 kg (2.5 lbs). We assessed overall agreement in pre-pregnancy BMI categories (birth certificate or PRAMS questionnaire compared to medical record), and in gestational weight gain categories (birth certificate compared to medical record), by calculating crude agreement and using the κ statistic to account for chance agreement.

We assessed quality of maternal height and weight variables (both continuous and categorized variables) by maternal demographic, behavioral, and infant characteristics. Chi-Square square tests were used to evaluate statistically significant differences in the distribution of under- or over-reporting by characteristics. We also calculated pre-

pregnancy BMI and gestational weight gain using combinations of height, pre-pregnancy weight and/or delivery weight from the medical record, birth certificate or PRAMS questionnaire to understand which variables and data sources contributed to misclassification of pre-pregnancy BMI or gestational weight gain categories.

Data from New York City and Vermont were combined for all analyses to enhance sample size (n=1,267). We removed three records from all analyses due to implausible gestational weight gain values recorded on medical records (weight loss greater than 18.1 kg [40 lbs] or weight gain greater than 90.7 kg [200 lb]). Due to missing data from the medical record, birth certificate or PRAMS questionnaire, sample sizes vary by each height or weight variable assessed; the subset of respondents with complete data on height and weight variables (n=633) were examined in sensitivity analyses. As the 2009 IOM recommendations were developed for full-term, singleton pregnancies, we examined gestational weight gain categories only among this subgroup of women (n=521). Statistical significance was considered $P<0.05$. We used SAS 9.3 with SAS-callable SUDAAN 11 for analyses to account for the complex sample design and weights utilized in PRAMS.

Results

Characteristics of women included in the data quality study were similar to those not included in that most women were 30–34 years old, had more than 12 years of education, were Hispanic, married, and entered prenatal care in the first trimester (Supplemental Table 1). Compared with women not included, those included were shorter, had a higher

pre-pregnancy BMI, had less gestational weight gain based on the birth certificate values and were more likely to report smoking during pregnancy.

Mean differences in height or weight values from the birth certificate or PRAMS questionnaire, compared with medical record, were small (less than 1cm or 1kg) (Table 1). Pre-pregnancy weights from the birth certificate and PRAMS questionnaire were within 2.3 kg of the medical record for 75% and 68% of women, respectively; under-reporting was more common on the PRAMS questionnaire than on the birth certificate. Delivery weight from the birth certificate was within 2.3 kg of the medical record for 80% of women, whereas gestational weight gain was within 2.3 kg of the medical record for 64%. On the birth certificate, agreement within 1.1 kg of the medical record was 56%, 70% and 44% for pre-pregnancy weight, delivery weight, and gestational weight gain, respectively (data not shown).

Under- and over-reporting in maternal height and weight varied by demographic, behavioral and infant characteristics (Supplemental Tables 2-6). For example, on the PRAMS questionnaire, the proportion of women under-reporting pre-pregnancy weight increased as pre-pregnancy BMI (classified by the medical record) increased (Figure 1). Additionally, on both the birth certificate and PRAMS questionnaire, a higher proportion of women who delivered small-for-gestational age infants under-reported pre-pregnancy weight compared with women delivering average- or large-for-gestational age infants (Figure 2 and 3 and Supplemental Table 3).

Overall, the birth certificate and medical record classified 87% (κ =0.79) of women into the same pre-pregnancy BMI category (Table 2); the birth certificate classified more women as obese and fewer women as overweight or normal weight. The PRAMS questionnaire and medical record classified 84% (κ =0.73) of women into the same pre-pregnancy BMI category (Table 2); PRAMS classified more women as obese and fewer women as overweight. Error in pre-pregnancy weight, rather than height, drove misclassification of pre-pregnancy BMI category for both the birth certificate and PRAMS (data not shown). Among women delivering full-term singleton infants, the birth certificate and medical record classified 70% (κ=0.54) into the same gestational weight gain category (Table 3); the birth certificate classified more women as gaining below recommendations, and fewer women as gaining within recommendations. Error in pre-pregnancy weight and delivery weight made approximately equal contributions to misclassification of gestational weight gain categories (Supplemental Table 7).

Agreement in calculated pre-pregnancy BMI category and gestational weight gain category also varied by maternal demographic, behavioral and infant health characteristics (Supplemental Tables 8-10). For example, on the birth certificate, agreement in pre-pregnancy BMI category was lower for women who delivered small-for-gestational age infants compared with women who delivered average- or large-for-gestational age infants.

Sensitivity analyses showed that women with complete data (n=633) were more likely to be non-Hispanic white, married, enter prenatal care in the first trimester, and participate

in Medicaid compared to those with missing data (data not shown); however, we found no meaningful differences in results when restricting to women with complete height or weight data (Table 1 and Supplemental Table 11).

Discussion

In this study, we used representative data from two PRAMS sites to examine the quality of maternal height and weight data reported on the revised birth certificate and PRAMS questionnaire. Compared to the medical record, the birth certificate and PRAMS questionnaire misclassified pre-pregnancy BMI category for 13% and 16% of women, respectively; additionally, the birth certificate misclassified gestational weight gain category for 30%. For the birth certificate and PRAMS questionnaire, error in pre-pregnancy weight, rather than height, drove misclassification of pre-pregnancy BMI, whereas error in both pre-pregnancy weight and delivery weight contributed to misclassification of gestational weight gain category.

Findings from this study have implications for surveillance activities. National adoption of the revised birth certificate was completed in 2016; thus, the birth certificate is poised to become the primary data source for monitoring pre-pregnancy obesity in the US. Our finding that fewer women were misclassified in pre-pregnancy BMI category by the birth certificate than the PRAMS questionnaire supports the use of birth certificate data for this surveillance purpose. As PRAMS combines birth certificate and questionnaire data, our finding may support decisions to source self-reported height and pre-pregnancy weight from the revised birth certificate rather than ascertain these data on the questionnaire; however, research in other jurisdictions may be needed to inform this decision.

Misclassification of categorical variables, such as pregnancy BMI or gestational weight gain category, may bias study results.[11] While it is common to qualitatively assess the influence of misclassification bias,[12] results from our study can quantitatively inform methods that assess and adjust for misclassification of pre-pregnancy BMI and gestational weight gain category. Specifically, probabilistic bias analysis methods simulate data using classification parameters and Monte Carlo sampling techniques; simulated data represent data that would have been observed had there been no misclassification, given the specified parameters.[13] Classification parameters are informed by validation studies; in our study, tables comparing the classification of pre-pregnancy BMI and gestational weight category from the birth certificate or PRAMS questionnaire, compared to medical records, can be used to inform these parameters.

Generally, we found less reporting error in pre-pregnancy weight and BMI reported on the revised birth certificate than has been previously observed. A study of Florida women enrolled in the Women, Infants and Children Program in 2005 found the birth certificate underestimated pre-pregnancy weight by nearly 2 kg compared to measured first trimester weights; overall, 75% of women were classified into correct pre-pregnancy BMI categories.[14] A study examining births from 2003 to 2010 at one Pennsylvania hospital found pre-pregnancy weight reported on the birth certificate was within 2.3 kg of self-reported pre-pregnancy weight from the medical record for 41% to 67% of women, depending on pre-pregnancy BMI category; agreement in pre-pregnancy BMI categories varied from 52% to 100% depending on pre-pregnancy BMI, race and gestational age.[15]

Differences between our findings and these previous studies may be explained by different study populations or different reference data; for example, the Florida study compared pre-pregnancy weight from the birth certificate to weight measured in the first trimester whereas our study primarily used self-reported pre-pregnancy weight in the first trimester as a referent. Continual evaluation of maternal height and weight variables reported on the birth certificate that use consistent reference measures is needed to ensure data quality.

Among women delivering full-term, singleton infants, only 70% were classified into correct gestational weight gain categories. Both pre-pregnancy weight and delivery weight contributed to misclassification of gestational weight gain categories, suggesting quality improvement efforts may need to focus on both variables. It may be more feasible to improve quality of delivery weight as this variable is frequently measured upon hospital admission prior to delivery. Indeed, we found delivery weight was more frequently reported within 1.1 kg and 2.3 kg of the medical record than pre-pregnancy weight; when delivery weight was misreported, it was more often under- than over-reported, which may indicate delivery weight was abstracted from measured weights earlier in pregnancy. For both pre-pregnancy weight and delivery weight – and many birth certificate variables – implementation of electronic medical record systems that securely transfer standardized data information to vital record systems will likely improve data quality. The NCHS along with the National Association for Public Health Statistics and Information Systems (NAPHSIS) and state and local jurisdictions have worked to develop data standards and establish electronic birth registration systems.[16]

Future studies may be needed to evaluate these efforts and to identify additional strategies that promote data quality.

Measured weight from the preconception period would be an ideal reference to compare self-reported pre-pregnancy weight from the birth certificate and PRAMS questionnaire; unfortunately, these data were not available in this study. While pre-pregnancy weight from the medical record is self-reported closer to the preconception period than weight self-reported on the birth certificate or PRAMS questionnaire, it may underestimate preconception weight by 0.4-1.6 kg;[17,18] furthermore, weight measured in the first trimester and recorded on medical records may reflect true first trimester weight gain. Missing data from the medical record, birth certificate, or PRAMS questionnaire caused sample sizes to vary by height and weight variables; however, overall results were consistent between those with and without complete data. Despite these limitations, our study is strengthened by the use of a large dataset representative of New York City and Vermont mothers who gave birth in the first six to eight months of 2009.

In summary, we found better agreement in pre-pregnancy BMI category from the birth certificate than PRAMS questionnaire when compared to medical record and agreement in gestational weight gain category was lower than agreement in pre-pregnancy BMI. Studies are needed that continually evaluate maternal height and weight data on the birth certificate and identify strategies for quality improvement. Importantly, results from this study can be used to inform bias analyses that adjust for misclassification of pre-pregnancy BMI or gestational weight gain category.

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Tables and Figures

Table 7-1: Mean and Distribution of Reporting Error in Maternal Height and Weight Data Reported on the Birth Certificate or PRAMS Questionnaire

Table 1: Mean and Distribution of Reporting Error in Maternal Height and Weight Data Reported on the Birth Certificate or PRAMS Questionnaire Compared to the Medical Record

	Medical Record		Birth Certificate				PRAMS Questionnaire			
				Distribution of Reporting Error (%)				Distribution of Reporting Error (%)		
	n	Mean (95% CI)	Mean[a] Difference (95% CI)	Under-report[b]	Consistent report[c]	Over-report[d]	Mean[a] Difference (95% CI)	Under-report[b]	Consistent report[c]	Over-report[d]
Height (cm)	1134	161.4 (160.7, 162.1)	0.3 (0.0, 0.7)	3.7	89.4	6.9	0.1 (-0.3, 0.6)	4.7	86.8	8.5
Pre-pregnancy weight (kg)	784	64.8 (63.1, 66.5)	0.3 (-0.5, 1.1)	14.1	75.4	10.6	-0.3 (-1.2, 0.6)	20.1	68.4	11.6
Pre-pregnancy BMI (kg/m2)	734	25.1 (24.4, 25.8)	0.2 (-0.2, 0.6)	18.5	68.6	12.9	-0.2 (-0.6, 0.2)	26.3	59.3	14.3
Delivery weight (kg)	1039	79.9 (78.2, 81.7)	-0.7 (-1.5, 0.0)	13.1	80.2	6.7	--[e]	--	--	--
Gestational weight gain (kg)	678	13.1 (12.2, 13.9)	-0.5 (-1.3, 0.3)	19.7	64.3	16.0	--	--	--	--

[a]Mean difference calculated as Birth Certificate or PRAMS Questionnaire – Medical Record

[b]Underreport by >2.5cm (for height), >2.3kgs (for pre-pregnancy weight, delivery weight, gestational weight gain) and >1 kg/m^2 (for pre-pregnancy BMI)

[c] Consistent reporting refers to report within by ±2.5cm (for height), ±2.3kgs (for pre-pregnancy weight, delivery weight, gestational weight gain) and ±1 kg/m^2 (for pre-pregnancy BMI)

[d]Over-report >2.5cm (for height), >2.3kgs (for pre-pregnancy weight, delivery weight, gestational weight gain) and >1 kg/m^2 (for pre-pregnancy BMI)

[e]Data not collected on the PRAMS Questionnaire

Table 7-2: Agreement in Pre-Pregnancy BMI Classification by Birth Certificate or PRAMS Questionnaire

Table 2: Agreement in Pre-Pregnancy BMI Classification by Birth Certificate or PRAMS Questionnaire Compared to Medical Record (n=734)

	Medical Record Classification				
	Underweight (%)	**Normal Weight (%)**	**Overweight (%)**	**Obese (%)**	***Row Total (%)***
Birth Certificate Classification[a]					
Underweight	2.9	1.2	0.0	0.0	*4.1*
Normal Weight	0.9	48.5	2.2	0.1	*51.6*
Overweight	0.0	2.7	22.2	0.8	*25.7*
Obese	0.0	1.1	3.9	13.7	*18.6*
Column Total	*3.8*	*53.5*	*28.2*	*14.5*	
PRAMS Questionnaire Classification[b]					
Underweight	2.8	1.4	0.8	0.0	*4.9*
Normal Weight	1.0	47.9	5.6	0.1	*54.7*
Overweight	0.0	2.1	19.6	1.1	*22.8*
Obese	0.0	2.1	2.3	13.3	*17.6*
Column Total	*3.8*	*53.5*	*28.2*	*14.5*	

[a]Overall agreement between birth certificate and medical record classification of pre-pregnancy BMI category is 87.3% (κ=0.79)

[b]Overall agreement between PRAMS questionnaire and medical record classification of pre-pregnancy BMI category is 83.6% (κ=0.73)

Table 7-3: Agreement in Gestational Weight Gain Classification by Birth Certificate

Table 3: Agreement in Gestational Weight Gain Classification by Birth Certificate Compared to Medical Record for Full-Term, Singleton Pregnancies (n=521)

	Medical Record Classification			
	Below Recommendations (%)	**Within Recommendations (%)**	**Above Recommendations (%)**	***Row Total (%)***
Birth Certificate Classification				
Below Recommendations	17.6	11.2	2.2	*30.9*
Within Recommendations	5.2	18.7	4.1	*28.0*
Above Recommendations	1.6	6.0	33.5	*41.1*
Column Total	*24.4*	*35.9*	*39.8*	

[a]Overall agreement between birth certificate and medical record classification of gestational weight gain categories is 69.8% (κ=0.54)

Figure 7-1: Distribution of Reporting Difference in Pre-Pregnancy Weight from PRAMS Questionnaire Compared to Medical Record (%)

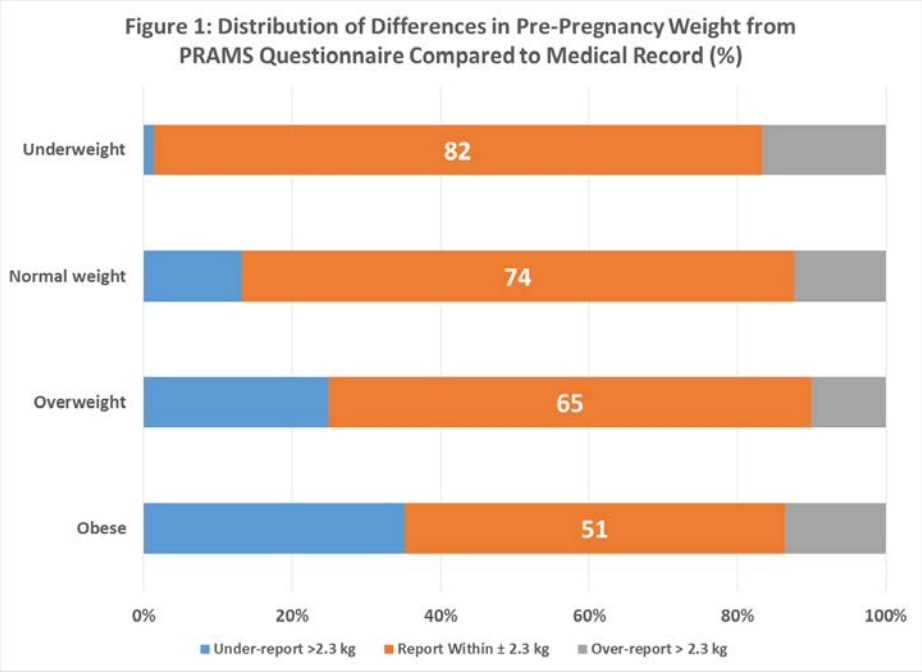


Figure 7-2: Distribution of Differences in Pre-Pregnancy Weight from Birth Certificate Compared to Medical Record, by Infant Birth Weight (%)

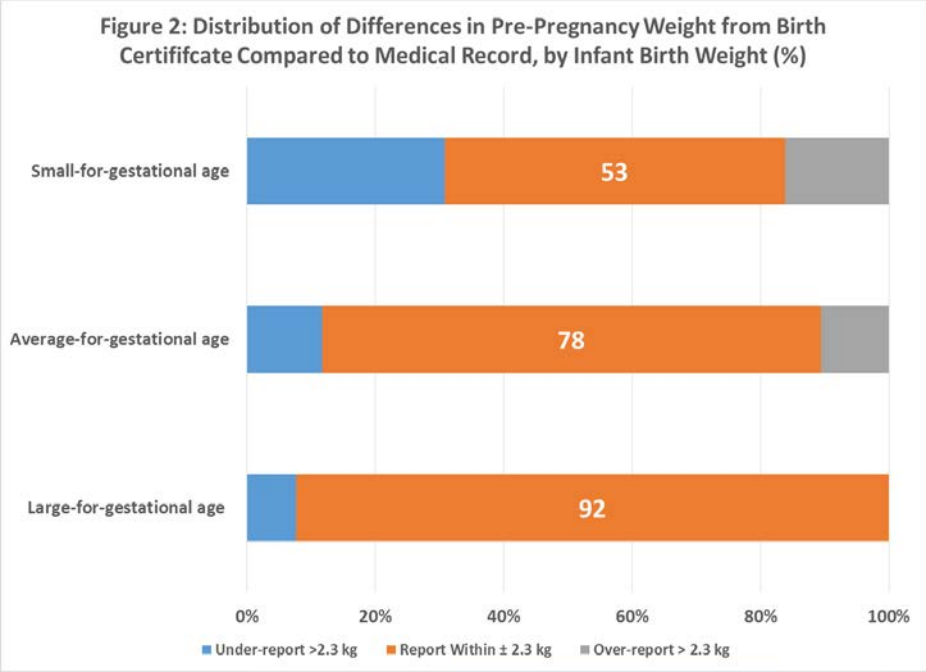
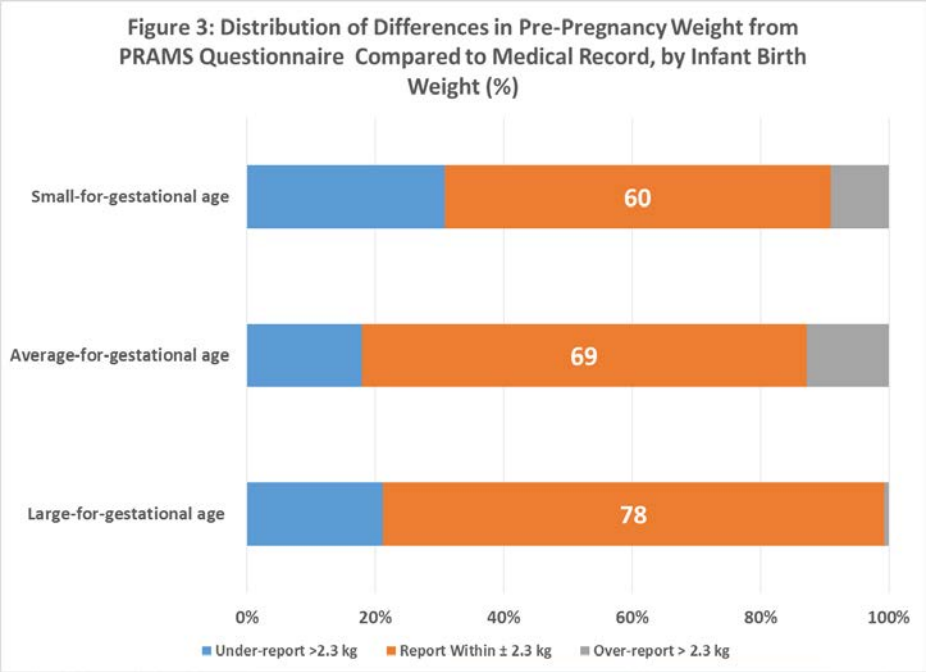


Figure 7-3: Distribution of Differences in Pre-Pregnancy Weight from PRAMS Questionnaire Compared to Medical Records, by Infant Birth Weight (%)



Supplementary Tables

Supplemental Table 1: Characteristics of 2009 New York City and Vermont PRAMS Participants by Involvement in Data Quality Study

Characteristic[b]	Data Quality Study Sub-Sample (n=1,264[a]) Mean (SE) or Un-weighted N (%)	Non Data Quality Study Sub-Sample (n=1,198[a]) Mean (SE) or Un-weighted N (%)	*P*
Height (cm)			
Birth Certificate	161.5 (0.3)	162.4 (0.3)	0.04
PRAMS Questionnaire	161.7 (0.3)	162.6 (0.3)	0.06
Pre-Pregnancy Weight (kg)			
Birth Certificate	66.4 (0.7)	65.3 (0.6)	0.26
PRAMS Questionnaire	65.6 (0.8)	64.9 (0.8)	0.50
Pre-Pregnancy BMI (kg/m$^{2)}$			
Birth Certificate	25.5 (0.3)	24.7 (0.2)	0.02
PRAMS Questionnaire	25.2 (0.3)	24.6 (0.3)	0.11
Delivery Weight (kg)			
Birth Certificate	78.8 (0.8)	79.4 (0.7)	0.54
Gestational Weight Gain (kg)			
Birth Certificate	12.6 (0.3)	14.0 (0.3)	<0.01
Maternal age			
< 20 years	68 (6.8)	64 (5.9)	0.43
20-24 years	277 (22.7)	218 (19.4)	
25-29 years	334 (24.6)	316 (24.5)	
30-34 years	334 (28.1)	331 (28.3)	
≥ 35 years	251 (17.8)	269 (21.9)	
Maternal education			
< 12 years	189 (23.8)	187 (21.7)	0.75
12 years	319 (26.1)	314 (26.5)	
> 12 years	753 (50.1)	691 (51.8)	
Race/ethnicity			
Non-Hispanic White	745 (27.4)	574 (31.0)	0.14
Non-Hispanic Black	149 (19.7)	180 (19.4)	
Hispanic	226 (38.1)	273 (31.7)	
Mixed or Other Race	144 (14.7)	171 (17.9)	
Marital status			
Married	752 (54.9)	678 (55.8)	0.77
Non-married	511 (45.1)	518 (44.2)	
Parity			
0	637 (46.1)	567 (46.3)	0.95
≥ 1	624 (53.9)	629 (53.7)	
Singleton			
Yes	1199 (98.5)	1127 (98.1)	0.48
No	65 (1.5)	71 (1.9)	
First trimester prenatal care			
Yes	993 (77.6)	931 (78.3)	0.82
No	183 (22.4)	198 (21.7)	
WIC enrollment			
Yes	620 (57.6)	617 (59.4)	0.56
No	633 (42.4)	569 (40.6)	
WIC enrollment[d]			
Yes	624 (56.5)	615 (58.4)	0.56
No	634 (43.5)	572 (41.6)	
Medicaid enrollment			
Yes	652 (60.0)	641 (58.3)	0.58

No	608 (40.0)	554 (41.7)	
Medicaid enrollment[d]			
Yes	581 (54.2)	562 (50.9)	0.30
No	683 (45.8)	625 (49.1)	
Any smoking during pregnancy			
Yes	128 (2.6)	75 (1.1)	0.03
No	1134 (97.4)	1117 (98.9)	
Smoking in last 3 months of pregnancy[d]			
Yes	155 (5.4)	94 (2.8)	0.03
No	1089 (94.6)	1084 (97.2)	
Gestational diabetes			
Yes	52 (4.1)	63 (4.2)	0.95
No	1202 (95.9)	1131 (95.8)	
Gestational diabetes[d]			
Yes	105 (9.5)	136 (11.8)	0.26
No	1151 (90.5)	1052 (88.2)	
Pre-gestational or gestational diabetes			
Yes	61 (4.7)	68 (5.2)	0.74
No	1198 (95.3)	1130 (94.8)	
Pre-gestational or gestational diabetes[d]			
Yes	123 (11.0)	151 (13.2)	0.29
No	1139 (89.0)	1047 (86.8)	
Gestational hypertension			
Yes	71 (3.0)	74 (2.6)	0.67
No	1187 (97)	1124 (97.4)	
Any hypertensive conditions before or during pregnancy			
Yes	106 (3.9)	109 (4.4)	0.68
No	1153 (96.1)	1089 (95.6)	
Any hypertensive conditions before or during pregnancy[d]			
Yes	179 (9.6)	182 (8.5)	0.49
No	1055 (90.4)	993 (91.5)	
Preterm birth			
Yes	295 (8.0)	328 (8.5)	0.72
No	969 (92)	869 (91.5)	
Birth Weight			
Small-for-gestational age	250 (12.4)	254 (10.8)	0.70
Average-for-gestational age	858 (80.6)	808 (82.3)	
Large-for-gestational age	89 (7.0)	63 (6.9)	

[a]Sample sizes may vary due to missing data for each characteristic
[b]All characteristics are derived from birth certificate unless otherwise noted
[c]Derived from medical record
[d]Derived from PRAMS questionnaire

Supplemental Table 2: Mean and distribution of reporting error between height from the birth certificate or PRAMS questionnaire compared with medical record, stratified by covariates of interest

	Medical Record		Birth Certificate					PRAMS Questionnaire				
				Distribution of Reporting Error (%)					Distribution of Reporting Error (%)			
Characteristic[a]	n	Mean (95% CI)	Mean Difference (95% CI)	Under-report >2.5 cm	Report within ±2.5 cm	Over-report >2.5 cm	*P*	Mean Difference (95% CI)	Under-report >2.5 cm	Report within ±2.5 cm	Over-report >2.5 cm	*P*
Overall	*1134*	*161.4 (160.7, 162.1)*	*0.3 (0.0, 0.7)*	*3.7*	*89.4*	*6.9*		*0.1 (-0.3, 0.6)*	*4.7*	*86.8*	*8.5*	
Pre-pregnancy BMI[b]	752											
Underweight	31	166.1 (161.1, 171.0)	-1.0 (-2.2, 0.1)	8.1	91.9	0.0	0.07	-1.1 (-2.4, 0.1)	7.2	92.8	0.0	< 0.01
Normal weight	395	162.1 (160.9, 163.3)	0.5 (-0.1, 1.1)	2.8	87.5	9.7		0.6 (0.0, 1.3)	2.1	87.8	10.0	
3.Overweight	180	160.3 (158.0, 162.6)	-0.1 (-1.4, 1.1)	3.9	91.8	4.3		0.2 (-1.2, 1.5)	8.6	78.9	12.4	
4.Obese	146	161.3 (158.9, 163.7)	0.1 (-0.5, 0.7)	4.6	93.9	1.5		0.4 (-0.2, 0.9)	0.9	96.8	2.3	
Maternal age	1134											
< 20 years	63	160 (157.9, 162.0)	-0.9 (-2.8, 1.0)	12.3	83.6	4.0	0.61	0.4 (-1.8, 2.7)	15.7	71.3	13.0	< 0.01
20-24 years	238	161.1 (159.7, 162.4)	0.4 (0.0, 0.9)	2.5	92.5	5.0		-0.6 (-1.5, 0.4)	4.8	94.2	1.0	
25-29 years	305	162.1 (160.6, 163.5)	0.1 (-0.8, 1.0)	5.8	85.0	9.3		-0.3 (-1.1, 0.5)	7.9	83.1	9.1	
30-34 years	304	160.9 (159.5, 162.4)	0.5 (0.0, 1.1)	1.6	91.3	7.2		0.6 (-0.1, 1.3)	1.6	85.9	12.6	
≥ 35 years	224	162.3 (160.7, 163.9)	0.6 (0.1, 1.0)	2.2	91.2	6.5		0.7 (0.1, 1.2)	1.2	91.3	7.5	
Maternal education	1132											
< 12 years	158	158.3 (156.7, 159.9)	0.4 (-0.6, 1.5)	7.2	81.7	11.0	0.01	0.6 (-0.5, 1.7)	11.4	70.7	18.0	< 0.01
12 years	292	160.2 (158.9, 161.5)	0.7 (0.2, 1.3)	2.2	86.3	11.5		-0.2 (-1.1, 0.8)	4.1	85.0	10.9	
> 12 years	682	163.4 (162.5, 164.2)	0.1 (-0.3, 0.5)	2.9	94.2	2.9		0.1 (-0.3, 0.5)	2.2	94.6	3.2	
Race/ethnicity	1134											
Non-Hispanic White	698	163.3 (162.3, 164.4)	0.2 (-0.1, 0.5)	2.9	92.0	5.1	0.10	-0.2 (-0.8, 0.5)	3.6	92.0	4.4	0.17
Non-Hispanic Black	128	163.8 (162.4, 165.2)	-0.1 (-0.5, 0.3)	3.2	94.9	1.8		-0.2 (-0.8, 0.5)	4.3	89.8	5.9	
Hispanic	177	158.7 (157.5, 160.0)	0.7 (-0.2, 1.5)	3.4	86.4	10.3		0.4 (-0.5, 1.2)	7.0	81.4	11.5	
Mixed or Other Race	131	160.7 (159.0, 162.4)	0.3 (-0.6, 1.1)	6.3	84.2	9.5		0.6 (-0.2, 1.4)	2.4	85.0	12.6	
Marital status	1133											
Married	684	161.8 (160.9, 162.7)	0.3 (0.0, 0.6)	3.7	89.4	6.9	1.00	0.1 (-0.4, 0.6)	4.4	87.7	7.9	0.86
Non-married	449	160.9 (159.8, 162.0)	0.3 (-0.3, 1.0)	3.6	89.3	7.0		0.2 (-0.5, 0.9)	5.1	85.7	9.2	
Parity	1132											
0	579	161.7 (160.7, 162.7)	-0.1 (-0.6, 0.4)	3.9	91.9	4.2	0.13	0 (-0.7, 0.6)	4.4	90.6	5.0	0.07

≥ 1	553	161.2 (160.2, 162.2)	0.7 (0.2, 1.1)	3.5	87.2	9.3		0.3 (-0.2, 0.8)	4.9	83.6	11.5	
Singleton	1134											
Yes	1080	161.4 (160.7, 162.2)	0.3 (0.0, 0.6)	3.7	89.3	6.9	0.03	0.2 (-0.1, 0.6)	4.4	87.0	8.5	0.25
No	54	160.3 (157.2, 163.3)	0.8 (-0.1, 1.7)	0.0	94.0	6.0		-5.3 (-14.6, 4.1)	22.5	74.7	2.8	
First trimester prenatal care	1068											
Yes	907	161.8 (161.1, 162.6)	0.4 (0.0, 0.7)	3.2	90.2	6.5	0.74	0.2 (-0.2, 0.6)	3.2	89.3	7.5	0.15
No	161	160.5 (158.8, 162.1)	0.1 (-0.8, 0.9)	5.4	88.2	6.4		-0.3 (-1.5, 0.9)	10.4	80.8	8.8	
WIC enrollment	1124											
Yes	557	160.4 (159.4, 161.3)	0.4 (-0.2, 0.9)	3.9	87.5	8.6	0.31	--[d]	--	--	--	--
No	567	162.8 (161.9, 163.8)	0.2 (-0.1, 0.6)	3.4	91.8	4.7		--	--	--	--	
WIC enrollment[c]	1128											
Yes	560	160.3 (159.4, 161.3)	--[d]	--	--	--	--	0 (-0.6, 0.5)	6.9	83.2	9.9	0.01
No	568	162.9 (161.8, 163.9)	--	--	--	--		0.3 (-0.2, 0.9)	2.0	92.6	5.5	
Medicaid enrollment	1132											
Yes	576	160.4 (159.4, 161.4)	0.4 (-0.1, 1.0)	4.9	86.1	9.0	0.03	--	--	--	--	--
No	556	162.8 (161.9, 163.8)	0.2 (-0.1, 0.5)	2.0	93.9	4.0		--	--	--	--	
Medicaid enrollment[c]	1134											
Yes	507	160.3 (159.3, 161.3)	--	--	--	--	--	0.2 (-0.5, 0.9)	5.5	81.8	12.7	<0.01
No	627	162.6 (161.7, 163.5)	--	--	--	--		0.1 (-0.3, 0.5)	3.9	92.1	4.0	
Any smoking during pregnancy	1132											
Yes	120	163 (161.3, 164.8)	0.5 (-0.1, 1.1)	1.1	96.7	2.3	0.07	--	--	--	--	--
No	1012	161.4 (160.7, 162.1)	0.3 (0.0, 0.7)	3.8	89.2	7.1		--	--	--	--	
Smoking in last 3 months of pregnancy[c]	1120											
Yes	146	163.5 (161.7, 165.4)	--	--	--	--	--	0.1 (-0.5, 0.7)	0.7	98.3	1.0	<0.01
No	974	161.2 (160.5, 162.0)	--	--	--	--		0.2 (-0.2, 0.6)	4.8	86.5	8.8	
Gestational diabetes	1125		--									
1.Yes	46	159.3 (154.5, 164.0)	-0.4 (-5.1, 4.4)	7.1	82.5	10.4	0.78	--	--	--	--	--
2.No	1079	161.5 (160.8, 162.2)	0.3 (0.0, 0.6)	3.6	89.6	6.8		--	--	--	--	

Gestational diabetes[c]	1127		--									
1.Yes	91	158.7 (156.5, 161.0)	--	--	--	--	--	1.1 (0.2, 2.0)	0.7	85.4	13.9	0.01
2.No	1036	161.7 (161.0, 162.4)	--	--	--	--		0 (-0.4, 0.5)	5.1	87.3	7.7	
Pre-gestational or gestational diabetes	1130											
Yes	55	159.2 (155.2, 163.3)	-0.2 (-4.3, 3.8)	6.0	84.5	9.5	0.84	--	--	--	--	--
No	1075	161.5 (160.8, 162.2)	0.3 (0.0, 0.6)	3.6	89.6	6.8		--	--	--	--	
Pre-gestational or gestational diabetes[c]	1133											
Yes	109	158.5 (156.5, 160.4)	--	--	--	--	--	1.1 (0.3, 1.8)	0.6	87.5	11.9	<0.01
No	1024	161.8 (161.1, 162.5)	--	--	--	--		0 (-0.4, 0.5)	5.2	87.0	7.8	
Gestational hypertension	1129		--									
1.Yes	67	163.2 (159.6, 166.9)	0.1 (-0.9, 1.1)	2.3	96.0	1.7	0.09	--	--	--	--	--
2.No	1062	161.4 (160.7, 162.1)	0.3 (0.0, 0.7)	3.7	89.2	7.1		--	--	--	--	
Any hypertensive conditions before or during pregnancy	1130											
Yes	99	163.7 (160.9, 166.6)	0.1 (-0.6, 0.9)	2.4	95.4	2.1	0.09	--	--	--	--	--
No	1031	161.3 (160.6, 162.0)	0.3 (0.0, 0.7)	3.7	89.1	7.1		--	--	--	--	
Any hypertensive conditions before or during pregnancy[c]	1109		--									
Yes	164	163.3 (161.3, 165.3)	--	--	--	--	--	0.1 (-0.4, 0.5)	2.1	96.8	1.0	<0.01
No	945	161.1 (160.4, 161.9)	--	--	--	--		0.2 (-0.2, 0.7)	4.5	86.7	8.9	
Preterm birth	1134											
Yes	262	161.1 (159.5, 162.7)	-0.2 (-0.8, 0.4)	9.1	86.3	4.6	0.24	0.1 (-0.9, 1.0)	12.2	81.3	6.6	0.33
No	872	161.5 (160.7, 162.2)	0.4 (0.0, 0.7)	3.2	89.7	7.2		0.2 (-0.3, 0.6)	4.0	87.4	8.6	
Birth Weight	1079											
Small-for-gestational age	220	159.5 (157.7, 161.3)	0.5 (-0.2, 1.2)	3.8	84.3	11.9	0.84	0.9 (0.1, 1.7)	2.5	84.3	13.2	0.58
Average-for-	779	161.5 (160.7, 162.3)	0.3 (-0.1, 0.7)	3.6	90.0	6.4		0.2 (-0.2, 0.6)	4.7	87.1	8.2	

gestational age										
Large-for-gestational age	80	164.3 (161.9, 166.7)	0.3 (-1.5, 2.2)	5.7	89.1	5.1	-0.3 (-1.4, 0.9)	4.1	90.5	5.4

[a]All characteristics are derived from birth certificate unless otherwise noted
[b]Derived from medical record
[c]Derived from PRAMS questionnaire
[d]Characteristic not applicable to birth certificate or PRAMS questionnaire

Supplemental Table 3: Mean and distribution of reporting error between pre-pregnancy weight from birth certificate or PRAMS questionnaire compared with medical record, stratified by covariates of interest

	Medical Record		Birth Certificate					PRAMS Questionnaire				
				Distribution of Reporting Error (%)					Distribution of Reporting Error (%)			
Characteristic[a]	n	Mean (95% CI)	Mean Difference (95% CI)	Under-report >2.3 kg	Report within ±2.3 kg	Over-report >2.3 kg	*P*	Mean Difference (95% CI)	Under-report >2.3 kg	Report within ±2.3 kg	Over-report >2.3 kg	*P*
Total	***784***	***64.8 (63.1, 66.5)***	***0.3 (-0.5, 1.1)***	***14.1***	***75.4***	***10.6***		***-0.3 (-1.2, 0.6)***	***20.1***	***68.4***	***11.6***	
Pre-pregnancy BMI[b]	758											
Underweight	32	47.8 (46.0, 49.7)	1.6 (-0.4, 3.5)	1.2	72.3	26.4	<0.01	1.5 (-0.1, 3.1)	1.3	82.0	16.7	0.02
Normal weight	402	57.6 (56.5, 58.7)	0.5 (-0.8, 1.8)	10.4	82.4	7.2		0.8 (-0.6, 2.3)	13.2	74.4	12.4	
Overweight	180	69.5 (67.4, 71.7)	1.4 (0.1, 2.6)	9.8	68.6	21.6		-1.3 (-2.7, 0.0)	24.9	65.1	10.0	
Obese	144	90.7 (85.8, 95.6)	-2.2 (-3.7, -0.6)	28.1	71.3	0.6		-2.9 (-5.2, -0.7)	35.1	51.2	13.6	
Maternal age	784											
< 20 years	45	61.8 (56.3, 67.3)	-0.8 (-3.0, 1.4)	29.6	61.9	8.5	0.23	0.5 (-3.1, 4.1)	22.5	69.4	8.1	0.71
20-24 years	175	65.6 (60.8, 70.4)	-0.4 (-1.5, 0.6)	14.0	78.2	7.8		-0.5 (-2.1, 1.1)	21.8	65.1	13.1	
25-29 years	213	65 (61.6, 68.4)	1.9 (0.3, 3.6)	8.5	64.7	26.9		-0.5 (-2.4, 1.4)	23.5	58.0	18.5	
30-34 years	208	62.8 (60.0, 65.5)	0.6 (-1.6, 2.8)	12.0	81.5	6.5		0.1 (-2.2, 2.4)	15.1	75.4	9.5	
≥ 35 years	143	67.7 (64.1, 71.2)	-0.6 (-1.4, 0.2)	16.6	78.7	4.7		-0.9 (-1.7, -0.2)	20.9	71.3	7.8	
Maternal education	782											
< 12 years	100	65 (60.3, 69.8)	-0.1 (-1.7, 1.6)	23.6	61.0	15.3	0.12	-0.7 (-3.1, 1.7)	30.8	53.8	15.4	0.14
12 years	213	62.7 (59.6, 65.9)	0.5 (-0.4, 1.4)	11.2	75.5	13.3		-0.5 (-1.4, 0.4)	19.4	67.0	13.5	
> 12 years	469	65.9 (63.8, 68.0)	0.3 (-1.1, 1.6)	11.5	81.7	6.8		-0.1 (-1.5, 1.3)	15.7	75.6	8.8	
Race/ethnicity	784											
Non-Hispanic White	523	64.3 (62.0, 66.5)	0.0 (-0.8, 0.7)	10.4	83.5	6.2	0.24	-0.7 (-1.5, 0.0)	18.4	73.7	7.9	0.32
Non-Hispanic Black	59	74.9 (68.7, 81.1)	1.0 (-3.1, 5.0)	20.3	66.9	12.8		0.2 (-4.3, 4.7)	30.6	48.1	21.3	
Hispanic	117	63.1 (60.6, 65.5)	0.6 (-0.4, 1.6)	14.0	70.7	15.3		-0.1 (-1.2, 0.9)	18.3	71.1	10.6	
Mixed or Other Race	85	58.6 (55.6, 61.7)	-0.9 (-1.8, 0.0)	15.9	79.5	4.7		-0.6 (-2.1, 0.9)	16.3	71.9	11.8	
Marital status	783											
Married	483	64.5 (62.2, 66.8)	0.1 (-0.4, 0.7)	9.7	83.3	7.0	0.01	-0.3 (-1.0, 0.3)	14.2	74.8	11.0	0.03
Nonmarried	300	65.2 (62.5, 67.9)	0.4 (-1.3, 2.1)	19.8	65.0	15.2		-0.4 (-2.2, 1.5)	27.7	59.9	12.4	
Parity	784											

0	402	63.3 (61.0, 65.6)	0.6 (-0.9, 2.0)	11.3	77.4	11.3	0.49	0.2 (-1.4, 1.7)	15.0	76.0	9.0	0.05
≥ 1	382	66.1 (63.6, 68.7)	0 (-0.8, 0.8)	16.5	73.6	9.9		-0.8 (-1.8, 0.2)	24.5	61.6	13.9	
Singleton	784											
Yes	748	64.8 (63.0, 66.5)	0.3 (-0.5, 1.1)	14.0	75.4	10.6	0.27	-0.3 (-1.2, 0.6)	19.9	68.6	11.5	0.20
No	36	66.8 (59.5, 74.1)	-0.2 (-2.7, 2.4)	20.0	76.2	3.8		-1.8 (-5.3, 1.8)	36.7	47.2	16.1	
First trimester prenatal care	736											
Yes	651	65.1 (63.3, 67.0)	0.2 (-0.7, 1.1)	13.5	77.4	9.0	0.14	-0.7 (-1.7, 0.3)	19.7	70.0	10.3	0.42
No	85	64.1 (58.4, 69.9)	0.7 (-1.3, 2.7)	19.8	58.9	21.3		1.1 (-1.3, 3.5)	22.8	58.7	18.5	
WIC enrollment	777											
Yes	381	65.4 (63.0, 67.9)	0.2 (-0.6, 1.1)	16.9	67.3	15.8	0.00	--	--	--	--	--
No	396	64 (61.5, 66.4)	0.3 (-1.2, 1.8)	10.4	85.9	3.7		--	--	--	--	
WIC enrollment[c]	780											
Yes	390	66 (63.4, 68.5)	--	--	--	--	--	-0.7 (-1.5, 0.2)	21.8	65.9	12.3	0.55
No	390	63.4 (61.1, 65.6)	--	--	--	--		0.2 (-1.6, 1.9)	17.0	72.2	10.8	
Medicaid enrollment	782											
Yes	391	64.1 (61.6, 66.5)	0.1 (-0.6, 0.9)	15.6	71.9	12.5	0.23	--	--	--	--	--
No	391	65.6 (63.3, 68.0)	0.4 (-1.2, 2.0)	12.2	80.8	7.0		--	--	--	--	
Medicaid enrollment[c]	784											
Yes	351	65.3 (62.6, 68.0)	--	--	--	--	--	-0.9 (-2.0, 0.1)	25.2	61.1	13.8	0.03
No	433	64.2 (62.2, 66.3)	--	--	--	--		0.3 (-1.2, 1.8)	14.4	76.4	9.2	
Any smoking during pregnancy	783											
Yes	93	73.5 (69.4, 77.7)	3.5 (-2.1, 9.1)	8.2	62.4	29.3	0.46	--	--	--	--	--
No	690	64.5 (62.8, 66.3)	0.2 (-0.6, 1.0)	14.2	75.7	10.0		--	--	--	--	
Smoking in last 3 months of pregnancy[c]	771											
Yes	107	67.9 (62.8, 73.0)	--	--	--	--	--	-1.6 (-3.0, -0.2)	29.5	66.8	3.8	0.08
No	664	64.6 (62.7, 66.4)	--	--	--	--		-0.2 (-1.2, 0.8)	18.9	68.7	12.4	
Gestational diabetes	778		--									
1.Yes	35	69.3 (58.2, 80.4)	0.4 (-1.4, 2.3)	14.3	71.7	14.0	0.95	--	--	--	--	--
2.No	743	64.6 (62.8, 66.3)	0.3 (-0.6, 1.1)	14.2	75.3	10.5		--	--	--	--	
Gestational diabetes[c]	778		--									
1.Yes	59	62.3 (57.3, 67.4)	--	--	--	--	--	0 (-1.6, 1.5)	11.1	80.8	8.1	0.42

2.No	719	65 (63.2, 66.9)	--	--	--	--		-0.3 (-1.3, 0.6)	20.3	67.8	11.9	
Pre-gestational or gestational diabetes	781											
Yes	42	71.7 (62.8, 80.5)	-0.2 (-1.8, 1.4)	23.7	65.5	10.8	0.75	--	--	--	--	--
No	739	64.5 (62.7, 66.2)	0.3 (-0.5, 1.1)	13.6	75.8	10.5		--	--	--	--	
Pre-gestational or gestational diabetes[c]	783											
Yes	71	65.9 (60.5, 71.3)	--	--	--	--	--	0.2 (-1.2, 1.6)	9.8	71.1	19.0	0.26
No	712	64.7 (62.9, 66.6)	--	--	--	--		-0.4 (-1.3, 0.6)	20.7	68.4	10.9	
Gestational hypertension	780		--									
1.Yes	43	73.4 (68.0, 78.9)	1.1 (-1.5, 3.8)	7.1	65.9	27.0	0.51	--	--	--	--	--
2.No	737	64.6 (62.9, 66.4)	0.3 (-0.6, 1.1)	14.2	75.5	10.3		--	--	--	--	
Any hypertensive conditions before or during pregnancy	781											
Yes	62	71.9 (67.3, 76.4)	1.1 (-1.1, 3.2)	5.5	71.0	23.5	0.2	--	--	--	--	--
No	719	64.6 (62.9, 66.4)	0.2 (-0.6, 1.1)	14.3	75.5	10.3		--	--	--	--	
Any hypertensive conditions before or during pregnancy[c]	764											
Yes	106	72.5 (65.0, 80.0)	--	--	--	--	--	1.1 (-6.1, 8.4)	22.3	64.6	13.1	0.92
No	658	63.9 (62.1, 65.7)	--	--	--	--		-0.4 (-1.1, 0.3)	19.5	68.7	11.8	
Preterm birth	784											
Yes	158	65.4 (62.7, 68.2)	0.3 (-0.5, 1.1)	10.3	80.9	8.9	0.57	-1.2 (-2.1, -0.3)	23.6	69.5	6.9	0.36
No	626	64.7 (62.9, 66.6)	0.3 (-0.6, 1.1)	14.4	74.9	10.7		-0.3 (-1.2, 0.7)	19.8	68.3	12.0	
Birth Weight Small-for-gestational age	155	63.4 (60.3, 66.6)	-1 (-2.5, 0.5)	30.8	53.0	16.2	<0.01	-2.2 (-4.0, -0.4)	30.9	60.1	9.1	0.01
Average-for-gestational age	529	64.3 (62.3, 66.3)	0.5 (-0.4, 1.5)	11.7	77.8	10.6		0.1 (-1.0, 1.1)	17.9	69.3	12.8	
Large-for-gestational age	63	73.5 (65.8, 81.1)	-0.3 (-0.9, 0.2)	7.7	92.3	0.0		-1.3 (-2.3, -0.3)	21.2	78.1	0.7	

[a]All characteristics are derived from birth certificate unless otherwise noted

[b]Derived from medical record

[c]Derived from PRAMS questionnaire
[d]Characteristic not applicable to birth certificate or PRAMS questionnaire

Supplemental Table 4: Mean and distribution of reporting error between pre-pregnancy BMI from birth certificate or PRAMS questionnaire compared with medical record, stratified by covariates of interest

	Medical Record			Birth Certificate					PRAMS Questionnaire				
					Distribution of Reporting Error (%)					Distribution of Reporting Error (%)			
Characteristic[a]	n	Mean (95% CI)		Mean Difference (95% CI)	Under-report >1 unit	Report within ±1 unit	Over-report >1 unit	*P*	Mean Difference (95% CI)	Under-report >1 unit	Report within ±1 unit	Over-report >1 unit	*P*
Total	***734***	***25.1***	***(24.4, 25.8)***	***0.2 (-0.2, 0.6)***	***18.5***	***68.6***	***12.9***		***-0.2 (-0.6, 0.2)***	***26.3***	***59.3***	***14.3***	
Pre-pregnancy BMI[b]	734												
Underweight	30	17.5	(17.1, 17.8)	0.7 (-0.2, 1.6)	1.7	74.6	23.8	0.03	0.4 (0.0, 0.8)	0.9	87.4	11.7	0.01
Normal weight	386	22.0	(21.7, 22.3)	0.2 (-0.4, 0.8)	17.0	73.5	9.5		0.2 (-0.4, 0.8)	19.8	65.4	14.8	
Overweight	175	27.0	(26.7, 27.2)	0.7 (-0.1, 1.4)	14.1	64.9	20.9		-0.5 (-1.4, 0.3)	36.1	50.4	13.4	
Obese	143	34.9	(33.5, 36.2)	-0.9 (-1.5, -0.2)	36.5	56.5	7.0		-1.3 (-2.1, -0.4)	38.0	46.8	15.2	
Maternal age	734												
< 20 years	43	24.2	(22.0, 26.4)	1 (-1.3, 3.2)	23.0	64.4	12.6	0.23	0.2 (-1.2, 1.5)	40.6	35.1	24.3	0.01
20-24 years	160	26.4	(24.3, 28.6)	-0.2 (-0.7, 0.3)	18.7	73.3	8.0		-0.1 (-0.9, 0.7)	25.2	56.6	18.1	
25-29 years	203	24.9	(23.6, 26.1)	1 (0.1, 1.8)	14.7	53.9	31.4		-0.1 (-1.2, 1.1)	35.4	38.4	26.2	
30-34 years	196	24.0	(23.1, 25.0)	0.2 (-0.7, 1.0)	16.2	75.6	8.2		-0.2 (-1.0, 0.7)	20.2	72.7	7.1	
≥ 35 years	132	26.0	(24.7, 27.2)	-0.4 (-0.8, -0.1)	23.6	70.6	5.7		-0.6 (-1.0, -0.2)	22.1	71.8	6.1	
Maternal education	732												
< 12 years	87	27.0	(24.9, 29.0)	0.6 (-0.6, 1.8)	24.3	54.4	21.2	0.13	-0.5 (-1.8, 0.8)	40.4	32.4	27.3	<0.01
12 years	199	24.8	(23.6, 25.9)	0.1 (-0.4, 0.5)	20.7	63.7	15.6		-0.4 (-0.9, 0.0)	30.8	51.4	17.8	
> 12 years	446	24.6	(23.8, 25.4)	0.2 (-0.4, 0.7)	15.3	76.1	8.6		0 (-0.6, 0.6)	19.2	72.7	8.1	
Race/ethnicity	734												
Non-Hispanic White	506	24.0	(23.2, 24.9)	-0.1 (-0.4, 0.3)	17.5	71.9	10.6	0.53	-0.3 (-0.7, 0.0)	25.5	61.0	13.5	1.00
Non-Hispanic Black	53	28.5	(26.0, 30.9)	0.5 (-1.1, 2.1)	20.8	66.1	13.1		0 (-1.9, 1.9)	26.5	57.5	16.0	
Hispanic	94	25.6	(24.7, 26.5)	0.6 (-0.1, 1.4)	15.0	66.5	18.5		-0.1 (-0.7, 0.6)	27.1	57.9	14.9	
Mixed or Other Race	81	22.9	(21.8, 23.9)	-0.5 (-1.1, 0.2)	26.1	68.2	5.7		-0.4 (-1.1, 0.4)	26.3	60.4	13.2	
Marital status	733												
Married	460	24.8	(23.9, 25.6)	0 (-0.3, 0.2)	16.8	72.2	11.0	0.37	-0.2 (-0.5, 0.1)	21.5	65.7	12.9	0.06
Non-married	273	25.6	(24.6, 26.7)	0.5 (-0.4, 1.5)	21.1	63.0	15.9		-0.2 (-1.1, 0.8)	34.0	49.4	16.6	
Parity	734												
0	382	24.2	(23.4, 25.1)	0.5 (-0.2, 1.2)	13.4	71.7	14.9	0.15	0.1 (-0.6, 0.8)	22.7	63.6	13.7	0.43

≥ 1	352	25.9	(24.9, 26.9)	-0.1 (-0.4, 0.3)	23.2	65.8	11.1		-0.5 (-1.0, 0.0)	29.7	55.4	14.9	
Singleton	734												
Yes	702	25.1	(24.4, 25.8)	0.2 (-0.2, 0.6)	18.4	68.6	13.0	0.49	-0.2 (-0.6, 0.2)	26.3	59.5	14.2	0.55
No	32	25.4	(22.8, 28.0)	-0.2 (-1.2, 0.9)	18.7	74.8	6.5		-0.5 (-1.9, 0.9)	28.6	47.6	23.8	
First trimester prenatal care	693												
Yes	617	25.0	(24.3, 25.6)	0.1 (-0.3, 0.5)	17.7	71.1	11.2	0.30	-0.3 (-0.7, 0.1)	24.5	63.3	12.1	0.14
No	76	25.9	(23.4, 28.5)	0.9 (-0.5, 2.3)	18.1	57.4	24.5		0.3 (-0.7, 1.3)	31.7	42.7	25.6	
WIC enrollment	728												
Yes	350	25.8	(24.9, 26.7)	0.4 (-0.2, 0.9)	18.7	63.1	18.2	0.03	--[d]	--	--	--	--
No	378	24.3	(23.3, 25.2)	0 (-0.6, 0.6)	18.2	75.1	6.7		--	--	--	--	
WIC enrollment[c]	730												
Yes	362	26.0	(25.0, 27.0)	--[d]	--	--	--	--	-0.2 (-0.8, 0.3)	29.3	51.2	19.5	0.01
No	368	24.0	(23.2, 24.8)	--	--	--	--		-0.1 (-0.8, 0.5)	22.0	69.6	8.3	
Medicaid enrollment	733												
Yes	358	25.4	(24.5, 26.4)	0.3 (-0.2, 0.8)	19.3	63.4	17.2	0.09	--	--	--	--	--
No	375	24.7	(23.8, 25.6)	0.1 (-0.5, 0.7)	17.3	74.7	8.0		--	--	--	--	
Medicaid enrollment[c]	734												
Yes	322	25.9	(24.8, 27.0)	--	--	--	--	--	-0.5 (-1.1, 0.1)	34.9	49.6	15.5	0.01
No	412	24.4	(23.6, 25.1)	--	--	--	--		0.1 (-0.4, 0.7)	18.3	68.5	13.2	
Any smoking during pregnancy	733												
Yes	91	27.9	(26.1, 29.7)	1.2 (-0.6, 3.0)	9.4	58.1	32.5	0.31	--	--	--	--	--
No	642	25.0	(24.3, 25.7)	0.2 (-0.2, 0.6)	18.8	69.0	12.2		--	--	--	--	
Smoking in last 3 months of pregnancy[c]	724												
Yes	103	25.4	(23.0, 27.8)	--	--	--	--	--	-0.6 (-1.0, -0.1)	31.6	56.4	12.1	0.88
No	621	25.1	(24.4, 25.8)	--	--	--	--		-0.2 (-0.6, 0.3)	26.0	59.8	14.3	
Gestational diabetes	728												
Yes	33	26.5	(23.6, 29.4)	1.3 (-2.4, 5.1)	16.4	67.4	16.2	0.96	--	--	--	--	--
No	695	25.0	(24.3, 25.6)	0.2 (-0.2, 0.5)	18.7	68.4	12.9		--	--	--	--	
Gestational diabetes[c]	728												
Yes	54	25.4	(22.9, 27.9)	--	--	--	--	--	-0.1 (-0.9, 0.8)	20.8	70.1	9.1	0.64
No	674	25.1	(24.4, 25.8)	--	--	--	--		-0.2 (-0.6, 0.3)	26.4	58.8	14.8	

Pre-gestational or gestational diabetes	731												
Yes	40	27.7	(25.0, 30.3)	0.8 (-2.1, 3.7)	25.5	62.1	12.4	0.86	--	--	--	--	--
No	691	25.0	(24.3, 25.6)	0.2 (-0.2, 0.5)	18.1	69.0	12.9		--	--	--	--	
Pre-gestational or gestational diabetes[c]	733								0				
Yes	66	26.8	(24.3, 29.3)	--	--	--	--	--	0 (-0.7, 0.7)	17.3	68.6	14.1	0.57
No	667	24.9	(24.2, 25.6)	--	--	--	--		-0.2 (-0.6, 0.3)	26.9	58.7	14.4	
Gestational hypertension	730												
Yes	41	28.6	(26.1, 31.1)	0.1 (-1.9, 2.1)	14.6	55.2	30.1	0.73	--	--	--	--	--
No	689	25.0	(24.3, 25.7)	0.2 (-0.2, 0.6)	18.5	68.9	12.6		--	--	--	--	
Any hypertensive conditions before or during pregnancy	731												
Yes	59	27.8	(25.7, 29.8)	0.2 (-1.4, 1.7)	11.4	62.5	26.1	0.55	--	--	--	--	--
No	672	25.0	(24.3, 25.7)	0.2 (-0.2, 0.6)	18.6	68.8	12.6		--	--	--	--	
Any hypertensive conditions before or during pregnancy[c]	717												
Yes	99	27.4	(24.7, 30.2)	--	--	--	--	--	0.5 (-2.3, 3.3)	21.3	62.4	16.3	0.84
No	618	24.9	(24.2, 25.5)	--	--	--	--		-0.3 (-0.6, 0.1)	26.4	59.6	14.0	
Preterm birth	734												
Yes	145	25.6	(24.1, 27.0)	0.1 (-0.4, 0.5)	12.7	75.2	12.0	0.47	-0.7 (-1.2, -0.3)	35.7	55.5	8.9	0.30
No	589	25.1	(24.3, 25.8)	0.2 (-0.2, 0.6)	19.0	68.0	13.0		-0.2 (-0.6, 0.3)	25.5	59.7	14.8	
Birth Weight	701												
Small-for-gestational age	143	24.7	(23.6, 25.8)	-0.2 (-0.8, 0.4)	28.6	54.7	16.7	0.01	-1.3 (-2.4, -0.2)	38.7	49.8	11.6	0.07
Average-for-gestational age	501	25	(24.2, 25.7)	0.3 (-0.2, 0.7)	18.0	68.7	13.3		-0.1 (-0.5, 0.4)	25.8	59.4	14.8	
Large-for-gestational age	57	27.8	(25.3, 30.2)	-0.1 (-0.3, 0.1)	2.7	96.7	0.6		0.1 (-0.8, 1.0)	6.9	82.1	11.0	

[a]All characteristics are derived from birth certificate unless otherwise noted

[b]Derived from medical record

[c]Derived from PRAMS questionnaire

[d]Characteristic not applicable to birth certificate or PRAMS questionnaire

Supplemental Table 5: Mean and distribution of reporting error between delivery weight from birth certificate or PRAMS questionnaire compared with medical record, stratified by covariates of interest

	Medial Record		Birth Certificate				
				Distribution of Reporting Error (%)			
Characteristic[a]	n	Mean (95% CI)	Mean Difference (95% CI)	Under-report > 2.3 kg	Report within ± 2.3 kg	Over-report > 2.3 kg	*P*
Overall	***1039***	***79.9 (78.2, 81.7)***	***-0.7 (-1.5, 0.0)***	***13.1***	***80.2***	***6.7***	
Pre-pregnancy BMI[b]	**672**						
Underweight	28	62.2 (59.9, 64.5)	0.2 (-0.1, 0.5)	2.1	96.8	1.1	0.10
Normal weight	350	71.3 (69.5, 73.2)	-0.6 (-1.5, 0.2)	11.9	82.1	6.0	
Overweight	157	84.3 (81.1, 87.4)	-1.4 (-2.5, -0.4)	18.4	80.0	1.6	
Obese	137	100.3 (94.2, 106.5)	-0.4 (-2.2, 1.4)	17.9	76.4	5.6	
Maternal age	1039						
< 20 years	60	76.3 (70.6, 82.0)	-1.6 (-3.0, -0.3)	16.8	82.0	1.2	0.11
20-24 years	231	83.3 (78.9, 87.6)	-0.8 (-1.5, -0.1)	13.4	82.4	4.2	
25-29 years	279	80.8 (77.1, 84.6)	-1.1 (-3.9, 1.7)	8.8	82.7	8.5	
30-34 years	274	77.4 (74.4, 80.3)	-0.3 (-1.5, 0.9)	12.3	80.7	6.9	
≥ 35 years	195	80 (77.0, 82.9)	-0.5 (-1.7, 0.7)	18.0	72.2	9.8	
Maternal education	1037						
< 12 years	154	78.7 (74.9, 82.5)	0.3 (-1.1, 1.6)	11.3	80.4	8.3	0.96
12 years	264	79.5 (75.3, 83.6)	-2 (-4.6, 0.5)	13.2	80.7	6.2	
> 12 years	619	80.8 (78.7, 82.9)	-0.6 (-1.2, 0.0)	13.9	79.9	6.2	
Race/ethnicity	1039						
Non-Hispanic White	646	80.6 (77.6, 83.6)	-0.4 (-1.1, 0.3)	8.7	85.1	6.2	0.10
Non-Hispanic Black	107	86.3 (81.1, 91.4)	0.9 (-0.6, 2.5)	15.0	68.9	16.1	
Hispanic	171	78.9 (76.5, 81.3)	-1 (-1.7, -0.3)	14.9	81.3	3.8	
Mixed or Other Race	115	73.2 (68.8, 77.6)	-2.8 (-7.0, 1.3)	14.1	83.0	3.0	
Marital status	1038						
Married	623	78.8 (76.5, 81.0)	-1.2 (-2.4, 0.1)	14.3	78.7	7.0	0.70
Non-married	415	81.4 (78.7, 84.1)	-0.2 (-1.0, 0.7)	11.5	82.1	6.4	
Parity	1036						
0	529	80.7 (77.7, 83.7)	-1.3 (-2.8, 0.2)	14.8	78.5	6.7	0.71
≥ 1	507	79.4 (77.4, 81.4)	-0.2 (-1.0, 0.5)	11.7	81.6	6.7	
Singleton	1039						
Yes	984	79.9 (78.1, 81.7)	-0.8 (-1.6, 0.0)	13.2	80.2	6.7	0.18
No	55	84.5 (78.4, 90.6)	1.3 (-0.7, 3.2)	5.5	84.6	9.9	
First trimester prenatal care	971						
Yes	827	80.3 (78.4, 82.3)	-1 (-1.9, 0.0)	13.0	81.4	5.6	0.56
No	144	80 (75.5, 84.4)	-0.3 (-1.7, 1.2)	14.4	76.0	9.7	
WIC enrollment	1032						
Yes	508	80.6 (78.1, 83.0)	-0.9 (-2.1, 0.4)	11.9	82.5	5.6	0.40
No	524	79.2 (76.7, 81.6)	-0.6 (-1.3, 0.1)	14.9	76.8	8.3	
Medicaid enrollment	1036						
Yes	528	79.3 (76.9, 81.8)	-0.8 (-2.0, 0.5)	13.1	80.0	6.9	0.95
No	508	80.6 (78.2, 83.0)	-0.6 (-1.3, 0.0)	12.3	81.3	6.4	
Any smoking during pregnancy	1038						
Yes	119	96.4 (81.1, 111.7)	0 (-0.6, 0.7)	1.8	93.5	4.7	0.01

No	919	79.5 (77.8, 81.2)	-0.8 (-1.6, 0.0)	13.4	79.9	6.8	
Gestational diabetes	1031						
Yes	41	73.4 (67.8, 79.0)	-2.5 (-5.9, 0.9)	18.9	76.7	4.4	0.66
No	990	80.1 (78.3, 81.9)	-0.7 (-1.5, 0.1)	12.9	80.3	6.8	
Pre-gestational or gestational diabetes	1035						
Yes	49	76.3 (70.2, 82.3)	-2.2 (-5.3, 0.9)	17.8	77.3	4.9	0.74
No	986	80.1 (78.3, 81.9)	-0.7 (-1.5, 0.1)	12.9	80.3	6.8	
Gestational hypertension	1034						
Yes	61	92.7 (83.2, 102.3)	0 (-0.7, 0.7)	8.3	88.3	3.4	0.41
No	973	79.5 (77.7, 81.2)	-0.8 (-1.6, 0.1)	13.2	79.9	6.8	
Any hypertensive conditions before or during pregnancy	1035						
Yes	90	96.9 (85.5, 108.3)	0 (-0.6, 0.5)	7.3	89.2	3.5	0.29
No	945	79.1 (77.4, 80.8)	-0.8 (-1.6, 0.1)	13.3	79.8	6.9	
Preterm birth	1039						
Yes	236	77.9 (75.1, 80.8)	0.8 (0.0, 1.7)	4.5	82.5	13.0	<0.01
No	803	80.1 (78.2, 82.0)	-0.9 (-1.7, 0.0)	13.9	80.0	6.1	
Large-for-gestational age birth	983						
Yes	78	85.5 (80.5, 90.5)	0.3 (-0.7, 1.4)	4.5	82.1	13.4	0.12
No	905	79.5 (77.6, 81.3)	-0.9 (-1.7, 0.0)	13.8	80.0	6.2	
Small-for-gestational age birth	983						
Yes	206	77.6 (72.5, 82.7)	-0.9 (-1.9, 0.2)	11.7	82.1	6.3	0.93
No	777	80.2 (78.3, 82.1)	-0.8 (-1.7, 0.1)	13.4	79.9	6.7	
Birth Weight	983						
Small-for-gestational age	206	77.6 (72.5, 82.7)	-0.9 (-1.9, 0.2)	11.7	82.1	6.3	0.35
Average-for gestational age	699	79.7 (77.7, 81.7)	-0.9 (-1.8, 0.1)	14.1	79.7	6.1	
Large-for-gestational age	78	85.5 (80.5, 90.5)	0.3 (-0.7, 1.4)	4.5	82.1	13.4	

[a]All characteristics are derived from birth certificate unless otherwise noted
[b]Derived from medical record

Supplemental Table 6: Mean and distribution of reporting error between gestational weight gain from birth certificate or PRAMS questionnaire compared with medical record, stratified by covariates of interest

	Medial Record		Birth Certificate				
				Distribution of Reporting Error (%)			
Characteristic[a]	n	Mean (95% CI)	Mean Difference (95% CI)	Under-report > 2.3 kg	Report within ± 2.3 kg	Over-report > 2.3 kg	*P*
Overall	***678***	***13.1 (12.2, 13.9)***	***-0.5 (-1.3, 0.3)***	***19.7***	***64.3***	***16.0***	
Pre-pregnancy BMI[b]	**664**						
Underweight	28	[c]--	--	--	--	--	0.04
Normal weight	346	13.6 (12.6, 14.7)	-0.7 (-1.7, 0.3)	18.4	69.7	11.9	
Overweight	154	14.1 (12.3, 15.9)	-1.9 (-3.4, -0.4)	29.1	57.8	13.1	
Obese	136	9.3 (6.9, 11.8)	1.9 (-0.5, 4.3)	10.0	58.2	31.8	
Maternal age	678						
< 20 years	41	14.8 (11.7, 18.0)	-2.6 (-5.2, 0.1)	35.4	54.5	10.2	0.83
20-24 years	156	14.1 (12.1, 16.1)	-0.4 (-2.1, 1.3)	17.8	63.2	19.0	
25-29 years	187	12.7 (10.5, 14.9)	0.2 (-1.8, 2.2)	20.5	60.5	19.0	
30-34 years	177	13 (11.8, 14.2)	-0.3 (-1.5, 0.9)	14.2	71.0	14.7	
≥ 35 years	117	11.5 (9.8, 13.2)	-0.7 (-2.6, 1.3)	24.2	62.2	13.6	
Maternal education	676						
< 12 years	81	11.7 (9.8, 13.7)	1.3 (-0.8, 3.4)	20.3	50.9	28.8	0.02
12 years	186	14.1 (12.4, 15.8)	-1.6 (-2.8, -0.4)	19.3	74.7	6.0	
> 12 years	409	13.1 (12.0, 14.1)	-0.6 (-1.7, 0.4)	19.7	64.1	16.1	
Race/ethnicity	678						
Non-Hispanic White	468	14.2 (12.7, 15.8)	-0.2 (-1.3, 0.9)	13.3	73.3	13.4	0.31
Non-Hispanic Black	45	11.4 (8.9, 14.0)	1.7 (-1.0, 4.4)	15.7	57.5	26.8	
Hispanic	88	13.1 (11.7, 14.4)	-1.7 (-3.0, -0.4)	28.5	57.6	13.9	
Mixed or Other Race	77	12.2 (10.5, 13.9)	-0.2 (-1.8, 1.4)	16.4	67.2	16.4	
Marital status	677						
Married	424	12.7 (11.8, 13.7)	-0.8 (-1.7, 0.0)	21.3	64.6	14.1	0.61
Non-married	253	13.6 (12.0, 15.1)	0.1 (-1.4, 1.5)	17.4	63.7	18.9	
Parity	678						
0	350	14 (12.6, 15.3)	-0.5 (-1.7, 0.8)	19.1	66.1	14.9	0.87
≥ 1	328	12.3 (11.2, 13.4)	-0.5 (-1.5, 0.5)	20.3	62.6	17.0	
Singleton	678						
Yes	647	13 (12.1, 13.8)	-0.5 (-1.3, 0.3)	19.9	64.3	15.9	0.20
No	31	21.8 (18.2, 25.3)	0 (-2.6, 2.6)	8.5	64.0	27.5	
First trimester prenatal care	634						
Yes	563	13.3 (12.3, 14.2)	-0.3 (-1.1, 0.5)	17.7	65.9	16.4	0.16
No	71	12.9 (10.6, 15.3)	-2.5 (-5.0, 0.0)	39.1	46.9	14.0	
WIC enrollment	673						
Yes	324	13 (11.9, 14.2)	-0.3 (-1.4, 0.9)	21.0	60.0	18.9	0.31
No	349	13.1 (11.8, 14.4)	-0.8 (-1.8, 0.3)	18.1	69.6	12.3	
Medicaid enrollment	676						
Yes	330	12.2 (11.1, 13.3)	-0.1 (-1.0, 0.9)	17.8	65.1	17.1	0.82
No	346	13.9 (12.6, 15.2)	-0.7 (-1.9, 0.5)	21.0	64.2	14.8	
Any smoking during pregnancy	678						
Yes	90	15.1 (13.8, 16.4)	-0.1 (-0.8, 0.7)	11.4	76.6	12.0	0.35
No	588	13 (12.1, 13.9)	-0.5 (-1.3, 0.3)	20.0	63.9	16.1	

Gestational diabetes	672						
Yes	--	--	--	--	--	--	0.80
No	643	13.2 (12.4, 14.1)	-0.5 (-1.3, 0.3)	19.8	64.4	15.8	
Pre-gestational or gestational diabetes	674						
Yes	35	9.3 (5.6, 13.0)	-0.2 (-3.7, 3.2)	18.4	61.0	20.6	0.94
No	639	13.2 (12.3, 14.1)	-0.5 (-1.3, 0.3)	19.8	64.4	15.8	
Gestational hypertension	673						
Yes	37	11.5 (9.4, 13.5)	-0.6 (-3.7, 2.4)	27.7	59.9	12.4	0.89
No	636	13.1 (12.2, 14.0)	-0.5 (-1.3, 0.3)	19.6	64.3	16.1	
Any hypertensive conditions before or during pregnancy	674						
Yes	53	12.4 (10.3, 14.4)	-0.7 (-3.1, 1.8)	24.7	64.4	10.9	0.74
No	621	13.1 (12.2, 14.0)	-0.5 (-1.3, 0.3)	19.6	64.2	16.1	
Preterm birth	678						
Yes	136	11.0 (8.0, 14.0)	0.0 (-1.1, 1.0)	13.4	72.0	14.6	0.64
No	542	13.2 (12.4, 14.1)	-0.5 (-1.4, 0.3)	20.3	63.6	16.1	
Large-for-gestational age birth	646						
Yes	59	14.7 (13.1, 16.2)	0.2 (-1.5, 1.9)	7.9	74.7	17.4	0.28
No	587	12.8 (11.9, 13.8)	-0.5 (-1.4, 0.3)	20.8	63.4	15.8	
Small-for-gestational age birth	646						
Yes	131	13 (10.7, 15.2)	-1.0 (-3.2, 1.1)	18.1	66.5	15.5	0.96
No	515	13 (12.1, 13.9)	-0.4 (-1.3, 0.4)	20.1	64.0	15.9	
Birth Weight	646						
Small-for-gestational age	131	13 (10.7, 15.2)	-1.0 (-3.2, 1.1)	18.1	66.5	15.5	0.62
Average-for gestational age	456	12.8 (11.8, 13.8)	-0.5 (-1.4, 0.4)	21.2	63.0	15.8	
Large-for-gestational age	59	14.7 (13.1, 16.2)	0.2 (-1.5, 1.9)	7.9	74.7	17.4	

[a]All characteristics are derived from birth certificate unless otherwise noted

[b]Derived from medical record

[c]Cannot display due to insufficient sample sizes

Supplemental Table 7: Misclassification of Gestational Weight Gain Categories when only Pre-Pregnancy Weight or Delivery Weight is Derived from Birth Certificate Compared to When Both Pre-Pregnancy Weight and Delivery Weight are Derived from Medical Record (Full-term, singleton pregnancies; n=521)

	Pre-Pregnancy Weight and Delivery Weight from Medical Record			
	Below Recommendations (%)	**Within Recommendations (%)**	**Above Recommendations (%)**	***Row Total (%)***
Pre-pregnancy weight from birth certificate[a]				
Below Recommendations	20.6	6.9	0.8	*28.3*
Within Recommendations	3.7	25.3	1.4	*30.3*
Above Recommendations	0.1	3.6	37.7	*41.4*
Column Total	*25.4*	*35.8*	*39.8*	
Delivery weight from birth certificate[b]				
Below Recommendations	21.3	7.1	2.7	*31.1*
Within Recommendations	1.6	27.2	3.6	*32.3*
Above Recommendations	1.5	1.6	33.6	*36.6*
Column Total	*24.4*	*35.8*	*39.8*	

[a]Overall agreement between birth certificate and medical record classification of gestational weight gain categories is 83.6%

[b]Overall agreement between birth certificate and medical record classification of gestational weight gain categories is 82.1%

Supplemental Table 8: Agreement in Pre-Pregnancy BMI Classification by Birth Certificate Compared to Medical Record, Stratified by Covariates of Interest

						Medical Record			
Characteristic[a]	**Level**	**n**	**Crude Agreement**	**κ**	**Birth Certificate**	**Under-weight (%)**	**Normal Weight (%)**	**Over-weight (%)**	**Obese (%)**
Overall		**734**	**87.2**	**0.79**	Underweight	**2.9**	**1.2**	**0.0**	**0.0**
					Normal Weight	**0.9**	**48.5**	**2.2**	**0.1**
					Overweight	**0.0**	**2.7**	**22.2**	**0.8**
					Obese	**0.0**	**1.1**	**3.9**	**13.7**
Maternal age	**< 20 years**	43	74.4	0.60	Underweight	0.9	7.8	0.0	0.0
					Normal Weight	0.0	40.1	0.5	0.0
					Overweight	0.0	9.6	23.9	0.0
					Obese	0.0	7.8	0.0	9.4
	20-24 years	160	95.9	0.94	Underweight	1.2	3.0	0.0	0.0
					Normal Weight	0.5	40.7	0.4	0.0
					Overweight	0.0	0.0	30.3	0.2
					Obese	0.0	0.0	0.0	23.8
	25-29 years	203	76.0	0.64	Underweight	6.2	0.0	0.0	0.0
					Normal Weight	3.2	39.6	0.8	0.2
					Overweight	0.0	8.7	17.0	2.7
					Obese	0.0	0.0	8.3	13.1
	30-34 years	196	90.6	0.82	Underweight	2.4	0.1	0.0	0.0
					Normal Weight	0.2	64.5	1.9	0.0
					Overweight	0.0	0.1	15.1	0.4
					Obese	0.0	1.6	5.2	8.7
	≥ 35 years	132	90.3	0.85	Underweight	2.4	0.3	0.0	0.0
					Normal Weight	0.4	44.2	6.1	0.0
					Overweight	0.0	0.4	29.8	0.1
					Obese	0.0	0.2	2.2	13.9
Maternal education	**< 12 years**	87	76.7	0.66	Underweight	0.5	3.1	0.0	0.0
					Normal Weight	0.0	25.0	3.8	0.0
					Overweight	0.0	6.6	29.8	0.3
					Obese	0.0	3.1	6.3	21.4
	12 years	199	86.7	0.78	Underweight	3.2	0.5	0.0	0.0
					Normal Weight	2.6	50.0	4.2	0.0
					Overweight	0.0	1.2	20.6	0.3
					Obese	0.0	0.0	4.5	12.8
	> 12 years	446	91.1	0.85	Underweight	3.5	1.0	0.0	0.0
					Normal Weight	0.4	55.7	0.5	0.1
					Overweight	0.0	2.1	20.4	1.2
					Obese	0.0	1.0	2.7	11.4
Race/ethnicity	**Non-Hispanic White**	506	90.6	0.82	Underweight	4.0	0.2	0.0	0.0
					Normal Weight	0.4	63.7	2.2	0.0
					Overweight	0.0	1.8	12.1	1.9
					Obese	0.0	0.1	2.9	10.8
	Non-Hispanic Black	53	83.8	0.76	Underweight	0.4	0.0	0.0	0.0
					Normal Weight	4.2	22.7	4.3	0.0
					Overweight	0.0	1.5	23.2	0.4
					Obese	0.0	3.0	3.0	37.4
	Hispanic	94	85.7	0.77	Underweight	0.3	0.2	0.0	0.0
					Normal Weight	0.2	38.6	1.8	0.1

					Overweight	0.0	5.1	36.0	0.0
					Obese	0.0	1.7	5.1	10.7
	Mixed or Other Race	81	86.0	0.73	Underweight	8.6	7.7	0.0	0.0
					Normal Weight	0.4	61.7	0.6	0.0
					Overweight	0.0	0.7	14.6	0.2
					Obese	0.0	0.0	4.4	1.0
Marital status	**Married**	460	89.8	0.83	Underweight	3.4	0.9	0.0	0.0
					Normal Weight	0.3	55.3	1.6	0.1
					Overweight	0.0	1.9	19.6	1.1
					Obese	0.0	0.1	4.2	11.5
	Non-married	273	83.1	0.75	Underweight	2.1	1.7	0.0	0.0
					Normal Weight	2.0	37.7	3.1	0.0
					Overweight	0.0	3.9	26.3	0.3
					Obese	0.0	2.7	3.3	17.0
Parity	**0**	382	87.1	0.77	Underweight	2.3	2.5	0.0	0.0
					Normal Weight	1.7	53.7	0.7	0.1
					Overweight	0.0	4.4	21.2	0.2
					Obese	0.0	2.3	1.0	10.0
	≥ 1	352	87.3	0.81	Underweight	3.5	0.0	0.0	0.0
					Normal Weight	0.2	43.6	3.5	0.0
					Overweight	0.0	1.1	23.2	1.3
					Obese	0.0	0.0	6.5	17.1
Singleton	**Yes**	702	87.4	0.80	Underweight	2.7	1.3	0.0	0.0
					Normal Weight	0.9	48.7	2.1	0.0
					Overweight	0.0	2.6	22.3	0.7
					Obese	0.0	1.1	3.9	13.6
	No	32	70.3	0.58	Underweight	14.3	0.0	0.0	0.0
					Normal Weight	4.2	31.1	5.9	0.0
					Overweight	0.0	12.6	9.5	7.0
					Obese	0.0	0.0	0.0	15.5
First trimester prenatal care	**Yes**	617	90.3	0.84	Underweight	2.7	0.8	0.0	0.0
					Normal Weight	0.4	51.5	1.7	0.1
					Overweight	0.0	2.3	22.8	0.8
					Obese	0.0	0.6	3.1	13.3
	No	76	68.0	0.55	Underweight	4.1	4.2	0.0	0.0
					Normal Weight	4.2	25.4	5.1	0.0
					Overweight	0.0	5.2	22.2	0.1
					Obese	0.0	4.0	9.2	16.3
WIC enrollment	**Yes**	350	84.4	0.77	Underweight	1.8	1.4	0.0	0.0
					Normal Weight	1.5	35.8	2.5	0.0
					Overweight	0.0	2.7	28.8	0.2
					Obese	0.0	1.1	6.3	17.9
	No	378	90.5	0.81	Underweight	4.1	1.1	0.0	0.0
					Normal Weight	0.2	63.3	1.8	0.1
					Overweight	0.0	2.7	14.4	1.4
					Obese	0.0	1.1	1.1	8.7
Medicaid enrollment	**Yes**	358	82.4	0.73	Underweight	1.8	2.3	0.0	0.0
					Normal Weight	1.5	39.5	3.5	0.0
					Overweight	0.0	3.7	26.7	0.4
					Obese	0.0	1.1	5.3	14.3
	No	375	92.7	0.87	Underweight	4.1	0.1	0.0	0.0
					Normal Weight	0.3	58.7	0.7	0.1
					Overweight	0.0	1.6	17.0	1.2
					Obese	0.0	1.1	2.2	12.9
	Yes	91	68.5	0.54	Underweight	2.9	0.9	0.0	0.0

Any smoking during pregnancy					Normal Weight	0.0	24.0	1.1	0.0
					Overweight	0.0	5.2	8.7	2.0
					Obese	0.0	0.0	22.3	32.9
	No	642	87.8	0.80	Underweight	2.9	1.2	0.0	0.0
					Normal Weight	1.0	49.3	2.2	0.0
					Overweight	0.0	2.6	22.7	0.7
					Obese	0.0	1.1	3.2	13.0
Gestational diabetes	**Yes**	33	68.3	0.56	Underweight	0.0	15.5	0.0	0.0
					Normal Weight	0.0	19.7	1.7	0.0
					Overweight	0.0	0.8	27.7	0.7
					Obese	0.0	0.0	13.0	20.9
	No	695	87.8	0.80	Underweight	3.0	0.7	0.0	0.0
					Normal Weight	1.0	49.9	2.2	0.0
					Overweight	0.0	2.8	22.0	0.8
					Obese	0.0	1.1	3.5	12.9
Pre-gestational or gestational diabetes	**Yes**	40	75.9	0.65	Underweight	0.0	11.8	0.0	0.0
					Normal Weight	0.0	15.0	1.3	0.0
					Overweight	0.0	0.7	31.4	0.5
					Obese	0.0	0.0	9.8	29.5
	No	691	87.8	0.80	Underweight	3.0	0.7	0.0	0.0
					Normal Weight	1.0	50.2	2.2	0.0
					Overweight	0.0	2.8	21.7	0.8
					Obese	0.0	1.2	3.6	12.8
Gestational hypertension	**Yes**	41	67.1	0.52	Underweight	0.0	0.0	0.0	0.0
					Normal Weight	0.0	40.2	2.9	2.5
					Overweight	0.0	0.0	10.7	0.0
					Obese	0.0	2.5	25.1	16.3
	No	689	87.6	0.80	Underweight	2.9	1.3	0.0	0.0
					Normal Weight	0.9	48.6	2.2	0.0
					Overweight	0.0	2.7	22.4	0.8
					Obese	0.0	1.1	3.4	13.6
Any hypertensive conditions before or during pregnancy	**Yes**	59	71.8	0.58	Underweight	1.9	0.0	0.0	0.0
					Normal Weight	0.0	43.5	2.2	1.9
					Overweight	0.0	0.0	9.6	0.0
					Obese	0.0	1.9	22.1	16.7
	No	672	87.6	0.80	Underweight	2.9	1.3	0.0	0.0
					Normal Weight	1.0	48.6	2.2	0.0
					Overweight	0.0	2.8	22.5	0.8
					Obese	0.0	1.1	3.4	13.6
Preterm birth	**Yes**	145	83.9	0.76	Underweight	4.4	1.5	0.0	0.0
					Normal Weight	1.3	28.5	3.8	0.0
					Overweight	0.0	3.1	35.8	0.7
					Obese	0.0	0.0	5.7	15.2
	No	589	87.5	0.80	Underweight	2.7	1.2	0.0	0.0
					Normal Weight	0.9	50.3	2.0	0.1
					Overweight	0.0	2.7	21.0	0.8
					Obese	0.0	1.2	3.7	13.5
Birth weight	**Small-for-gestational age**	143	82.2	0.70	Underweight	1.8	0.6	0.0	0.0
					Normal Weight	1.7	47.8	5.8	0.4
					Overweight	0.0	0.0	29.1	4.2
					Obese	0.0	0.4	4.7	3.4
	Average-for-	501	87.4	0.80	Underweight	3.1	1.4	0.0	0.0

gestational age								
				Normal Weight	0.8	49.5	1.7	0.0
				Overweight	0.0	3.1	19.9	0.2
				Obese	0.0	1.3	4.0	14.9
Large-for-gestational age	57	99.0	0.98	Underweight	0.0	0.0	0.0	0.0
				Normal Weight	0.0	37.3	0.0	0.0
				Overweight	0.0	0.0	45.4	1.0
				Obese	0.0	0.0	0.0	16.3

[a]All characteristics are derived from birth certificate

Supplemental Table 9: Agreement in Pre-Pregnancy BMI Classification by PRAMS Questionnaire Compared to Medical Record, Stratified by Covariates of Interest

						Medical Record			
Characteristic[a]	**Level**	**n**	**Crude Agreement**	**κ**	**PRAMS Questionnaire**	**Under-weight (%)**	**Normal Weight (%)**	**Over-weight (%)**	**Obese (%)**
Overall		**734**	**83.6**	**0.73**	Underweight	**2.8**	**1.4**	**0.8**	**0.0**
					Normal Weight	**1.0**	**47.9**	**5.6**	**0.1**
					Overweight	**0.0**	**2.1**	**19.6**	**1.1**
					Obese	**0.0**	**2.1**	**2.3**	**13.3**
Maternal age	**< 20 years**	43	72.9	0.55	Underweight	0.9	8.3	0.0	0.0
					Normal Weight	0.0	48.7	1.9	0.0
					Overweight	0.0	0.5	14.8	1.0
					Obese	0.0	7.8	7.8	8.4
	20-24 years	160	82.6	0.74	Underweight	1.0	1.0	0.0	0.0
					Normal Weight	0.7	36.9	6.2	0.2
					Overweight	0.0	3.3	21.8	0.9
					Obese	0.0	2.5	2.7	22.8
	25-29 years	203	78.3	0.67	Underweight	6.2	0.0	3.5	0.0
					Normal Weight	3.2	43.1	3.7	0.2
					Overweight	0.0	2.6	16.4	3.3
					Obese	0.0	2.7	2.5	12.6
	30-34 years	196	85.6	0.72	Underweight	2.2	1.8	0.0	0.0
					Normal Weight	0.4	60.3	5.5	0.1
					Overweight	0.0	2.5	14.6	0.3
					Obese	0.0	1.6	2.1	8.6
	≥ 35 years	132	90.6	0.85	Underweight	2.4	0.0	0.0	0.0
					Normal Weight	0.4	44.6	8.4	0.0
					Overweight	0.0	0.5	29.7	0.1
					Obese	0.0	0.0	0.0	13.9
Maternal education	**< 12 years**	87	68.7	0.55	Underweight	0.5	3.1	4.0	0.0
					Normal Weight	0.0	28.3	10.8	0.0
					Overweight	0.0	0.2	18.5	0.3
					Obese	0.0	6.2	6.6	21.4
	12 years	199	87.1	0.79	Underweight	3.1	2.2	0.0	0.0
					Normal Weight	2.7	48.7	6.1	0.1
					Overweight	0.0	0.8	23.2	0.9
					Obese	0.0	0.0	0.1	12.2
	> 12 years	446	86.9	0.77	Underweight	3.4	0.3	0.0	0.0
					Normal Weight	0.5	54.3	3.6	0.1
					Overweight	0.0	3.4	18.1	1.5
					Obese	0.0	1.8	1.9	11.1

Race/ethnicity	**Non-Hispanic White**	506	85.9	0.72	Underweight	3.9	0.4	0.1	0.0
					Normal Weight	0.4	62.3	7.1	0.1
					Overweight	0.0	3.2	9.8	2.6
					Obese	0.0	0.0	0.2	9.9
	Non-Hispanic Black	53	74.2	0.63	Underweight	3.9	0.0	4.5	0.0
					Normal Weight	0.6	15.3	8.5	0.0
					Overweight	0.0	5.4	17.5	0.3
					Obese	0.0	6.5	0.0	37.5
	Hispanic	94	87.7	0.80	Underweight	0.3	0.2	0.0	0.0
					Normal Weight	0.2	42.1	4.9	0.1
					Overweight	0.0	0.2	34.7	0.2
					Obese	0.0	3.2	3.4	10.5
	Mixed or Other Race	81	79.0	0.57	Underweight	4.3	8.0	0.0	0.0
					Normal Weight	4.8	61.9	0.6	0.2
					Overweight	0.0	0.2	11.9	0.0
					Obese	0.0	0.0	7.2	1.0
Marital status	**Married**	460	88.2	0.80	Underweight	3.2	1.0	0.0	0.0
					Normal Weight	0.4	54.3	4.1	0.2
					Overweight	0.0	2.2	19.4	1.1
					Obese	0.0	0.8	1.9	11.4
	Non-married	273	76.4	0.64	Underweight	2.1	1.9	1.9	0.0
					Normal Weight	2.0	38.0	8.0	0.0
					Overweight	0.0	1.9	19.9	1.0
					Obese	0.0	4.2	2.8	16.3
Parity	**0**	382	84.9	0.73	Underweight	3.4	1.8	0.1	0.0
					Normal Weight	0.6	56.3	4.0	0.1
					Overweight	0.0	2.6	15.6	0.6
					Obese	0.0	2.2	3.3	9.6
	≥ 1	352	82.4	0.73	Underweight	2.2	1.0	1.4	0.0
					Normal Weight	1.4	40.2	7.1	0.1
					Overweight	0.0	1.6	23.3	1.5
					Obese	0.0	2.0	1.3	16.7
Singleton	**Yes**	702	83.8	0.74	Underweight	2.7	1.4	0.8	0.0
					Normal Weight	0.9	48.0	5.5	0.1
					Overweight	0.0	2.1	19.8	1.1
					Obese	0.0	2.1	2.3	13.2

	No	32	67.8	0.50	Underweight	8.4	0.0	0.0	0.0
					Normal Weight	10.1	38.0	15.3	0.0
					Overweight	0.0	5.7	0.0	1.0
					Obese	0.0	0.0	0.0	21.5
First trimester prenatal care	**Yes**	617	85.7	0.76	Underweight	1.9	0.2	0.9	0.0
					Normal Weight	1.2	52.1	5.9	0.1
					Overweight	0.0	2.3	18.8	1.2
					Obese	0.0	0.6	1.9	12.9
	No	76	77.0	0.68	Underweight	8.1	4.6	0.0	0.0
					Normal Weight	0.2	25.5	4.7	0.0
					Overweight	0.0	1.3	27.2	0.3
					Obese	0.0	7.4	4.7	16.2
WIC enrollment[b]	**Yes**	362	83.2	0.75	Underweight	1.8	1.5	1.3	0.0
					Normal Weight	1.6	37.4	6.0	0.1
					Overweight	0.0	0.4	25.6	0.7
					Obese	0.0	1.1	4.0	18.4
	No	368	84.9	0.70	Underweight	4.0	0.1	0.1	0.0
					Normal Weight	0.4	61.1	5.2	0.2
					Overweight	0.0	4.2	12.6	1.5
					Obese	0.0	3.4	0.2	7.2
Medicaid enrollment[b]	**Yes**	322	79.8	0.69	Underweight	1.9	1.7	1.5	0.0
					Normal Weight	1.7	39.0	9.5	0.1
					Overweight	0.0	0.1	22.9	0.8
					Obese	0.0	1.2	3.6	15.9
	No	412	87.2	0.77	Underweight	3.6	1.0	0.0	0.0
					Normal Weight	0.4	56.3	1.9	0.1
					Overweight	0.0	4.0	16.5	1.3
					Obese	0.0	3.0	1.0	10.8
Smoking in last 3 months of pregnancy[b]	**Yes**	103	84.5	0.75	Underweight	1.1	1.8	0.0	0.0
					Normal Weight	0.0	46.1	1.9	0.0
					Overweight	0.0	8.5	14.0	3.3
					Obese	0.0	0.0	0.0	23.3
	No	621	84.3	0.75	Underweight	3.0	0.8	0.8	0.0
					Normal Weight	1.1	48.0	5.9	0.1
					Overweight	0.0	1.7	20.4	0.9
					Obese	0.0	2.3	1.9	12.9
Gestational diabetes[b]	**Yes**	54	80.5	0.73	Underweight	9.4	0.0	0.0	0.0
					Normal Weight	8.0	29.2	0.9	0.4
					Overweight	0.0	0.9	22.6	0.9
					Obese	0.0	0.0	8.4	19.3

	No	674	84.3	0.74	Underweight	2.3	0.9	0.8	0.0
					Normal Weight	0.5	49.6	6.0	0.1
					Overweight	0.0	2.2	19.4	1.1
					Obese	0.0	2.3	1.8	12.9
Pre-gestational or gestational diabetes[b]	**Yes**	66	84.4	0.78	Underweight	7.7	0.0	0.0	0.0
					Normal Weight	6.3	23.7	0.7	0.3
					Overweight	0.0	0.7	22.9	1.0
					Obese	0.0	0.0	6.6	30.1
	No	667	84.0	0.73	Underweight	2.3	1.0	0.8	0.0
					Normal Weight	0.5	50.6	6.1	0.1
					Overweight	0.0	2.3	19.4	1.1
					Obese	0.0	2.3	1.8	11.7
Any hypertensive conditions before or during pregnancy[b]	**Yes**	99	88.5	0.81	Underweight	0.5	0.0	0.0	0.0
					Normal Weight	0.0	45.8	0.9	0.5
					Overweight	0.0	1.9	10.5	2.1
					Obese	0.0	5.3	0.8	31.7
	No	618	83.9	0.74	Underweight	3.1	1.0	0.9	0.0
					Normal Weight	1.2	48.4	6.1	0.1
					Overweight	0.0	2.2	20.6	1.0
					Obese	0.0	1.8	1.9	11.8
Preterm birth	**Yes**	145	78.4	0.67	Underweight	3.6	1.5	0.0	0.0
					Normal Weight	2.1	30.4	13.0	0.1
					Overweight	0.0	1.2	31.6	2.9
					Obese	0.0	0.0	0.8	12.9
	No	589	84.1	0.74	Underweight	2.7	1.3	0.8	0.0
					Normal Weight	0.9	49.5	4.9	0.1
					Overweight	0.0	2.2	18.5	0.9
					Obese	0.0	2.3	2.4	13.3
Birth weight	**Small-for-gestational age**	143	71.9	0.52	Underweight	1.5	1.3	6.5	0.0
					Normal Weight	1.9	45.7	11.1	0.4
					Overweight	0.0	1.9	22.0	4.9
					Obese	0.0	0.0	0.0	2.6
	Average-for-gestational age	501	85.2	0.76	Underweight	3.1	1.5	0.0	0.0
					Normal Weight	0.8	49.1	5.0	0.0
					Overweight	0.0	2.2	18.5	0.6
					Obese	0.0	2.6	2.1	14.5
	Large-for-gestational	57	88.2	0.82	Underweight	0.0	0.0	0.0	0.0

age					
	Normal Weight	0.0	37.3	0.6	1.0
	Overweight	0.0	0.0	35.2	0.6
	Obese	0.0	0.0	9.6	15.7

[a]All characteristics are derived from birth certificate unless otherwise notes
[b]Derived from the PRAMS Questionnaire

Supplemental Table 10: Agreement in Gestational Weight Gain Classification by Birth Certificate Compared to Medical Record, Stratified by Covariates of Interest

						Medical Record		
Characteristic[a]	**Level**	**n**	**Crude Agreement**	**κ**	**Birth Certificate**	**Below Recs. (%)**	**Within Recs. (%)**	**Above Recs. (%)**
Overall		**521**	**69.7**	**0.54**	Below Recs.	**17.6**	**11.2**	**2.2**
					Within Recs.	**5.2**	**18.7**	**4.1**
					Above Recs.	**1.6**	**6.0**	**33.5**
Maternal age	**< 20 years**	32	80.5	0.71	Below Recs.	18.5	0.0	10.2
					Within Recs.	0.1	31.5	8.7
					Above Recs.	0.6	0.0	30.5
	20-24 years	120	75.6	0.62	Below Recs.	19.9	11.9	0.0
					Within Recs.	4.7	14.9	3.3
					Above Recs.	0.0	4.5	40.8
	25-29 years	144	68.9	0.52	Below Recs.	10.1	10.6	3.9
					Within Recs.	0.2	23.5	0.5
					Above Recs.	8.3	7.6	35.3
	30-34 years	140	63.4	0.44	Below Recs.	13.9	10.7	2.0
					Within Recs.	10.7	18.4	4.2
					Above Recs.	0.0	9.0	31.1
	≥ 35 years	85	69.6	0.55	Below Recs.	28.0	16.6	0.0
					Within Recs.	3.7	13.6	6.7
					Above Recs.	0.0	3.6	27.9
Maternal education	**< 12 years**	59	69.8	0.54	Below Recs.	13.5	7.9	0.0
					Within Recs.	7.3	24.7	0.2
					Above Recs.	6.5	8.2	31.6
	12 years	141	78.2	0.67	Below Recs.	21.0	7.4	3.4
					Within Recs.	3.2	20.4	7.3
					Above Recs.	0.0	0.6	36.8
	> 12 years	320	65.0	0.48	Below Recs.	17.5	14.8	2.5
					Within Recs.	5.4	15.0	4.1
					Above Recs.	0.2	8.0	32.6
Race/ethnicity	**Non-Hispanic White**	376	77.4	0.64	Below Recs.	15.2	6.4	2.2
					Within Recs.	2.5	20.9	4.5
					Above Recs.	0.2	6.7	41.3
	Non-Hispanic Black	28	--[b]	--	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
	Hispanic	63	61.7	0.42	Below Recs.	12.3	16.4	1.6
					Within Recs.	6.5	19.6	6.8
					Above Recs.	0.2	6.7	29.8
	Mixed or Other Race	54	71.5	0.56	Below Recs.	29.7	8.2	4.4
					Within Recs.	11.6	21.9	0.0
					Above Recs.	0.0	4.2	19.9
Marital status	**Married**	338	69.9	0.55	Below Recs.	22.8	12.1	2.2
					Within Recs.	6.0	16.5	4.2
					Above Recs.	0.2	5.4	30.5
	Non-married	182	69.6	0.52	Below Recs.	9.6	9.8	2.1
					Within Recs.	4.0	21.9	4.0

					Above Recs.	3.7	6.9	38.0
Parity	**0**	267	73.6	0.60	Below Recs.	13.7	13.4	3.0
					Within Recs.	4.7	23.3	1.8
					Above Recs.	0.2	3.3	36.6
	≥ 1	254	66.3	0.49	Below Recs.	21.0	9.2	1.4
					Within Recs.	5.7	14.6	6.2
					Above Recs.	2.7	8.4	30.8
First trimester prenatal care	**Yes**	438	71.8	0.57	Below Recs.	19.0	10.4	2.5
					Within Recs.	4.7	19.2	4.1
					Above Recs.	1.1	5.5	33.6
	No	49	61.6	0.41	Below Recs.	10.9	21.0	0.9
					Within Recs.	6.1	11.1	5.6
					Above Recs.	0.0	4.7	39.6
WIC enrollment	**Yes**	248	70.9	0.55	Below Recs.	14.8	9.5	2.8
					Within Recs.	5.7	18.8	5.0
					Above Recs.	2.6	3.6	37.3
	No	270	68.4	0.53	Below Recs.	20.9	13.3	1.4
					Within Recs.	4.7	18.6	3.0
					Above Recs.	0.2	9.0	28.8
Medicaid enrollment	**Yes**	246	69.2	0.54	Below Recs.	17.6	11.3	2.6
					Within Recs.	4.1	21.9	2.9
					Above Recs.	2.7	7.2	29.6
	No	274	70.0	0.54	Below Recs.	17.7	11.2	1.7
					Within Recs.	6.7	15.1	5.6
					Above Recs.	0.2	4.7	37.1
Any smoking during pregnancy	**Yes**	64	88.0	0.74	Below Recs.	14.2	2.9	0.0
					Within Recs.	0.2	7.4	4.7
					Above Recs.	0.0	4.1	66.5
	No	457	69.2	0.54	Below Recs.	17.7	11.4	2.2
					Within Recs.	5.4	19.0	4.1
					Above Recs.	1.6	6.0	32.6
Gestational diabetes	**Yes**	20	78.4	0.63	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
	No	500	69.4	0.54	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
Pre-gestational or gestational diabetes	**Yes**	24	78.4	0.63	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
	No	497	69.4	0.54	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
Gestational hypertension	**Yes**	25	92.3	0.87	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
	No	495	69.4	0.54	Below Recs.	--	--	--
					Within Recs.	--	--	--
					Above Recs.	--	--	--
	Yes	36	89.2	0.82	Below Recs.	38.2	4.7	0.0

Any hypertensive conditions before or during pregnancy					Within Recs.	0.3	10.5	0.0
					Above Recs.	3.5	2.2	40.5
	2.No	485	69.4	0.54	Below Recs.	17.2	11.3	2.2
					Within Recs.	5.3	18.8	4.2
					Above Recs.	1.5	6.1	33.4
Birth weight	**Small-for-gestational age**	107	77.3	0.66	Below Recs.	14.9	12.5	0.0
					Within Recs.	1.7	26.5	0.7
					Above Recs.	0.5	7.2	36.0
	Average-for-gestational age	361	69.3	0.54	Below Recs.	18.8	11.3	2.7
					Within Recs.	6.2	17.9	4.2
					Above Recs.	1.8	4.5	32.7
	Large-for-gestational age	53	62.2	0.37	Below Recs.	8.8	7.9	0.0
					Within Recs.	0.5	14.7	8.3
					Above Recs.	0.6	20.5	38.8

[a]All characteristics are derived from birth certificate unless otherwise notes
[b]Insufficient sample size

Supplemental Table 11: Mean and Distribution of Reporting Error in Maternal Height and Weight Data Reported on the Birth Certificate or PRAMS Questionnaire Compared to the Medical Record for Women with Complete Height and Weight Data

		Medical Record		Birth Certificate				PRAMS Questionnaire		
				Distribution of Reporting Error (%)				Distribution of Reporting Error (%)		
	n	Mean (95% CI)	Mean Difference[a] (95% CI)	Underreport > 2.5 cm, > 2.3 kg or > 1kg/m²	Report within ± 2.5 cm, ± 2.3 kg or ± 1 kg/m²	Over-report > 2.5 cm, > 2.3 kg or > 1k g/m²	Mean Difference (95% CI)	Underreport > 2.5 cm, > 2.3 kg or > 1kg/m²	Report within ± 2.5 cm, ± 2.3 kg or ± 1 kg/m²	Over-report > 2.5 cm, > 2.3 kg or > 1k g/m²
Height (cm)	633	161.6 (160.5, 162.7)	0.0 (-0.4, 0.4)	3.9	91.8	4.4	0.4 (-0.1, 0.8)	3.5	89.8	6.6
Pre-pregnancy weight (kg)	633	66.0 (63.8, 68.2)	-0.2 (-0.7, 0.3)	11.5	80.7	7.8	-0.6 (-1.4, 0.2)	18.1	72.0	10.0
Pre-pregnancy BMI (kg/m2)	633	25.2 (24.4, 26.0)	0.0 (-0.3, 0.3)	17.3	71.7	11.0	-0.3 (-0.6, 0.0)	24	63.3	12.7
Delivery weight (kg)	633	79.1 (76.8, 81.4)	-0.7 (-1.3, 0.0)	13.9	81.1	5.0	--	--	--	--
Gestational weight gain (kg)	633	13.1 (12.2, 14.0)	-0.5 (-1.3, 0.3)	20.0	64.9	15.0	--	--	--	--

[a]Mean difference calculated as Birth Certificate or PRAMS Questionnaire – Medical Record

[b]Data not collected on the PRAMS Questionnaire

Chapter 8 – Summary, Implications and Conclusions

Main Findings

Gestational weight gain is associated with important health outcomes for both mothers and their infants. In 2009, the Institute of Medicine (IOM) revised gestational weight gain recommendations, which balance risks associated with too little or too much gain in order to promote optimal maternal and infant health. Despite important health outcomes associated with weight gain outside recommendations, surveillance data on gestational weight gain are lacking in the United States and there is little research on maternal and healthcare factors that may influence weight gain outside recommendations. In this dissertation, we undertook several analyses to fill these critical data gaps related to prevalence and determinants of gestational weight gain.

Our first analysis examined the prevalence of gestational weight gain below, within and above the 2009 IOM recommendations (referred to as inadequate, appropriate and excessive, respectively). To produce the most comprehensive prevalence estimates possible, we combined 2013 National Vital Statistics System (NVSS) birth data from 43 jurisdictions that had adopted the 2003 revised birth certificate with 2012 data from five additional states participating in the Pregnancy Risk Assessment Monitoring System (PRAMS). Among women delivering full-term, singleton infants, we found nearly half of women had excessive gestational weight gain, whereas approximately 20% had inadequate and 32% had appropriate weight gain. The prevalence of inadequate, appropriate and excessive gestational weight gain varied by jurisdiction: 20 states and New York City had a prevalence of inadequate gain that was ≥20%, whereas 17 states

had a prevalence of excessive gain that was ≥ 50%. In nearly every state, overweight women had the highest prevalence of excessive gestational weight gain. To our knowledge, these findings represent the first nearly national prevalence estimates of gestational weight gain since the release of the 2009 IOM recommendations and can serve as a benchmark for future surveillance activities related to gestational weight gain.

Next, we examined maternal characteristics that may influence women's weight gain outside gestational weight gain recommendations. For this analysis, we combined PRAMS data from 28 states in 2010 and 2011 and examined demographic, behavioral, psychosocial and medical characteristics that had been previously identified by the IOM as potential determinants for inadequate or excessive gestational weight gain. Pre-pregnancy BMI was among the factors most strongly associated with excessive weight gain, such that overweight and obese women had more than twice the odds of excessive gain compared with normal weight women after controlling for covariates. Because the 2009 IOM recommendations are specific to pre-pregnancy BMI category, we examined the association between maternal characteristics and weight gain outside recommendations separately for underweight, normal weight, overweight and obese women. Most characteristics associated with gestational weight gain were demographic and varied by pre-pregnancy BMI category. For example, non-Hispanic black, Hispanic, and Asian race/ethnicity was associated with inadequate gain primarily among normal weight women. Few behavioral characteristics were associated with gestational weight gain; notably, smoking cessation was associated with excessive gain among normal

weight and obese women only. Our findings may be useful to clinicians or public health practitioners for identifying at-risk subgroups of women.

The 2009 IOM recommendations have been adopted by clinical organizations that guide healthcare practice, including the American College of Obstetricians and Gynecologists (ACOG). In our third analysis, we estimated the proportion of women receiving advice from a healthcare provider that was consistent with the IOM recommendations. Using data from four PRAMS states in 2010 and 2011, we found only 26% of women reported receiving advice from a healthcare provider that was consistent with the IOM recommendations. We found healthcare provider advice influenced women's actual weight gain during pregnancy, however, associations varied by pre-pregnancy BMI category. Specifically, compared with women receiving IOM-consistent advice, underweight and normal weight women who received advice below the IOM recommendations were more likely to have inadequate weight gain; conversely, normal weight, overweight and obese women who received advice above the IOM recommendations were more likely to have excessive gain. The low proportion of women receiving healthcare provider advice consistent with IOM recommendations suggests providers may benefit from campaigns that promote awareness of the IOM recommendations; alternatively, interventions may be needed to equip providers with the confidence and skills to approach potentially sensitive topics, such as weight-related issues.

Because birth certificate and PRAMS data are valuable for meeting surveillance and research needs related to pre-pregnancy BMI and gestational weight gain, our final analysis evaluated the quality of these variables by comparing them to information abstracted from medical records, which we considered to be the standard. Data for this study came from two PRAMS sites (New York City and Vermont) that had participated in a data quality study. Compared to values abstracted from medical records, we found overall mean differences in height or weight variables from the birth certificate or PRAMS questionnaire were small (less than 1 cm or 1 kg). Pre-pregnancy weight form the birth certificate and PRAMS questionnaire were within ± 2.3 kg (5 lbs) of medical record values for approximately 75% and 68% of women, respectively. Delivery weight and gestational weight gain from the birth certificate were within ± 2.3kg (5lbs) of medical record values for approximately 80% and 64%, respectively. Compared to medical record data, agreement in pre-pregnancy BMI categories from the birth certificate was higher than from the PRAMS questionnaire (87% vs 84%); agreement in gestational weight gain categories (inadequate, adequate, and excessive) from the birth certificate was approximately 70%. In evaluating the quality of maternal height and weight data on the birth certificate and PRAMS questionnaire, we provide insight into the quality of these variables that will be useful for future research and surveillance activities.

Strengths and Limitations

A major strength of all analyses in this dissertation is the use of representative data sources that more closely reflect the population of women giving birth in the US; notably, the majority of previous studies relied on data from small, clinic-based samples, which

may not be representative of the whole population. Our analysis examining the prevalence of inadequate, adequate and excessive gestational weight gain utilized NVSS birth data representative of 43 jurisdictions that had adopted the 2003 revised birth certificate by 2013, and also utilized PRAMS data representative of five states. The use of NVSS and PRAMS data allowed us to produce the most comprehensive prevalence estimates possible and provide baseline data for future surveillance activities and public health objectives, such as those developed for the Healthy People goals (1). While these data are representative of a majority of births in the United States in 2013, they are not nationally representative. The IOM has called for ongoing, national monitoring of gestational weight gain (2). Our research group has continued these efforts by publishing gestational weight gain prevalence estimates using data from 48 states and the District of Columbia that had adopted the revised birth certificate by 2015 (3). Future work will be needed to continue leveraging revised birth certificate data to provide continuous surveillance of gestational weight gain.

In revising the gestational weight gain recommendations, the IOM specifically recommended that future research utilize large, representative data sources in order to reflect the current population of women giving birth in the US (2). In this dissertation, our analyses addressed this recommendation: our analysis examining maternal characteristics associated with gestational weight gain utilized PRAMS data representative of 28 states, whereas our analysis examining healthcare provider advice and gestational weight gain used PRAMS data representative of four states. It is important to note, however, that our analyses may not be completely generalizable to the

underlying populations due to missing data. Missing data may influence the generalizability of our findings when the subpopulation included in analyses differs from the target population and, unfortunately, this was the case in some of our analyses. Furthermore, missing data may introduce bias into estimates of association when the missing data mechanism is associated with the exposure and outcome of interest. Multiple imputation is one approach used to address missing data (4, 5); however, guidance on how to apply these methods to complex surveys are still being developed (6).

PRAMS collects information on a variety of behaviors and experiences before, during and after pregnancy and allowed us to examine an extensive set of maternal characteristics associated with gestational weight gain. Unfortunately, information on physical activity and dietary behaviors during pregnancy were not available in PRAMS. Physical activity has been found to decrease during pregnancy (7), but women with higher levels of physical activity have consistently been found to have less excessive gain (8). The association between dietary behaviors during pregnancy and gestational weight gain is less clear because dietary assessment methods and control for confounding variables have varied considerably between studies; however, lower energy intake and vegetarian diets have been associated with less excessive gain in some studies (2, 8, 9). Of note, few studies have been able to examine the association between diet and gestational weight gain among large representative samples of women; the National Health and Nutrition Examination Survey (NHANES) is the only representative data

source that captures this information, but data are limited by relatively small sample sizes as pregnant women are no longer oversampled (10).

As in all surveys, quality of demographic or medical information from the birth certificate and self-reported information from the PRAMS questionnaire is a concern. On the PRAMS questionnaire, data quality may be impaired by respondent biases related to memory or social desirability. Importantly, many PRAMS questions have been pretested to evaluate respondent interpretation and formulation of answers (11). Furthermore, recent studies have examined the quality of maternal and infant health indicators on the PRAMS questionnaire and found many variables had excellent (>90%) or moderate (>70%) sensitivity when compared to data from medical records (12).

In Chapter 7, we evaluated the quality of maternal height and weight variables on the birth certificate and PRAMS questionnaire and found pre-pregnancy BMI and gestational weight gain categories are subject to misclassification. While results of our data quality study can be used to inform bias analyses in future studies, it is important to note that we compared maternal height and weights from the birth certificate or PRAMS questionnaire to medical record information obtained earlier in pregnancy; thus, our analysis reflects *relative* rather than *absolute* validity. To determine absolute validity, birth certificate and PRAMS data would need to be compared to a true gold standard – that is, height and weight measurements obtained in the preconception period.

Public Health Implications and Future Directions

These dissertation findings have implications for future public health activities on many levels. First, our analysis of NVSS birth data examining the proportion of women gaining below, within and above the 2009 IOM recommendations represents the most comprehensive gestational weight gain prevalence estimates published since the release of the revised recommendations. Importantly, state-specific and national surveillance of gestational weight gain should continue on a regular basis to enable researchers, clinicians and policy makers to gauge how many women may experience inadequate or excessive gain, identify disparities by subgroup and inform and monitor progress of intervention activities (13).

In addition to continual monitoring of gestational weight gain, enhancements to surveillance systems currently in place may be needed to provide representative data about determinants of gestational weight gain. For example, NHANES may need to resume oversampling pregnant women to provide sufficient sample sizes for analyses of dietary intake related to gestational weight gain. Pregnant women included in the NHANES sample could also provide information on physical activity via self-reported questionnaires or objective instruments, such as accelerometers, that could be lent to participants at the time of household assessments and returned at the time of the health examination. Alternatively, the PRAMS questionnaire may need to be amended to include dietary assessments (e.g. a modified version of a 26-item dietary screening questionnaire previously included in the 2009-2010 NHANES (14)), or physical activity assessment (e.g. a modified version of the Pregnancy Physical Activity Questionnaire

(15)). Assessment of healthcare providers' knowledge of gestational weight gain recommendations should also be continually assessed – both via the PRAMS questionnaire and by ACOG surveys – to provide complementary descriptions of advice regarding gestational weight gain.

Our finding that a majority of women gain outside recommendations underscores the need for researchers to identify and implement effective interventions. Interventions to reduce excessive gestational weight gain have, on average, yielded positive results; however, intervention targets (i.e. dietary vs physical activity behaviors), activities (e.g. providing face-to-face counseling vs mailed information) and intensity (e.g. one counseling session vs many) vary widely between studies and may make it difficult to identify specific strategies that are most effective (16-19). One systematic review focusing on behavior-change strategies concluded that successful interventions should combine several strategies, including 1) setting goals for daily calories or physical activity, 2) setting goals for overall weight gain, 3) self-monitoring weight gain throughout pregnancy, and 4) receiving information about consequences of excessive gestational weight gain (18). Another systematic review and meta-analysis found the efficacy of interventions varied by maternal pre-pregnancy BMI category and characteristics of the intervention (16). Specifically, interventions that promoted physical activity (e.g. by providing pedometers or holding supervised physical activity classes) were successful across pre-pregnancy BMI categories, whereas those that provided dietary and physical activity counselling (e.g. by providing face-to-face counseling sessions, mailing healthy eating and physical activity materials) were successful among

normal weight women only. Interventions promoting appropriate weight gain may need to be further tailored to culturally relevant factors, such as ideal body image, which has been found to play an important role in weight-loss interventions in non-pregnant populations (20). Our findings also indicate behaviors that increase the likelihood of excessive gain, such as smoking cessation, may need to be jointly targeted during intervention activities; notably, in non-pregnant populations, smoking cessation interventions combined with certain weight management strategies, such as physical activity, are effective at improving smoking cessation and reducing post-cessation weight gain (21). In addition to testing new strategies or combinations of strategies, future studies should replicate previous intervention approaches to identify the most effective strategies.

A growing body of literature has assessed both clinician knowledge and patient-report of healthcare provider advice and suggests providers may benefit from activities that promote knowledge of the 2009 IOM gestational weight gain recommendations (22-28). The ACOG has developed and disseminated several educational materials meant to inform clinicians about current clinical and scientific practices on topics related to weight before and during pregnancy; these materials include a Committee Opinion on gestational weight gain (29), a Practice Bulletin on obesity in pregnancy (30), and an Obesity Toolkit, which provides additional guidance on screening for obesity, engaging with patients about weight loss, and other treatment options (31). The dissemination of obesity-related materials has been associated with higher proportions of clinicians reporting appropriate weight management practices among non-pregnant patients (32);

however, evaluation of gestational weight gain-specific materials is needed. Furthermore, additional in-depth information about gestational weight gain, similar to what is provided in the Obesity Toolkit, may be needed to provide clinicians with the detailed knowledge about gestational weight gain recommendations and strategies to promote appropriate weight gain.

In addition to promoting knowledge of the gestational weight gain recommendations, clinicians may require interventions that address barriers to providing weight-related advice; these barriers may include lack of training on counseling techniques and concern over sensitivity of weight-related topics (22, 33). To our knowledge, no interventions have addressed barriers to providing weight-related advice among healthcare providers that interact with pregnant women (34), although one trial is underway to evaluate training healthcare providers on the use of IOM materials in promoting appropriate gestational weight gain (35). Examples from the general (non-pregnant) population suggest physicians trained on weight-related counseling techniques may provide better guidance about weight-loss strategies when assessed by their obese patients (36) and weight loss counseling may improve patients' motivation to lose weight (37, 38). Brief behavioral counseling on weight loss from a healthcare provider has been found to produce modest weight loss (less than approximately 5 lbs) among non-pregnant populations; weight loss has been found to increase slightly when healthcare provider counseling is combined with more frequent advice from a nurse or dietitian (39). Taken together, studies from non-pregnant populations suggest that training clinicians on weight-related counseling techniques may enhance delivery of effective gestational

weight gain advice, and it is possible this advice may promote appropriate gain. Future work will be needed to evaluate training initiatives and whether these strategies promote appropriate gestational weight gain.

While patient-centered and clinician-focused interventions will be needed to promote appropriate weight gain, future activities may also need to focus more broadly on social norms and information sources commonly used by pregnant women. The notion of "eating for two" during pregnancy has been posited as a social norm that may overshadow messages from clinicians about healthy eating and exercise habits and, as a result, may indirectly influence women's weight gain during pregnancy (40). Indeed, among non-pregnant populations, social norms have been associated with dietary practices, including consumption of fruits and vegetables (41). Perceptions about physical activity causing pregnancy complications (e.g. preterm birth, fetal injury) may also prevent women from being physically active during pregnancy (42). Moreover, studies have found that women often turn to the internet as a source of information about pregnancy-related topics, with nutrition frequently being a research topic of interest (43); unfortunately, many websites provide incomplete or inaccurate information, or do not provide specific weight gain recommendations, thus limiting the utility of this information (44). It is possible that inaccurate information on the internet or elsewhere may reinforce social norms and contribute to promoting unhealthy weight gain. Future work will likely need to improve the quality of information sources on the internet and address social norms, possibly through public health campaigns that promote healthy

eating and physical activity and direct women to reliable sources of information from the CDC, IOM or elsewhere.

Our finding that pre-pregnancy BMI category was an important determinant of gestational weight gain outside recommendations suggests interventions that promote healthy weight before pregnancy may be needed. Indeed, increasing the proportion of women entering pregnancy with a healthy weight has been recognized as a key preconception health behavior and is included as a national priority for improving overall preconception health of women (1, 45). The ACOG Obesity Toolkit (31) and Practice Bulletin (30) on obesity provide clinicians with resources that can be used to promote healthy weight among women prior to becoming pregnant; included in these documents are guidance on how to engage in conversations about weight-change behaviors and how and when to refer patients to specialists, such as dietitians. As nearly half of pregnancies in the US are unintended (46), promotion of healthy weight may need to be targeted to all women – not only those who indicate pregnancy intention. This speaks to a larger need to prevent obesity and promote healthy weight among the general population. Recently, the IOM proposed an integrated systems approach to achieve this goal (47), which includes: promoting physical activity as a routine part of life, addressing the food and beverage environment to make healthy options more available, improving marketing practices targeting children to emphasize healthy food options, encouraging healthcare providers to leverage their interactions with patients to promote healthy weight, and strengthening schools' ability to provide opportunities for physical activity and healthy

foods options (47). Future work will be needed to implement and evaluate efforts to promote healthy weight among the general population and women entering pregnancy.

Findings from this dissertation are also informative for future research activities. For example, in Chapter 7, we examined the quality of maternal height and weight variables on the birth certificate and PRAMS questionnaire by comparing these data to information abstracted from medical records. As previously noted, this analysis does not represent absolute validity because heights and weights recorded in the prenatal records may not represent true preconception values. Thus, future studies should strive to attain measured heights and weights in the preconception period to use as a gold standard when evaluating the quality of medical record and birth certificate information. Medical record information from large, integrated health care systems that service non-pregnant and pregnant populations may be a potential source of information for such a study (48); however, quality of anthropometric measurements during routine care may remain a concern.

Nevertheless, results from Chapter 7 provide insight into relative data quality of maternal height and weight variables, and can be used to assess and adjust for misclassification. For example, contingency tables presenting the agreement between birth certificate and medical record gestational weight gain categories can be used to inform bias parameters in probabilistic bias analyses (49). In this type of analysis, bias parameters generally take the form of predictive probabilities (e.g. the probability of truly having had excessive weight gain [based on the medical record] given being classified as having had excessive

gain [based on the birth certificate]). Monte Carlo sampling techniques are used to repeatedly sample from distributions informed by bias parameters; selected parameters are then used to re-classify gestational weight gain in simulated populations. Analyses can be performed on these simulated datasets to estimate associations that represent results that would have been observed had there been no misclassification, given the specified bias parameters. Bias parameters derived from relative data quality studies (such as our own) may be unable to completely account for misclassification as birth certificate data were compared to an imperfect standard. It is also possible that correlated errors resulting from weight variables on the birth certificate and medical record relying on self-report may influence bias-adjusted associations, which has been noted in methods that correct for measurement error in dietary intakes (50, 51). Regardless, the use of bias analysis methods to understand the influence of misclassification on associations of interest will advance understanding of how data quality may influence associations of interest. To our knowledge, only one previous study has used this type of bias analysis to adjust for misclassification of gestational weight gain and only among obese women (52). While the authors concluded that the pattern of results was consistent with conventional analyses, they noted misclassification biased results both toward and away from the null; thus, bias analyses were important in understanding the direction and magnitude of these unpredictable biases. Future work is needed to continue to evaluate the influence of misclassified pre-pregnancy BMI and gestational weight gain categories on exposures and outcomes of interest, ideally using bias parameters informed by absolute validation studies.

Summary

In this dissertation, our overall objective was to further knowledge around prevalence and determinants of gestational weight gain, with the goal of providing information for clinicians, program planners, and public health officials that could be leveraged to inform practice or policies that may promote appropriate gestational weight gain. We found that nearly 50% of women in 2013 gained weight above the 2009 IOM gestational weight gain recommendations – an alarming statistic given the important short- and long-term health outcomes associated with excessive gestational gain. Clearly, interventions that promote appropriate weight gain are needed. Future research should continue to identify – and confirm – effective strategies that help women achieve recommended weight gain; importantly, research may be needed to understand how strategies should be tailored to maternal characteristics to be most effective. As only 26% of women reported receiving advice from a healthcare provider that was consistent with the 2009 IOM recommendations, future work may be needed to educate providers and address barriers to providing appropriate weight gain advice. Continued surveillance of gestational weight gain using nationally representative data sources, such as the revised birth certificate, will enable program planner and public health officials to evaluate future intervention activities that promote appropriate weight gain.

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