University of Cincinnati

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I, Erika M. Ritcher, hereby submit this original work as part of the requirements for the degree of Master of Science in Nutrition.

It is entitled:
Predictors of Excessive Gestational Weight Gain and Infant Birth Weight in Overweight and Obese Postpartum Mothers

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Predictors of Excessive Gestational Weight Gain and Infant Birth Weight in Overweight and Obese Postpartum Mothers

A thesis submitted to the
Graduate School
of the University of Cincinnati
in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in the Department of Nutritional Sciences
of the College of Allied Health Sciences
by

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Committee Chair: Grace Falciglia, Ph.D., R.D., L.D.
Abstract

Objectives. To describe the predictors associated with and occurrence of excessive gestational weight gain (GWG) in a sample of postpartum Cincinnati women. To compare the effects of pre-pregnancy body mass index (BMI, kg/m²) and GWG on fetal macrosomia (birth weight ≥ 4000g) using the 2009 Institute of Medicine recommendations.

Design. This is a secondary analysis of data derived from a study for prevention of childhood obesity.

Subjects. 116 mother-infant pairs recruited through obstetric clinics within an urban hospital in Cincinnati.

Methods. Overweight and obese postpartum women between the ages of 21-35 years with no other co-morbidities were recruited six weeks after delivery. Women were categorized according to pre-pregnancy BMI and GWG adequacy. Chi-square tests were used for the outcome of excessive GWG. Linear and multivariate logistic regression models were estimated for infant birth weight and fetal macrosomia.

Results. Within the total sample, 69.7%, 77.3%, and 84.6% of normal weight, overweight, and obese mothers had excessive weight gain during pregnancy, respectively ($p < 0.001$). Parity was significantly associated with excessive pregnancy weight gain ($p < 0.003$). Maternal GWG ($p < 0.01$) and parity ($p < 0.008$) were significantly associated with infant birth weight, however, there was no association between birth weight and pre-pregnancy BMI.
**Conclusion.** This sample of mothers was more likely to exceed weight gain recommendations and significant gains are associated with number of previous pregnancies. Regardless of pre-pregnancy BMI, excessive weight gain during pregnancy may be associated with infant birth weight.
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Introduction

Birth weight is often considered as an indicator of the health of a given society.\textsuperscript{1} An increase in a population’s mean birth weight has been associated with good prenatal care and a high standard of living.\textsuperscript{1} For many years the focus has been on increasing birth weight, which is positively correlated with maternal weight gain during pregnancy.\textsuperscript{2} Although increases in gestational weight gain (GWG) reduces the incidence of low birth weight, excess GWG has a negative impact on maternal and infant outcomes. Mothers with excessive GWG may experience caesarean section delivery, hemorrhages, hypertensive syndromes in pregnancy, and postpartum weight retention (PPWR).\textsuperscript{3} The developing neonate can be greatly affected by its prenatal environment, as it may considerably influence the health of the infant later on.\textsuperscript{4,5} High maternal pre-pregnancy body mass index (BMI) and excessive GWG are associated with increased risk of macrosomia, childhood obesity, cardiometabolic complications, and diabetes in the offspring.\textsuperscript{2,6}

Specifically focusing on fetal macrosomia, it has been well documented that GWG and pre-pregnancy BMI are important predictors of infant birth weight. While some studies suggest that GWG has a greater effect, others note that pre-pregnancy BMI plays a dominant role in the predisposition of being born large.\textsuperscript{6} Other potential risk factors for macrosomia include parental height, parity, ethnicity, maternal age, infant male gender and previous delivery of a high birth weight infant.\textsuperscript{7}

The Institute of Medicine (IOM) published new recommendations in 2009 with regard to weight gain in pregnancy to minimize adverse perinatal outcomes and optimize fetal growth. In the U.S., nearly 60% of American women enter pregnancy above a normal weight and less than 30% of women gain gestational weight within recommendations.\textsuperscript{8} As it is critical to gain a deeper understanding of the factors that hinder appropriate weight gain, one facet of this thesis
was to identify which characteristics were most strongly associated with excessive maternal weight gain and, therefore, infant birth weight. The network of factors that influence adequate maternal weight gain is unique to each mother-infant pair.

This thesis prioritized excessive weight gain as a potentially modifiable event during pregnancy that can impact not only adverse perinatal outcomes for the mother and infant, but also the long-term health of the offspring. First, maternal characteristics of overweight and obese postpartum mothers that potentially contribute to excessive weight gain were examined. Then, the study focused on two measures of maternal anthropometry: pre-pregnancy BMI and GWG, and two fetal outcomes: infant birth weight and macrosomia (birth weight ≥ 4000g). The study also assessed the relationship between unmodifiable characteristics: age, race, and parity on infant birth weight. The following research questions were explored:

- What are the maternal predictors of gestational weight gain in this population?
- What is the relationship between maternal pre-pregnancy BMI and GWG on infant birth weight in this population?
  - Is there an association between pre-pregnancy BMI and infant birth weight?
  - Is there an association between GWG and infant birth weight?
- What are the predictors of infant birth weight in this population?

In addition to the high U.S. prevalence of obesity, 59.2% of women in the greater Cincinnati area were overweight and obese in 2012. In order to provide effective education regarding the benefits of appropriate maternal weight gain, there is a need to identify current trends and predictors of weight gain and infant birth weight. This may be of particular
importance in this sample of postpartum women as maternal obesity may influence the health of the mother and infant later on.
Review of Literature

Current Trends and Prevalence of Obesity

Obesity has reached epidemic proportions in the United States, and prevalence of BMI-defined obesity in adults has shown little change since 2003. Although there appears to have been a slowing of the rate increase since the last decades of the 20th century, more than one-third of U.S. adults were obese in 2011–2012. Women of reproductive age are not immune to this national epidemic. Results from the 2009-2010 National Health and Nutrition Examination Survey estimated 55.8% of reproductive aged women (20-39 y) were overweight and obese. Among women who gave birth in 26 states and New York City in 2004-5, approximately 1 in 5 was obese; in some subgroups the prevalence was as high as one-third.

High obesity rates among adults and pregnant women parallel those seen in children. In 2009-2010, about 12.5 million U.S. children and adolescents were obese, and youth are becoming overweight and obese at earlier ages. The prevalence of obesity among children aged 2-4 years increased from 13.1% in 2001 to 14.4% in 2010. Disturbingly, obesity in neonates and in childhood, particularly in adolescence, is a key predictor for obesity in adulthood. Childhood and adolescent obesity is more prevalent in black, Hispanic, and American Indian/Alaska Natives compared to whites. These health differences are due in part to the disproportionate obesity epidemic among racial-ethnic groups in the U.S.; whereas 35% of all women > 20 years old are obese, the prevalence is higher for black (50%) and Hispanic (43%) women. Identifying factors during critical periods in early life that are predictive of obesity later in life could help reduce the incidence of obesity in the general population.
Characteristics of Maternal Obesity

The pregnancy rate for 2005 was 103.2 (per 1,000 women aged 15-44) and was highest for women in their twenties.\textsuperscript{19} Birth rates dropped more than one-third for married women while rising considerably in unmarried women. Chu et al.\textsuperscript{12} reported black women had a pre-pregnancy obesity prevalence about 70\% higher than white and Hispanic women (black: 29.1\%; white: 17.4\%; Hispanic: 17.4\%). Obesity prevalence was also 50\% higher among women whose delivery was paid for by Medicaid than by other means (e.g., private insurance, cash, HMO).\textsuperscript{12} However, these estimates may not be representative of maternal obesity in all U.S. women.

Pregnancy has been suggested to be one of the causes for developing overweight and obesity in women.\textsuperscript{20} According to the American Journal of Clinical Nutrition, pregnancy has been identified as a trigger for the development of obesity in women of reproductive age because of excessive weight gain and long-term weight retention.\textsuperscript{21} It is suggested that excessive weight gain in one pregnancy will often lead to obesity at the beginning of the next.\textsuperscript{22} Although many women return to their pre-pregnancy weight, some women retain a significant amount of weight. Weight retention associated with pregnancy can vary greatly, with as many as 20\% of women retaining $\geq$ 5 kg.\textsuperscript{23} Ohlin and Rossner report changes in body weight of -12.3 to +26.5 kg from preconception to one year postpartum.\textsuperscript{24}

Epidemiology of Gestational Weight Gain

A woman’s nutritional status, namely her body composition, height, and weight relate to the metabolic capacity of the mother and her ability to provide an environment in which the delivery of nutrients to the fetus is optimal.\textsuperscript{25} Due to the vital role nutrition plays in fetal
development, balancing the amount of weight gain needed to optimize the size of the baby without jeopardizing the health of the mother, both in the short and long term, is essential.\(^\text{26}\) There are several maternal characteristics that are consistently associated with gestational weight gain. Previous study results support influences of maternal genetic, sociodemographic, and behavioral factors on gestational weight gain.

**Maternal Weight Gain Recommendations**

Gestational weight gain (GWG) is a modifiable, easily calculated factor that may influence pregnancy outcomes. Less than half of the total weight gain of a singleton pregnancy resides in the fetus, placenta, and amniotic fluid; the remainder is found in maternal reproductive tissues, fluid, blood, and “maternal stores,” a component composed largely of fat.\(^\text{27}\) Various methods for assessing gestational weight gain have been used, including total weight gain during pregnancy, total weekly rate of weight gain and weekly rate of gain over specific trimesters or months.\(^\text{28}\) The most common calculation used in the literature is ‘total’ GWG. Total GWG is calculated by subtracting pre-pregnancy weight from weight at delivery.

In 1990, the Institute of Medicine (IOM) provided guidelines for weight gain during pregnancy based on pre-pregnancy maternal body mass index (BMI).\(^\text{29}\) However, obese women were advised to gain a minimum of 15 pounds during pregnancy and no upper limit was given. Following the publication, major increases in maternal body weight and adverse pregnancy outcomes occurred. In response, many, including the IOM, called for a reevaluation of the 1990 guidelines.\(^\text{30}\) In 2009, the IOM provided new recommendations (Table 1)\(^\text{31}\) that differ from the latter in two ways. First, they are based on the World Health Organization BMI categories rather than previous ‘low, normal, high’ categories from the Metropolitan Life Insurance tables.\(^\text{29}\) The
classes defined by the World Health Organization are: <18.5 for underweight, 18.5-24.9 normal weight, 25-29.9 overweight, and ≥30 obese. Second, the revised guidelines include a specific and relatively narrow range of recommended weight gain for obese women.²⁹

**Table 1. Recommendations for gestational weight gain, by pre-pregnancy BMI**

<table>
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<th>Classification</th>
<th>Total weight gain BMI (kg/m²)</th>
<th>Range (kg)</th>
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<td>Underweight</td>
<td>&lt; 18.5</td>
<td>12.5-18</td>
</tr>
<tr>
<td>Normal</td>
<td>18.5 – 24.9</td>
<td>11.5-16</td>
</tr>
<tr>
<td>Overweight</td>
<td>25-29.9</td>
<td>7-11.5</td>
</tr>
<tr>
<td>Obese</td>
<td>≥ 30.0</td>
<td>5-9</td>
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**Adequacy of Pregnancy Weight Gain**

In the United States, nearly 60% of American women enter pregnancy above a normal weight and less than 30% of women gain gestational weight within recommendations.⁸ This suggests that conceiving at a healthy body weight and following GWG guidelines poses a challenge to the majority of women. GWG recommendations are often exceeded in those with high pre-pregnancy BMI, given the narrow range of acceptable gain for higher BMI categories.⁶

In a population-based sample from the 2004-2005 Pregnancy Risk Assessment Monitoring System, an ongoing surveillance project of the Centers for Disease Control and Prevention (CDC), approximately 40% of normal weight and 60% of overweight women exceeded recommended limits for pregnancy weight gain.³⁰ Obese women gained the least, but one-fourth of these women gained 35 or more pounds. Because excessive weight gain is
associated with postpartum weight retention (PPWR) and higher BMI later in life, these results predict that many normal weight women will become overweight and many overweight women will become obese due to excessive pregnancy weight gain.\textsuperscript{30}

A recent review by Headen et al.\textsuperscript{17} used nationally representative data (N = >52,000) to indicate racial-ethnic differences in the prevalence of GWG based on pre-pregnancy BMI. More than 50\% of white, American Indian, and multi-race women gained excessively compared to 48, 43, and 33\% of black, Hispanic and Asian women, respectively.\textsuperscript{17} Although there was no significant racial-ethnic difference in excessive GWG, it is concerning that > 40\% of black and Hispanic women have excess GWG.\textsuperscript{17}

**Maternal Predictors**

Numerous studies have examined the maternal predictors of GWG, including biological, sociodemographic, and psychological factors. Findings from existing studies suggest excessive GWG may be associated with higher BMI before pregnancy,\textsuperscript{12, 24, 29, 32-40} increasing age,\textsuperscript{33, 39} first time pregnancy,\textsuperscript{12, 35, 37, 39} white mothers compared to other ethnicities,\textsuperscript{12, 35, 37} less maternal education,\textsuperscript{12, 29, 35} and lower income.\textsuperscript{24, 29, 33} Some studies did not find significant effects between excessive gain and parity, education level, ethnicity or marital status, while others reported GWG was higher among younger compared to older women.\textsuperscript{32, 34-37} One study of pregnant women who were receiving prenatal care included pre-pregnancy BMI from medical chart review and found that those who were overweight before pregnancy were over twice as likely as other women to gain excessive weight during pregnancy.\textsuperscript{32} Four other studies also reported overweight women to be significantly more likely to gain excessive gestational weight compared to other BMI groups.\textsuperscript{12, 29, 32, 34} Additionally, an observational study found significantly more pregnancy weight
gain in mothers who reported less perceived levels of physical activity, perceived increased food intake, and less sleep.\textsuperscript{34} Actual minutes of physical activity and total energy intake did not have a significant association with GWG. However, many of these studies were based on the 1990 IOM guidelines and relied on self-reported anthropometric data that was collected retrospectively. Understanding the determinants of pregnancy weight gain is essential for designing clinical and public health interventions to prevent overweight in mothers and their offspring.\textsuperscript{32

**Maternal Anthropometry and Adverse Outcomes**

Fetal growth is determined by a complex interplay of various genetic and environmental influences.\textsuperscript{7} Several studies have examined various relationships between maternal pre-pregnancy weight and GWG on maternal and/or neonatal outcomes (Figure 1).\textsuperscript{6,41} Current research investigates a possible relationship between pre-pregnancy BMI and GWG on infant birth weight. This, in turn, also suggests a possible correlation between macrosomia and risk of obesity in the offspring.
**Body Mass Index**

BMI, or weight in kilograms divided by height in meters squared, is a fairly reliable estimate of body fatness for most adults. According to the CDC, BMI does not measure body fat directly, but research has shown that BMI correlates to highly accurate measures of body fat such as underwater weighing and dual x-ray absorptiometry. Overweight (BMI 25-29.9) and obesity (BMI ≥ 30) are major risk factors for a number of chronic diseases, including diabetes, cardiovascular diseases and cancer.⁴²

Obesity in pregnant women is a risk factor for higher incidence of pregnancy-related hypertension, gestational diabetes, blood clots, cesarean section, longer hospital stay after childbirth, and postpartum weight retention.⁴³ Not surprisingly, obese women are four times more likely and severely obese women almost nine times more likely to develop gestational
diabetes than lean women. Maternal obesity not only poses health risks for the mother, but neonates are affected too. Given the parallel increases between maternal and offspring BMI, it has been hypothesized that high BMI during pregnancy could have a ‘programming’ effect on body composition, appetite control and energy expenditure in offspring. Obesity has considerable effects on glucose metabolism in pregnancy with a loss of the reduction in fasting glucose and significant enhancement of peripheral and hepatic insulin resistance. It is proposed that mothers transfer increased concentrations of glucose and amino acids across the placenta to the developing fetus with subsequent increased fetal secretion of insulin. This results in increased fetal growth and ‘programs’ lifelong obesity risk. Recent evidence suggests that even modest fasting hyperglycemia (between 4.2 and 5.6 mmol/L), currently thought to be within normal limits, is linearly associated with adverse pregnancy outcomes including increased birth weight, cesarean delivery and neonatal hypoglycemia.

Studies investigating the relationship between maternal obesity and fetal growth have shown that obese women have an 18-26% increased chance of delivering large-for-date infants, even after controlling for maternal diabetes. Jain et al. reported rates of macrosomia roughly 50-170% higher than women with normal BMI prior to pregnancy. Maternal obesity creates an intra-uterine environment that impacts fetal development and hence future generations.

**Gestational Weight Gain**

During periconceptual period and pregnancy, the composition of a woman’s diet is of particular importance, as it may considerably influence the health of the infant later on. Gestational weight gain reflects the exposure of the developing fetus to the prevailing nutritional environment and thus provides an opportunity to examine the influence of overnutrition as
opposed to obesity per se. Considering that 50% of pregnancies are unintended, for the vast majority of women, GWG is the only weight parameter that is modifiable once prenatal care and associated counseling are initiated. For many years the focus has been on increasing birth weight, which is positively correlated with maternal weight gain during pregnancy. However, the new 2009 IOM guidelines suggests women with a high pre-pregnancy BMI should limit weight gain. The new recommendations has as its objective restoring body fat storage levels in low-weight women and minimizing fat gain in overweight and obese women. There is yet insufficient evidence to suggest that women with a very high BMI (BMI ≥40) should lose weight in pregnancy.

Excessive GWG, aside from contributing to PPWR and risks of future obesity, is associated with several complications, among which are caesarean section delivery, hemorrhages, hypertensive syndromes in pregnancy, fetal macrosomia, and even low birth weight. When pre-pregnancy obesity is combined with excessive GWG, there is an even higher risk for negative outcomes. The risk for a caesarean section more than doubled when obese women gained excessive weight compared with obese women with a normal GWG.

The association between maternal GWG and infant birth weight is well established. GWG within the recommended levels has favorable gestational outcomes, especially on infant birth weight. Insufficient GWG is considered a risk factor for gestational complications, especially low birth weight, intrauterine growth restriction, and prematurity. Exceeding GWG recommendations, on the other hand, may increase the risk of diabetes and cardiometabolic complications in children. Excessive weight gain may result in an overproduction of insulin, thereby increasing the risk that the fetus will become macrosomic. In addition, women who
gain excessive amounts of weight may consume too many calories during pregnancy, which in turn, may further accelerate fetal growth.\textsuperscript{48}

Maternal weight gain of more than 11 kg is strongly associated with high birth weight.\textsuperscript{7} In a 2009 evidence-based review, 11 of 12 studies demonstrated an association between high pregnancy weight gain and macrosomia, however, it was unclear whether pre-pregnancy BMI modifies this relationship.\textsuperscript{41,47-49} It has been suggested that GWG does not significantly impact infant birth weight in overweight and obese women and that heavier women may deliver average to large-sized infants in the absence of weight gain or even loss.\textsuperscript{6} It is therefore important to combine maternal weight gain and pre-pregnancy BMI in analyses of the association between weight gain and infant birth weight.\textsuperscript{2}

\textbf{Fetal Macrosomia}

Fetal macrosomia is varyingly defined as either an absolute birth weight greater than 4,000 g, 4,500 g or 5,000 g, or as customized birth weight centile of greater than the 90\textsuperscript{th}, 95\textsuperscript{th} or 97\textsuperscript{th} percentile for the infant’s gestational age.\textsuperscript{7} A birth weight of 4 kg at 40 weeks corresponds to the 90\textsuperscript{th} centile, and this is consistent with a definition of large for gestational age (LGA).\textsuperscript{50}

Birth trauma rates for the macrosomic fetus appear to be more closely related to absolute birth weight rather than birth weight centile.\textsuperscript{7} LGA neonates are at risk for cardiac anomalies, neural tube defects, shoulder dystocia, cesarean delivery, intrauterine fetal demise, neonatal intensive care unit admissions, and long-term obesity.\textsuperscript{47} Having a birth weight more than 4,000 g also entails an increased risk of certain types of diseases in adulthood, e.g., breast cancer in women and an increased risk of type 2 diabetes mellitus.\textsuperscript{2} The metabolic consequences of
macrosomia, however, are more likely to be secondary to pathological overgrowth and abnormal fat deposition in utero than to either absolute birth weight or birth weight centile.\(^7\)

Macrosomia incidence is increasing worldwide and is likely to continue to do so as levels of maternal obesity rise.\(^50\) However, the prevalence of macrosomic births in the U.S. are declining. In the 2010 Pediatric Nutrition Surveillance System, 6.3% of infants had high birth weights, compared with 8.0% in 2001.\(^14\) The prevalence of fetal macrosomia was lower than in 2008 (7.6%), the most recent U.S. rate available.\(^14\) Reports on the incidence of macrosomia also varies among race and ethnicity. High birth weight was higher for American Indian or Alaska Native (8.5%) infants than for white (7.5%), Hispanic (6.6%), Asian or Pacific Islander (4.5%), or black (3.9%) infants.\(^14\)

Maternal weight, GWG, and maternal glucose homeostasis are the most significant risk factors for fetal macrosomia and also most amenable to intervention. Birth weights in infants of diabetic mothers are increased, with up to 35% above the 95\(^{th}\) percentile.\(^7\) The majority of macrosomic infants, however, are born to non-diabetic women.\(^7\) Still, a number of potential risk factors for macrosomia are unmodifiable. These include parental height, parity, ethnicity, maternal age, infant male gender and previous delivery of a LGA infant.\(^7\) An analysis of over 8 million births in the U.S. from 1995 to 1997 by Boulet et al. confirmed that mothers of macrosomic infants were significantly more likely than those of normal birth weight infants to be married and older (>35 y), and less likely to be under 18 years old and primiparous.\(^7\) Recently published research did not find an association between maternal age or the risk of macrosomia in women with gestational diabetes gaining more than the IOM recommendations compared with those gaining within the IOM recommendations based on pre-pregnancy BMI.\(^6,51\)
Reducing Adverse Perinatal Outcomes

There are currently no evidence-based guidelines related to weight management for maternal obesity. Current dietary recommendations suggest that women should not diet or intentionally lose weight during pregnancy as it is potentially harmful for the developing fetus. Furthermore, a Cochrane review has indicated that there is a paucity of evidence to recommend interventions aimed at controlling excessive weight gain in pregnancy, even though the risks of obesity, to both the mother and infant, are substantial when pregnant.\textsuperscript{52}

As most of the adverse outcomes of obese pregnancies show strong associations with pre-pregnancy BMI, it is reasonable to assume that the ideal intervention would be to reduce obesity prior to pregnancy.\textsuperscript{53} However, this is difficult to achieve because 50\% of pregnancies are unplanned and a recent study concluded that only a small proportion of women planning pregnancy follow nutrition and lifestyle recommendations.\textsuperscript{53} We can conclude that an intervention targeting women prior to conception may reach only a small proportion of pregnancies.

A 2011 review assessed 709,575 births and stratified women according to obesity classes I, II and III. Small weight losses up to 5 kg were associated with less LGA births for obese class I women, but an increase in small-for-gestational-age births was also noted with weight loss for this category of obesity.\textsuperscript{52} For obese class III, no increase in neonatal morbidity or mortality was observed.\textsuperscript{52} An additional 2011 analysis indicates that all obese women who lose weight in pregnancy appear to have less risk of cesarean birth and delivering LGA infants, and no significantly increased risk of developing pre-eclampsia, and other complications associated with birth and for the infant normally associated with obesity when compared with weight gains of 5.0
to 9.0 kg. The overall incidence of LGA infants was 13.2% in obese II and III who gained within the current recommendations for their weight, and reduced to 8.8% if weight was lost.

Oteng et al. sought to determine the efficacy of lifestyle intervention on pregnancy outcomes in a systematic review and meta-analyses of randomized and non-randomized clinical trials in overweight and obese pregnant women. Analysis showed that combined antenatal lifestyle, dietary and activity intervention restricts gestational weight gain and reduced the prevalence of gestational diabetes. Still, there was no robust evidence that lifestyle intervention is associated with a lower prevalence of cesarean delivery or macrosomia or any alteration in birth weight. Given the large body of literature that links GWG and gestational diabetes to high infant birth weight, there is thus a research gap regarding effective lifestyle intervention during pregnancy to reduce the prevalence of adverse perinatal outcomes.

**Purpose**

The primary purpose of this study was to examine the characteristics associated with and occurrence of excessive gestational weight gain in overweight and obese postpartum mothers. The secondary purpose was to examine the relationship between pre-pregnancy BMI and gestational weight gain on infant birth weight.
Methods

Study Overview

The data for the current analysis was derived from a study on prevention of childhood obesity. Subjects were recruited through a major hospital in Cincinnati. At baseline (six weeks child’s age), women provided information on age, race, completed years of education, employment status, personal history of chronic disease and obstetric history. Information on maternal and infant height and weight were self-reported and also collected at baseline. Upon meeting eligibility criteria by trained personnel, informed consent was obtained from the mother for participation. The study was approved by the Institutional Review Board of the institution where the study took place.

Participants

Participants included in this study sample are defined as overweight and obese postpartum women aged 21-35 years who delivered a single, full-term infant. Eligible women had no other co-morbidities and full medical clearance from a physician to participate. Mothers who had a BMI ≤ 25.0 after pregnancy, were on special diets or using alcohol, illegal drugs, or tobacco were excluded.

Mother-infant pairs were eligible for inclusion in this study if they reported complete demographic information and anthropometric data before pregnancy and at delivery (N = 132). After excluding for loss to follow-up and incomplete or missing data, 116 mother-infant pairs remained for the continued study.
**Measurements**

The outcome variables of interest were GWG and infant birth weight. Women were grouped into one of three categories according to pre-pregnancy BMI set forth by the IOM. These categories were used by the IOM to develop GWG guidelines for optimal pregnancy outcome.\(^{54}\) GWG was calculated as the difference between maternal pre-gestational weight and weight at delivery. To classify GWG, we used the formulated ranges for weight gain in each category of pre-pregnancy BMI. Adequate GWG was defined as 11.5-16 kg, 7-11.5 kg and 5-9 kg, for normal weight, overweight and obese women, respectively. Total weight gain above the IOM recommendations was classified as excessive GWG, and those below the guidelines were classified as inadequate GWG. Pre-pregnancy BMI was calculated in the dataset by dividing weight (kg) by maternal height in meters squared (kg/m\(^2\)). Infants were categorized according to the American College of Obstetricians and Gynecologists: low birth weight (LBW) (<2,500 g), normal birth weight (2,500-3,999 g), and macrosomia (≥4,000 g).\(^{55}\)

Demographic variables obtained from the dataset were of *a priori* based on review of previous research. Maternal characteristics were categorized by: age (20-29, ≥ 30 y), pre-pregnancy BMI (normal weight, overweight, obese), parity (first born child, ≥2 childbirths), marital status (married, single), race (white, non-Hispanic, African American, non-Hispanic/other), education (high school diploma or less, completed/some college), and employment status (employed, not employed).
**Statistical Analysis**

All statistical analyses were conducted using SAS software (version 9.3, 2008, SAS Institute, Cary, NC). Descriptive statistics and frequencies were calculated for maternal characteristics and infant birth weight. For analysis between maternal characteristics and IOM weight gain adequacy, too few participants in the sample were classified as inadequate weight gain to permit analysis and were, therefore, combined with adequate weight gain. Maternal characteristics of weight gain exceeding or not exceeding the recommended IOM range were compared using chi-square statistics. Analysis of Variance (ANOVA) was used to compare mean infant birth weight between normal weight, overweight, and obese pre-pregnancy BMI categories. Mean infant birth weight was also compared between inadequate, adequate, and excessive GWG categories using ANOVA. Age, race, parity, pre-pregnancy BMI, and GWG were entered as continuous variables into a multivariate regression model that presented an association with infant birth weight. Statistical significance was set at $p < 0.05$.

**Results**

**Participant Characteristics**

Descriptive characteristics for all mothers are shown in the first column of Table 1. Before pregnancy, 28.4% of the women were normal weight, 37.9% were overweight, and 33.6% were obese. Nearly 51% of the women were 30 or more years, and 49% were between the ages of 20-29 years. Women were predominately white (75.0%), married (75.0%), employed
(68.9%), and had some college or a college degree (82.7%). Fifty-two percent of the sample had one to four previous births, and 48.3% were nulliparous.

When the mothers are divided by weight gain exceeding or not exceeding recommendations, excessive weight gain was greater for women who had a pre-gestational status of overweight, were single, white, more educated, and employed, but was not statistically significant when compared to women who did not exceed the recommendation. Considering all of the characteristics between groups, parity was the only variable significantly associated with excessive GWG \( (P < 0.003) \).

With respect to GWG adherence in Figure 1, classification of GWG adequacy was significantly different among the sample \( (P < 0.001) \). Only 16.4% of all women had adequate weight gain during pregnancy. Eighty-four percent of all mothers gained outside of the ranges recommended by the IOM, and 77.6% gained excessively. Seventy percent of normal weight women exceeded IOM guidelines. Comparably, 77.3% of overweight and 84.6% of obese women were excessive gainers. Normal weight women had the greatest percentage of adequate weight gain (27.3%), and obese women were least likely to stay within GWG recommendations (7.7%). Only 6.0% of all mothers gained inadequate gestational weight relative to pre-pregnancy BMI category.
Table 2. Association Between Maternal Characteristics and IOM Weight Gain Adequacy, $n = 116$

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Category</th>
<th>$n$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Combined</td>
</tr>
<tr>
<td>Age (years)</td>
<td>20-29</td>
<td>57 (49.1)</td>
</tr>
<tr>
<td></td>
<td>≥30</td>
<td>59 (50.9)</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>Normal</td>
<td>33 (28.5)</td>
</tr>
<tr>
<td></td>
<td>Overweight</td>
<td>44 (37.9)</td>
</tr>
<tr>
<td></td>
<td>Obese</td>
<td>39 (33.6)</td>
</tr>
<tr>
<td>Parity</td>
<td>First born child</td>
<td>56 (48.3)</td>
</tr>
<tr>
<td></td>
<td>Previous children</td>
<td>60 (51.7)</td>
</tr>
<tr>
<td>Marital status</td>
<td>Married</td>
<td>87 (75.0)</td>
</tr>
<tr>
<td></td>
<td>Single</td>
<td>29 (25.0)</td>
</tr>
<tr>
<td>Race</td>
<td>White, non-Hispanic</td>
<td>87 (75.0)</td>
</tr>
<tr>
<td></td>
<td>African American, non-Hispanic/Other</td>
<td>29 (25.0)</td>
</tr>
<tr>
<td>Education</td>
<td>High School Diploma or less</td>
<td>20 (17.2)</td>
</tr>
<tr>
<td></td>
<td>Some College or more</td>
<td>96 (82.8)</td>
</tr>
<tr>
<td>Employment</td>
<td>Employed</td>
<td>80 (69.0)</td>
</tr>
<tr>
<td></td>
<td>Not Employed</td>
<td>36 (31.0)</td>
</tr>
</tbody>
</table>

*Note.* Inadequate and adequate IOM categories were combined. NS = not significant.

**$p < 0.01$**
Figure 2. Percentage of Mother’s Gestational Weight Gain Adequacy by Pre-pregnancy BMI Category, n = 116

**Neonatal Size by Pre-Pregnancy BMI Category**

In Table 3, the association of mothers’ pre-pregnancy BMI to infant birth weight is presented. The prevalence of normal birth weight infants was 87.2% among obese women, 84.8% in normal weight, and 81.2% in overweight women. The mean infant birth weight in overweight women was 3,471g (SD 494), compared to 3,443g (SD 549) in normal weight and 3,314g (SD 586) in obese women. However, there was no significant difference in mean infant birth weight between BMI categories. The percentage of infants with macrosomia was 15.9% in overweight women, and 7.6% in obese women.
Table 3. Association of Mothers’ Pre-pregnancy Weight Status to Infant Birth Weight, n = 116

<table>
<thead>
<tr>
<th>Neonatal size (g)</th>
<th>Pre-pregnancy BMI, n (%)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal, BMI 18.5-24.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n = 33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2500</td>
<td>1 (3.0)</td>
<td>1 (2.3)</td>
<td>2 (5.1)</td>
<td></td>
</tr>
<tr>
<td>2500 – 3999</td>
<td>28 (84.8)</td>
<td>36 (81.8)</td>
<td>34 (87.2)</td>
<td></td>
</tr>
<tr>
<td>≥ 4000</td>
<td>4 (12.1)</td>
<td>7 (15.9)</td>
<td>3 (7.6)</td>
<td></td>
</tr>
<tr>
<td>Infant birth weight (mean±SD)</td>
<td>3443±549</td>
<td>3471±494</td>
<td>3314±586</td>
<td></td>
</tr>
</tbody>
</table>

Note. Means are not significantly different at p = 0.29 using ANOVA.

**Neonatal Size by Gestational Weight Gain**

The association of mother’s GWG adequacy to infant birth weight is summarized in Table 4. Independent of pre-pregnancy BMI, the greatest number of macrosomic infants was present in mothers with excessive pregnancy weight gain (11 of 14). The mean infant birth weight among women with GWG exceeding IOM recommendations was 3,445g (SD 506), compared to 3,346g (SD 561) for women with adequate weight gain and 3,141g (SD 879) for women with inadequate weight gain. While mean infant birth weight increases as GWG weight gain increases, there was no significant difference in mean infant birth weight between IOM categories.

Eighty-five percent of women with excessive GWG had normal weight infants at birth, and 78.6% of all normal birth weight infants are paired with mothers who exceeded GWG recommendations. Eighty-four percent of women with adequate GWG and 71.4% of women with inadequate gain had normal birth weight infants.
Table 4. Association of Mothers’ Gestational Weight Gain Adequacy to Infant Birth Weight, $n = 116$

<table>
<thead>
<tr>
<th>Neonatal size (g)</th>
<th>Gestational weight gain, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inadequate $n = 7$</td>
</tr>
<tr>
<td>Infant birth weight</td>
<td>1 (14.2)</td>
</tr>
<tr>
<td>&lt;2500</td>
<td>5 (71.4)</td>
</tr>
<tr>
<td>$\geq 4000$</td>
<td>1 (14.2)</td>
</tr>
<tr>
<td>Infant birth weight (mean±SD)</td>
<td>3141 ± 879</td>
</tr>
</tbody>
</table>

*Note.* Means are not significantly different at $p = 0.11$ using ANOVA.

**Predictors of Infant Birth Weight**

Results from the linear regression analyses are presented in Table 5. Gestational weight gain ($p = 0.01$) and parity ($p = 0.008$) were significantly associated with infant birth weight. There was no association between birth weight and pre-pregnancy BMI, age or race.

IOM guidelines were used to assess the likelihood of macrosomia using logistic regression (data not shown). Women who gained above the GWG recommendations across all BMI categories were not significantly more likely to deliver a macrosomic infant and was, therefore, excluded from the results.
Table 5. Linear Regression Model Showing Predictors Related to Infant Birth Weight, \( n = 116 \)

<table>
<thead>
<tr>
<th>Maternal Predictor</th>
<th>( \beta )</th>
<th>SE(( \beta ))</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>-0.03664</td>
<td>0.01169</td>
<td>0.85</td>
</tr>
<tr>
<td>Race</td>
<td>0.00152</td>
<td>0.05607</td>
<td>0.51</td>
</tr>
<tr>
<td>Parity</td>
<td>0.00217</td>
<td>0.04785</td>
<td>0.008**</td>
</tr>
<tr>
<td>Pre-pregnancy BMI (kg/m(^2))</td>
<td>0.12933</td>
<td>0.01045</td>
<td>0.88</td>
</tr>
<tr>
<td>Gestational weight gain (kg)(^1)</td>
<td>0.02171</td>
<td>0.00829</td>
<td>0.01**</td>
</tr>
</tbody>
</table>

*Note. R\(^2\) = 0.11 for all maternal predictors.*

\(*p < 0.01\)

**Discussion**

The growing trend of overweight and excessive gestational weight gain among U.S. women may increase future adverse pregnancy outcomes.\(^{48}\) The present study examined the predictors of excessive maternal weight gain and infant birth weight, and compared pre-pregnancy BMI and GWG to infant birth weight. Overall, these findings support two recommendations to reduce the risk of adverse pregnancy outcomes: (1) weight management during pregnancy is important for every woman as greater maternal weight gain increases birth weight in the offspring, and (2) women should avoid excess pregnancy weight gain regardless of pre-pregnancy BMI. In our study population, increasing parity and GWG had greater effects on infant birth weight which outweighed the effects of pre-pregnancy BMI.

Based on the most recent IOM guidelines, 77.6% of all women gained excessive weight, and only 27.3% of normal weight, 15.9% of overweight, and 7.7% of obese women met recommendations. Excessive weight gain in pregnancy is associated with later overweight and
obesity in mothers and offspring. This study found that parity strongly affected maternal weight gain in normal weight, overweight and obese women. This is consistent with previous work suggesting that previous pregnancies have an independent role in influencing GWG using the most recent IOM guidelines. Other studies have reported trends with parity and maternal weight gain between 1996 and 2009. The analyses did not show a significant association between age, pre-pregnancy BMI, marital status, race, maternal education or employment on GWG adequacy. These relationships are consistent in a prospective study with a similar sample size (N = 103) by Weisman et al.. Age, marital status, ethnicity, education level and employment were not significantly associated with weight gain during pregnancy across all BMI categories. Although not statistically significant, these factors should not be dismissed due to a relatively small number of subjects.

Several authors have reported that high pre-pregnancy BMI is a strong determinant of gaining above IOM guidelines, although mean weight gain is lowest among overweight or obese women. This study also found that heavier women were more likely to exceed guidelines despite lower mean gains, given the narrow ranges recommended by the IOM. However, inclusion criteria for the parent study selected overweight and obese postpartum mothers. Although the number of mothers with a normal pre-pregnancy weight are comparable to overweight and obese mothers in our sample, subjects with minimal pregnancy weight gain may have been excluded from the study.

The secondary objective was to investigate infant birth weight. There are no other known studies that combine determinants of maternal weight gain in analyses on the association between weight gain or pre-pregnancy BMI (maternal anthropometrics) and infant birth weight of overweight and obese postpartum mothers using current IOM guidelines. Maternal weight
gain was the most important modifiable predictor of birth weight when analyzing weight gain as a continuous variable. Parity was the strongest predictor in the model overall, however, its effect on infant birth weight may not be of clinical significance. In a systematic review by Siega-Riz et al., there was moderate evidence for an association between weight gains in excess of the IOM guidelines and higher birth weight. Seven studies found an association, and two studies reported no association; however, the study populations differed by race and pre-gravid weight status. Pre-pregnancy BMI did not have a significant association with infant birth weight in this study. Still, five preceding studies found that infant birth weight increased as pre-pregnancy BMI increased.

Based on the 2009 IOM guidelines, both Margerison Zilko et al. and Moore Simas et al. found LGA infants in relation to pre-pregnancy weight status and adherence to GWG recommendations. Specifically, excessive GWG was associated with increased odds of LGA among all BMI categories, with trends for increased odds in underweight women. The current study results differ from previous observations possibly due to stratification of a smaller sample size.

While the results of this study yield important and interesting insight into the predictors of GWG and of infant birth weight, there are several areas of improvement for future research. The sample size in this study was relatively small. Future research in this area would benefit from increasing the sample size for heightened precision. Mothers who consented to participate were predominately white, overweight, married, employed and of higher education, and is not representative of the Cincinnati population. Furthermore, our small sample size precluded our ability to stratify our sample by GWG adequacy and pre-pregnancy BMI when exploring the relationships of predictors of excessive GWG and birth weight. Our findings are from a
secondary analysis and additional results from larger, prospective studies may confirm the associations we observed.

Records did not contain sufficient information on infant gestational age which is normally controlled in the analyses. In spite of this, participants were without any co-morbidities other than obesity, were not on special diets or using alcohol, tobacco or drugs which are known to affect neonatal size.

Lastly, the analyses showed pre-pregnancy BMI was not associated with excessive GWG or infant birth weight. These results are different than had been largely documented. Self-reported maternal anthropometrics were also subject to intentional or unintentional recall error and may have skewed maternal and infant outcomes. However, previous studies have shown that self-reported pre-pregnancy weight is a good approximation of true weight, and that women’s self-reported weight is usually within 3 lbs. of their actual weight.\textsuperscript{48}

This study adds to knowledge by demonstrating that total GWG may be an even more important predictor of infant birth weight than pre-pregnancy BMI. Since most pregnancies are unplanned, it is important to focus on the factors that an expecting mother can modify. For years, recommendations have primarily focused on increasing birth weight, but there has recently been a shift in the other direction to prevent fetal macrosomia. These data support the need to develop health and lifestyle interventions for reproductive age women that lead to healthy weight trajectories and adherence to the 2009 IOM guidelines during pregnancy.\textsuperscript{58} Appropriately describing the restrictions and implications of excessive weight gain during pregnancy, rather than pre-pregnancy BMI, could improve short and long-term health outcomes for both mothers and offspring.
References


