# LEISURE-TIME PHYSICAL ACTIVITY, GESTATIONAL WEIGHT GAIN, AND POSTPARTUM WEIGHT RETENTION

By

Rebecca A. Schlaff

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**ABSTRACT**

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Excess gestational weight gain (GWG) is a major public health concern because of its known association with several adverse pregnancy outcomes. Given the high prevalence of excess GWG, many women fail to lose all the weight they gained during pregnancy and suffer from postpartum weight retention (PPWR). It is important to identify modifiable factors, such as leisure-time physical activity (LTPA), that might help women achieve an appropriate amount of GWG and reduce PPWR. Therefore, the purpose of this dissertation was to prospectively examine the separate and combined effects of GWG, pregnancy and postpartum LTPA on PPWR at six months after delivery.

Our sample consisted of a subset of women who participated in the Archive for Research on Child Health (ARCH) study. Pre-pregnancy weight was obtained via questionnaire at enrollment and abstracted from each woman's birth certificate after delivery. Pregnancy LTPA was self-reported via enrollment questionnaire and six month postpartum LTPA was self-reported via phone interview. GWG was calculated by subtracting pre-pregnancy weight (self-reported at study enrollment or abstracted from birth certificates) from weight at delivery (abstracted from birth certificates) and classified as "excess" or "not excess" using the upper limit of the 2009 IOM recommended range. Pre-pregnancy weight (self-reported at enrollment and abstracted from birth certificates) was subtracted from self-reported postpartum weight to calculate two different values of six month PPWR. Logistic regression and linear regression

were used to examine independent and combined associations among GWG, pregnancy LTPA, and postpartum LTPA, and PPWR.

Overall, the only variable that significantly predicted GWG was pre-pregnancy body mass index (BMI). Overweight and obese women were more likely to experience excess GWG, compared to normal weight women. Pregnancy and postpartum LTPA were not related to the appropriateness of GWG or PPWR. After adjusting for covariates, excess GWG was the only variable that remained significant. The magnitude and significance level of all associations varied as a function of GWG and PPWR calculation methods.

The results of this study highlight the importance of achieving appropriate GWG among women in all BMI categories. Furthermore, our findings demonstrate the need for the validation of birth certificate abstracted pre-pregnancy weight. Although we did not find pregnancy or postpartum LTPA to be beneficial in attenuating body weight, future studies should not ignore the potential benefits of LTPA. Research is needed with improved measures of LTPA assessment to test and refine our findings while continuing to explore the interrelationships among GWG, pregnancy LTPA, postpartum LTPA, and PPWR.

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# CHAPTER ONE: INTRODUCTION

As adults' prevalence of obesity continues to increase in the United States, more women are entering pregnancy overweight or obese[1]. This phenomenon can have negative implications, since research suggests that as pre-pregnancy body mass index (BMI) increases, risk for adverse maternal and offspring health outcomes also increases[2, 3]. In addition to pre-pregnancy weight being a health issue, the incidence of pregnancy-related maladies is often exacerbated by the amount of weight a woman gains during pregnancy[4]. In order to evaluate the appropriateness of gestational weight gain (GWG), one usually consults recommendations published by the Institute of Medicine (IOM)[5]. The Institute of Medicine has developed guidelines that recommend specific GWG ranges, based on a woman's pre-pregnancy BMI[5]. With each increasing BMI category, the recommended range of GWG decreases. These recommendations were developed to vary in this fashion because, to date, evidence suggests that one GWG recommendation is not appropriate for women of all body sizes. In fact, recent findings indicate that obese women optimize positive maternal and offspring health outcomes with more restricted GWG[6].

Unfortunately, the number of U.S. women who exceed the GWG guidelines is significant. In a nationally representative sample of U.S. women, it was estimated that almost 50% of U.S. women gain weight in excess of the recommended amount[7]. Therefore, it is important to identify modifiable factors that might help women achieve an appropriate amount of GWG. One such behavior is leisure-time physical activity (LTPA) participation during pregnancy. Observational studies and intervention trials investigating the association between LTPA participation and appropriateness of GWG have generally yielded promising results with respect to the role LTPA might have in helping control weight gain[8]. However, it is important that studies investigate this association in all BMI categories in order to appropriately identify at-risk sub-groups and properly tailor interventions to elicit positive results.

As a result of the high prevalence of excess GWG, many pregnant women later suffer from excess postpartum weight retention (PPWR)[9]. In fact, several studies have found GWG to be one of the strongest predictors of PPWR[10]. However, the magnitude of this association varies, depending on when PPWR is assessed. Furthermore, many of these studies have not considered lifestyle behaviors such as LTPA in the postpartum period. Even fewer studies have examined prospectively, the combined effects of the appropriateness of GWG and LTPA participation during pregnancy and postpartum on PPWR. Gaining more insight into these relationships might help inform future research and interventions aiming to attenuate GWG and reduce PPWR.

The overall purpose of this dissertation is to prospectively evaluate the associations between GWG, LTPA (during pregnancy and postpartum), and PPWR. Our sample was a subset of women participating in the Archive for Research on Child Health (ARCH) study. ARCH study participants were enrolled prior to 14 weeks gestation and asked to report frequency and duration of moderate and vigorous physical activities they performed most often during a typical week. Pre-pregnancy height and weight were obtained via self-report at enrollment and abstracted from birth certificates. In the postpartum period, weight at delivery was abstracted from birth certificates to calculate GWG. Women were contacted at 6 months, 1 year, and 2 years postpartum and asked questions about their current weight and LTPA. Using data from this cohort, the dissertation will address the following five Specific Aims.

**RESEARCH AIMS:**

*Specific Aim 1:* To examine the proportion of women who experience excess gestational weight gain (GWG) and determine its relationship with pre-pregnancy BMI.

*H 1.1.* We hypothesized that at least half of the sample (i.e. $\geq$50%) would experience excess GWG.

*H 1.2.* Women whose pre-pregnancy BMI was in the overweight category (BMI $\geq$ 25 and < 30 kg/m$^2$) would be more likely to experience excess GWG compared to women whose pre-pregnancy BMI was normal or obese.

*Specific Aim 2:* To determine the relationship between pregnancy leisure-time physical activity (LTPA; measured prospectively with questionnaire) and GWG category (excess or not excess).

*H 2.1.* We hypothesize that women who engaged in more LTPA would be less likely to experience excess GWG.

*Specific Aim 3:* To determine whether pre-pregnancy BMI moderates the relationship between pregnancy LTPA and GWG categorization.

*H 3.1.* We hypothesized that overweight women (BMI $\geq$ 25 and < 30 kg/m$^2$) who engaged in more LTPA, would be less likely to experience excess GWG compared to women whose pre-pregnancy BMI was normal or obese.

*Specific Aim 4:* To determine the relationship between GWG and postpartum weight retention (PPWR) at six months, one year, and two years after delivery.

*H 4.1.* We hypothesized that women who experienced excess GWG would retain more weight at six months postpartum compared to women who did not experience excess GWG.

*H 4.2.* Women who experienced excess GWG would retain more weight over time (six months until two years postpartum) compared to women who did not experience excess GWG

*Specific Aim 5:* To determine the relationship between pregnancy and postpartum LTPA and PPWR at six months, one year, and two years after delivery.

*H 5.1.* We hypothesized that women who participated in any pregnancy and postpartum LTPA would retain the least amount of weight at six months postpartum.

*H 5.2.* Women who participated in any pregnancy and postpartum LTPA would retain the least amount of weight over time (six months until two years postpartum).

*Specific Aim 6:* To determine the combined relationship among GWG category and pregnancy and postpartum LTPA on PPWR at six months, one year and two years after delivery.

*H 6.1.* We hypothesized that women who did not experience excess GWG and participated in any pregnancy and postpartum LTPA would retain the least amount of weight at six months postpartum

*H 6.2.* Women who did not experience excess GWG and participated in any pregnancy and postpartum LTPA would retain the least amount of weight over time (six months until two years postpartum).

**ORGANIZATION OF THE DISSERTATION**

This dissertation will be organized into five chapters. Chapter one is the introduction and aims. Chapter two is a review of literature on topics related to the Specific Aims of this study. Chapters three and four address the Specific Aims of this dissertation. These chapters are organized in manuscript form (abstract, introduction, methods, results, discussion, and references). Chapter three focuses on the relationships among pre-pregnancy BMI, appropriateness of GWG and pregnancy LTPA and chapter four focuses on postpartum weight retention and its relationships with appropriateness of GWG, pregnancy LTPA and postpartum LTPA. A summary of all results is provided in the final chapter (chapter five), as well as recommendations for the direction of future research.

**REFERENCES**

## References


**1.** Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA.* Jan 20 2010;303(3):235-241.

**2.** Sebire NJ, Jolly M, Harris JP, et al. Maternal obesity and pregnancy outcome: a study of 287,213 pregnancies in London. *Int J Obes Relat Metab Disord.* Aug 2001;25(8):1175-1182.

**3.** Callaway LK, Prins JB, Chang AM, McIntyre HD. The prevalence and impact of overweight and obesity in an Australian obstetric population. *Med J Aust.* Jan 16 2006;184(2):56-59.

**4.** Oken E. Excess gestational weight gain amplifies risks among obese mothers. *Epidemiology.* Jan 2009;20(1):82-83.

**5.** Weight gain during pregnancy: reexamining the guidelines. Washington DC: Institute of Medicine; 2009.

**6.** Artal R, Lockwood CJ, Brown HL. Weight gain recommendations in pregnancy and the obesity epidemic. *Obstet Gynecol.* Jan 2010;115(1):152-155.

**7.** Olson CM. Achieving a healthy weight gain during pregnancy. *Annu Rev Nutr.* 2008;28:411-423.

**8.** Streuling I, Beyerlein A, Rosenfeld E, Hofmann H, Schulz T, von Kries R. Physical activity and gestational weight gain: a meta-analysis of intervention trials. *BJOG.* Feb 2011;118(3):278-284.

**9.** Melzer K, Schutz Y. Pre-pregnancy and pregnancy predictors of obesity. *Int J Obes (Lond).* Dec 2010;34 Suppl 2:S44-52.

**10.** Schmitt NM, Nicholson WK, Schmitt J. The association of pregnancy and the development of obesity - results of a systematic review and meta-analysis on the natural history of postpartum weight retention. *Int J Obes (Lond).* Nov 2007;31(11):1642-1651.

# CHAPTER TWO: REVIEW OF LITERATURE

## INTRODUCTION

Obesity has become a significant problem in the United States that affects much of the population, including women of childbearing age[1]. Of all women giving birth in the United States in 2004-2005, it was estimated that one in five were obese[11]. This is especially problematic since previous research has demonstrated that compared to normal weight women, obese pregnant women have an increased risk for many pregnancy related maladies. In addition, the presence or absence of maternal and offspring complications may also be influenced by the appropriateness of gestational weight gain (GWG)[4, 12], regardless of pre-pregnancy body size[13-16].

The number of pregnant women in the US who gain in excess of Institute of Medicine (IOM) recommendations is significant. For example, Weisman et al. found that 51% of 103 pregnant women sampled gained weight in excess of the IOM recommended ranges, according to the 2009 IOM recommendations[17]. Since GWG recommendations were recently updated by the IOM, less information is available pertaining to adherence to these guidelines compared to the previous 1990 IOM recommendations. However, it was estimated that according to prior IOM recommendations (1990), ~30% of U.S. pregnant women, on average, gain the appropriate amount of weight, while ~46% and ~23% experience excess and inadequate weight gain, respectively[7].

Gaining too much weight during pregnancy has been found to be positively associated with weight retention in the early postpartum period and long-term weight-development[18-21].

The association between excess GWG and postpartum weight retention is not exclusive to overweight and obese women, as it has also been found in underweight and normal weight women[20-22]. Therefore, pregnancy related weight gain is likely a contributing factor and potential link to increased obesity prevalence in women of childbearing age. Consequently, it is important to identify modifiable factors and lifestyle behaviors, like participation in leisure-time physical activity (LTPA) that may help women achieve GWG within recommended ranges. LTPA participation has an important role in the regulation of body weight, since physical activity assists in energy balance. Participation in LTPA must be evaluated during pregnancy and in the postpartum period in order to determine its effectiveness in attenuating GWG into recommended ranges and reducing postpartum weight retention. However, little is known about the interrelationships among pre-pregnancy BMI, GWG and LTPA participation during pregnancy and in the postpartum period. It is important to disentangle these relationships to most effectively target subpopulations for future intervention efforts.

**MATERNAL PRE-PREGNANCY OVERWEIGHT/OBESITY**

There are many known health risks associated with overweight/obesity, the prevalence of which has increased in the United States in recent years[1, 23]. In developed countries, the etiology of overweight/obesity is multi-factorial, but is thought to be mostly attributable to sedentary lifestyle habits and overconsumption of readily accessible high-energy foods. According to data collected in nine U.S. states through the Pregnancy Risk Assessment Monitoring System (PRAMS), 23% of women are considered overweight while 19% are considered obese, as classified by BMI using self-reported pre-pregnancy height and weight[11]. Furthermore, PRAMS indicates a 70% rise in obesity (based on pre-pregnancy BMI) from 1993-

2003. These statistics are troubling since many adverse health outcomes during pregnancy and delivery have been associated with pre-pregnancy overweight/obesity.

*Adverse Pregnancy Outcomes*

Excess adipose tissue is associated with increased insulin resistance, decreased glucose uptake and increased inflammatory cytokines. Diabetes that develops during pregnancy (gestational diabetes mellitus, GDM) is a result of insufficient insulin secretion to compensate for increased insulin resistance. Pre-pregnancy obesity has repeatedly been shown to be a risk factor for the development of GDM. For example, a prospective cohort study of 287,213 pregnancies found that women with a pre-pregnancy BMI $\geq 30$ were 3.65 (CI 3.25-3.98) times more likely to develop GDM than women with a pre-pregnancy BMI of 20.0 – 24.9 [2]. The reason for this increased risk is multi-factorial, but thought to be a result of the association of insulin resistance with pregnancy and the effect excess adipose tissue has on glucose metabolism and insulin signaling[24]. However, it appears that obesity serves as a modifiable risk factor since it has been shown that a weight loss of 4.5 kilograms between pregnancies may reduce risk for recurring GDM up to 40 percent, with 10% body weight loss between pregnancies in obese women to be ideal for risk reduction[3]. The long-term consequences of gestational diabetes combined with obesity are also concerning, since it has been found that 70 percent of obese women diagnosed with GDM develop type 2 diabetes within 15 years of delivery, compared to 30 percent of diagnosed normal weight women[25].

Preeclampsia is another disorder associated with pre-pregnancy obesity. The pathogenesis of preeclampsia is not fully understood, although it has been shown to be associated with endothelial dysfunction, marked by inflammation[26, 27]. Normal pregnancies are accompanied by a systemic increase in inflammation. However, an exaggerated inflammatory response is found in women who develop preeclampsia. Consequently, any physiological insult that disrupts endothelial function and increases an inflammatory response has been found to be associated with preeclampsia. Therefore, maternal obesity and the insulin resistance that accompanies gestational diabetes (both of which are associated with the production of a physiological stress response) are associated with a concomitant increased in the risk for preeclampsia[26, 27]. For example, maternal pre-pregnancy BMI has been found to be positively associated with pregnancy-induced hypertension and preeclampsia. Specifically, every 5-7 $kg/m^2$ increase in BMI was found to be associated with a two-fold increased risk[28]. Frederick et al. investigated inter-pregnancy weight change and its effect on preeclampsia risk. The researchers found that for every unit increase in pre-pregnancy BMI, risk of preeclampsia increased[29]. Villamor et al. supported these findings with results from another population-based study, and reported a significant decrease in risk with a decrease in pre-pregnancy in BMI between pregnancies[30].

There is also a positive relationship between maternal pre-pregnancy BMI and risk for planned and unplanned cesarean sections[31-33]. Planned cesarean deliveries are often medically indicated for women who develop gestational diabetes and/or preeclampsia, but studies have also found that obesity is independently associated with cesarean delivery[31-33]. Cesarean sections are risky in obese populations, as there is an increased risk for excessive bleeding, operative complications and postpartum infections[34, 35]. Obese women are five times more likely than normal weight women to develop postpartum hemorrhage after operative delivery[36].

Evidence is mixed regarding risk for preterm delivery in obese populations. Several studies have investigated the incidence of preterm delivery in obese women, with most concluding that the risk of spontaneous premature birth is not increased, compared to normal weight women[35, 37-40]. In fact, Hendler et al. found that obese women had a lower risk of spontaneous preterm delivery than women in other pre-pregnancy BMI categories[40]. Studies finding significant associations have used the outcome measure of medically indicated preterm delivery, which typically means preterm delivery resulting from complications of preeclampsia and other medical conditions. Increased risk using non-spontaneous preterm delivery makes sense, considering the demonstrated increased risk of these pregnancy complications associated with increasing maternal pre-pregnancy BMI.

Many of the aforementioned pregnancy complications discussed in this section are also associated with excess GWG. Since excess body weight prior to pregnancy is associated with complications, it is not overly speculative to assume that gaining too much weight during pregnancy might also be related to the same outcomes. Furthermore, if excess body weight itself is problematic, then the amount of GWG necessary to sustain a healthy pregnancy and elicit optimal birth outcomes should vary depending on pre-pregnancy body size. In order to determine the range of GWG that is considered to be optimal, GWG should be evaluated on a continuous scale to determine its relationship with commonly experienced maternal pregnancy complications and diseases in women of different body sizes

**MATERNAL BODY SIZE AND GESTATIONAL WEIGHT GAIN**

It was previously believed that all women, regardless of pre-pregnancy body size, should gain the same amount of weight during pregnancy[41, 42]. However, more recent research has shown that GWG recommendations should be based on pre-pregnancy body size, since one general weight gain recommendation does not appear to benefit all women equally[43]. As a result, the Institute of Medicine (IOM) has recommended that GWG vary by pre-pregnancy body mass index (BMI). Women classified as overweight or obese are advised to gain less weight than underweight and normal weight women[5]. This classification system is a minor update to their 1990 guidelines[43].

***Table 2.1: Institute of Medicine gestational weight gain recommendations (2009)***

| **Pre-pregnancy BMI category ($kg/m^2$)** | **Recommended gestational weight gain (lbs)** |
|---|---|
| <18.5 (Underweight) | 28-40 |
| 18.5-24.9 (Normal weight) | 25-35 |
| 25.0-29.9 (Overweight) | 15-25 |
| >30.0 (Obese) | 11-20 |

The rationale for releasing updated GWG recommendations was multi-factorial. The 1990 weight gain recommendations were developed primarily in response to concerns about the adequacy of GWG in relation to infant size at birth (low birth weight, specifically). However, since few women appear to experience low GWG, more recent concern relates to its interaction with the incidence of gestational diabetes, pregnancy-induced hypertension, preeclampsia, risk for cesarean delivery and postpartum weight retention. These concerns are also fueled by the fact that women are becoming pregnant later in life and are more likely to enter pregnancy overweight or obese. All of the aforementioned concerns have implications for the amount of GWG that is appropriate, particularly for obese women, since they seem to be at highest risk for these maladies.

Two major changes were made to the 1990 IOM recommendations when they were updated in 2009. First, maternal pre-pregnancy BMI is expressed according to the cut-points developed by the World Health Organization (instead of categories derived from the Metropolitan Life Insurance tables), to keep pace with what has been more commonly used in peer-reviewed research and adopted in health care practice.  Second, recommended weight gain for women who are obese prior to pregnancy is now a narrow range (11-20 pounds) instead of "at least 15 pounds," as the 1990 IOM guidelines recommended.  In making the latter change, the committee used an evidence-based approach and considered the relationship between weight-gain patterns during pregnancy/postpartum period and both acute and long term maternal and offspring health outcomes in obese women.  The evidence suggested that more favorable health outcomes were found with more restrictive GWG.  Additionally, the committee reevaluated the same type of evidence (prevalence of the outcomes of greatest interest: postpartum weight retention, cesarean delivery, gestational diabetes mellitus, and preeclampsia) for all pre-pregnancy BMI categories to determine whether the GWG value or range for each pre-pregnancy BMI category needed to be updated.  However, there was not compelling evidence to suggest that the recommended weight gain ranges be changed for underweight, normal weight, and overweight women, so the guidelines remained the same for these BMI categories.

In spite of the IOM recommendations, the number of pregnant women in the US who gain excess weight during pregnancy is significant.  Since GWG recommendations were recently updated by the IOM, fewer data are available pertaining to adherence to the 2009 guidelines (as compared to the 1990 IOM recommendations).  However, it was estimated that according to prior IOM recommendations (1990), ~30% of U.S. pregnant women, on average, gain the appropriate amount of weight, while ~46% and ~23% experience excess and inadequate weight gain, respectively[7].  Although not as abundant, available data investigating compliance with the 2009 IOM recommendations is not drastically different than these estimates.  For example, a recent study by Weisman et al. found that 51% of pregnant women sampled gained weight in excess of the IOM recommended ranges while 33% met recommendations and 16% were below the recommendation, according to the 2009 IOM recommendations[17]. Although it is beneficial to know this information about the total sample or population, knowing the adequacy of GWG in each pre-pregnancy BMI stratum identifies the most at-risk categories, which could facilitate effective interventions to the appropriate body type.

Research indicates that a significant number of women from all pre-pregnancy BMI categories have difficulty meeting GWG recommendations and significantly more exceed the guidelines than have inadequate GWG. Some studies have concluded that the prevalence of excess GWG is highest in women who are obese prior to pregnancy[14, 44-46], while others have suggested that excess GWG is an issue not exclusive to the highest BMI category, but rather, is more prevalent in overweight women[47-50]. Consequently, it is important to understand the implications that excess GWG has for both maternal and offspring health and identify modifiable factors and lifestyle behaviors that may help women achieve GWG within the recommended range.

## EXCESS GESTATIONAL WEIGHT GAIN AND ADVERSE OUTCOMES

### *Maternal Pregnancy and Delivery Outcomes*

Since pre-pregnancy body size and GWG are strongly correlated, it is often difficult to determine their independent influences on maternal disease diagnoses during pregnancy and delivery outcomes. Excess body weight, whether accrued prior to or during pregnancy, is associated with unfavorable maternal and birth outcomes. Consequently, many investigators who have investigated the relationship between pre-pregnancy overweight/obesity and adverse outcomes have also reported similar relationships between GWG and the same adverse outcomes. Among the most-studied pregnancy maternal outcomes resulting from excess GWG are gestational diabetes mellitus, preeclampsia and mode of delivery. Unfortunately, much of the literature in these areas does not allow for strong causal inference since evidence is provided solely from observational cohort studies. Randomized controlled trials would provide much stronger evidence for evaluating causality but are impossible to conduct ethically, given the nature of the exposure. Therefore, it cannot be stated unequivocally that GWG causes these outcomes, but rather the strength of the associations with these outcomes can be investigated.

It has been well established that obese pregnant women tend to develop more pronounced insulin resistance and are at a greater risk for gestational diabetes compared to women who are not obese[51]. Although there is biological plausibility for the effect of GWG on glucose tolerance (higher GWG and fat deposition could influence insulin sensitivity), the relationship between excess GWG and incidence of gestational diabetes has been found to be rather weak. The Agency for Healthcare Research Quality (AHRQ) recently commissioned a comprehensive, systematic evidence-based review of the literature pertaining to pregnancy outcomes and absolute GWG as well as the appropriateness of GWG, according to IOM guidelines[52]. Eleven studies were identified, including those that investigated the association between GWG and gestational diabetes incidence. Of these eleven studies, four reported that GWG above the 1990 IOM recommended range was positively associated with gestational diabetes[53-56], three reported that GWG below the recommended range was associated with a higher likelihood of gestational diabetes[57-59], and four studies found no significant association[37, 60-62]. These inconsistent findings may be due in part to the way in which GWG was used in the analyses. All but one study[56] used total GWG as the exposure variable, rather than weight gain until the time of diagnosis. Expressing the exposure in this way is problematic because part of standard treatment for gestational diabetes includes nutritional counseling to manage blood glucose levels and control weight gain. Therefore, since weight gain and fat deposition influence insulin sensitivity and risk for the development of gestational diabetes, weight gain until the time of diagnosis is likely a more appropriate exposure when comparing GWG in women diagnosed with gestational diabetes to non-diabetic controls. Unfortunately, to date, studies utilizing this GWG exposure measurement are lacking, so comment on its association with risk for gestational diabetes would be speculative.

Similar to gestational diabetes, risk for preeclampsia during pregnancy is greater among women who are overweight or obese prior to becoming pregnant. For example, preeclampsia has been shown to be twice as prevalent in women with a pre-pregnancy BMI that is considered overweight, and three times as prevalent in women who are considered obese pre-pregnancy, compared to women with a pre-pregnancy BMI that is considered normal weight[63, 64]. Although the relationship between preeclampsia and pre-pregnancy overweight/obesity is well established, the relationship between GWG and preeclampsia is less clear. Studies investigating this association are limited and many results have been inconclusive. A possible reason for these inconsistent findings relates to the pathogenesis of preeclampsia. Preeclampsia is a condition typically characterized by placental dysfunction early in pregnancy leading to a decrease in normal plasma volume expansion, potentially limiting early GWG[65]. However, increased vascular permeability and decreased plasma oncotic pressure (caused by preeclampsia) may result in increased edema and weight gain later in gestation. For these reasons, studies investigating the association between total GWG and preeclampsia incidence should be interpreted cautiously.

The outcome of preeclampsia has been examined in studies that utilize total GWG as the exposure. Several observational studies have found a positive association between total GWG and risk of preeclampsia[38, 53, 57, 66-69]. Other observational studies have found no association between total GWG and risk of preeclampsia[54, 59, 61, 70]. However, comparing results across studies and making inferences pertaining to all pregnant women can be problematic. First, the definition of preeclampsia has not been consistent in the literature. Second, it appears that pre-pregnancy BMI may modify the relationship between GWG and preeclampsia. After reviewing the available literature, it appears that lower total GWG is protective against preeclampsia risk in overweight/obese samples, but not in predominately underweight and normal weight women. This evidence of effect modification by BMI provides support for the need for GWG recommendations to vary according to pre-pregnancy body size.

Although many investigators have studied the relationship between total GWG and mode of delivery, few have considered and properly controlled for potentially confounding variables. In general, the body of available evidence suggests that high total GWG is associated with increased risk of unplanned cesarean delivery. However, only five observational studies were identified that adjusted for route of previous delivery for multiparous women and co-morbidities that could have also contributed to the route of delivery[71-75]. Even after appropriate statistical adjustments, all five studies reported a positive association between unplanned cesarean delivery and total GWG.

When investigating GWG categorically (according to IOM recommendations), observational studies have provided evidence that GWG in excess of recommendations is associated with unplanned cesarean delivery among normal- and underweight women, but not in overweight and obese women[53, 59, 66, 67]. However, available evidence from observational studies suggests that women who enter pregnancy overweight or obese have a higher risk of unplanned cesarean delivery, compared to normal weight women, regardless of GWG[61, 71-75].

Unfortunately, the aforementioned maternal outcomes have been investigated primarily with respect to 1990 IOM recommendations for GWG, and fewer studies are available that classify the adequacy of participants' GWG according to the 2009 IOM recommendations. However, studies mentioned in this section of the literature review provide support for the recently updated GWG recommendations from the IOM. More research is necessary before the incidence of adverse maternal outcomes can properly be evaluated according to the 2009 IOM recommendations, specifically for obese women.

*Offspring Anthropometric Outcomes*

Exceeding pre-pregnancy BMI specific GWG recommendations have been associated with many adverse outcomes for the maternal-fetal unit. A large body of research on the relationship between excess GWG and offspring anthropometrics is available. Anthropometric outcomes are particularly important to study because of their relationships with later adult body size and health status. In particular, birth weight, rapid weight gain during infancy and childhood, and childhood BMI have been found to be predictors of obesity in adulthood[76-78]. Given the current obesity epidemic in the United States[1], understanding the relationship between excess GWG and these outcomes is worthy of investigation.

One of the most consistently noted adverse outcomes resulting from high gestational weight gain is increased birth weight. Previous research has demonstrated a positive relationship between weight gain in excess of IOM guidelines and birth weight, regardless of pre-pregnancy BMI[47, 59, 79, 80]. A systematic review by Siega-Riz et al. included several studies that showed failure to meet IOM guidelines for GWG was associated with an increased risk of macrosomia (birth weight ≥4000 grams)[81]. However, using birth weight as an outcome can be problematic when trying to compare women, since birth weight is likely to be somewhat dependent on gestational age at delivery. Therefore, research has also focused on the association between excess GWG and size for gestational age.

In order to determine whether birth weight is high for a woman's gestational age, it is compared to established percentiles. If the birth weight is greater than the 90th percentile for a specific gestational age, the infant is categorized as large for gestational age (LGA). After reviewing the available literature, Siega-Riz et al. found the relationship between excess GWG and LGA to be similar to what was found with birth weight. In eight different studies, women who gained excess weight typically had higher odds of delivering a LGA infant[81]. Despite the reviewed studies using different size for gestational age reference standards, the positive relationship was consistent. In addition, this association was not isolated to obese women, since normal and overweight women were also at increased risk when GWG was in excess of the IOM guidelines. Similar findings were evident in research conducted after this systematic review was published and the 2009 IOM guidelines were released[14, 45, 82, 83].

Although moderate-to-strong evidence supports the relationship between gestational weight gain and offspring anthropometric outcomes, several methodological issues and limitations must be considered. First, the relationship between excess GWG and offspring size at birth could be confounded by the presence of gestational diabetes mellitus or pregnancy-induced hypertension. However, a recent study estimated odds for LGA in women with and without a gestational diabetes or hypertension diagnosis and found the odds of delivering a LGA infant was significantly higher, regardless of the presence of co-morbidities[84]. It is important that future studies investigate this association in women with and without these diagnoses to increase confidence in this finding.

A wealth of information has been assembled regarding GWG, birth weight, and size for gestational age, but less is known about how the appropriateness of GWG influences offspring body composition. Results from a recently published study showed that mothers who gained the most weight during pregnancy had offspring with higher percent fat values than those who gained less[85]. However, the authors did not evaluate weight gain according to BMI specific recommended ranges, so inferences about the associations between appropriateness of GWG in women from different BMI categories and offspring body composition are not possible. Furthermore, the observed relationship between GWG and offspring body composition could be confounded by other lifestyle factors, since the offspring were 30 years old at the time of assessment.

Finally, since the most recent IOM guidelines were released in 2009, there are few studies that evaluate the new recommended ranges to classify appropriateness of GWG. More research will likely occur in the coming years, as updated IOM guidelines become more widely disseminated and evaluated. However, it is important that research incorporating the new guidelines focus on modifiable factors related to GWG in excess of the guidelines. The relationship between pregnancy behaviors and appropriateness of GWG, according to the 2009 guidelines, is not well established. While it is clear that excess GWG is detrimental to the maternal-fetal unit, an appropriate next step in scientific inquiry should be to identify and examine behaviors that may attenuate GWG into recommended ranges.

## MATERNAL PHYSICAL ACTIVITY DURING PREGNANCY

### *Evolution of the Recommendations*

The first U.S. guidelines for exercise during pregnancy were released by the American College of Obstetricians and Gynecologists (ACOG) in 1985[86]. These guidelines were very conservative and recommended that pregnant women limit "strenuous exercise" to 15 minutes and keep heart rate below 140 beats per minute, due to concerns about increased risk for a variety of maladies (preterm delivery, growth restriction, fetal hypoxia, acidosis, and hyperthermia)[87]. However, research since that time has shown that, in general, LTPA does not increase risk for the aforementioned adverse outcomes and may actually elicit positive maternal and offspring health outcomes[87-89]. As a result, the most current ACOG guidelines (2002) recommend that, in the absence of contraindications, pregnant women should participate in at least 30 minutes of moderate LTPA on most days of the week[90]. Furthermore, recreational and competitive athletes who become pregnant may continue their exercise program while under supervision of their health care providers. As pregnancy progresses, it is likely that athletes will need to modify their exercise routines; however, it is important to understand that vigorous activities during pregnancy are not contraindicated. Activities associated with fetal trauma and impaired venous return (sports with high potential for contact or falls, scuba diving, and prolonged activity in the supine position) are not recommended by the ACOG (2002)[90].

Most recently, the U.S. Department of Health and Human Services (DHHS) released its Physical Activity Guidelines For Americans in 2008[91]. This evidence-based report included a section for "special populations," which included exercise during pregnancy. In accordance with the ACOG's guidelines[90], it was recommended that women who were not active prior to becoming pregnant engage in 150 minutes of moderate aerobic activity per week during pregnancy. This recommendation is essentially the same as that suggested as a minimum for non-pregnant adults. Similar to the ACOG guidelines, the DHHS guidelines also encourage women who habitually engage in vigorous activities to continue their exercise routines throughout gestation, as long as they consult with, and follow the advice of, their health care providers.

*Epidemiology of Physical Activity During Pregnancy*

Evenson and Wen recently published data from the National Health and Nutrition Examination Survey (NHANES) describing the prevalence, trends, and correlates of physical activity over a span of eight years (1999-2006) using self-reported, cross-sectional data from a nationally representative sample of pregnant women in each trimester[92]. Their findings indicated that ~57% of pregnant women in the U.S. reported participating in moderate-to-vigorous LTPA in the past month, while ~14% reported meeting the U.S. government/ACOG guidelines of $\geq$150 minutes of moderate LTPA per week. Percentage of women meeting recommendations increased to ~23% when vigorous LTPA was included. Furthermore, the authors found that while many trends over the eight-year time period did not significantly change, participation in moderate intensity LTPA increased from 1999-2002 to 2003-2006[92].

The timing of this increase is noteworthy, as the latter four years followed the release of the ACOG's physical activity recommendations.

The most commonly reported leisure activities by pregnant women are walking (40.9%), recreational activities (18.6%), and indoor aerobic conditioning activities (11.8%)[92]. While the prevalence of the most popular leisure-activities did not vary according to trimester, more vigorous activities (such as jogging and muscle strengthening) were reported less frequently as pregnancy progressed. Many studies have corroborated the finding that LTPA participation decreases with increasing gestation[93-97]. For example, Pereira et al. assessed LTPA in 1442 women via 7-day recall and found that total activity time decreased from 9.6 to 6.9 hours/week from the first to the second trimester[97]. Similarly, Schmidt et al. (n=250) found that moderate activity energy expenditure was lower in the third trimester (0.8 MET-hr/day), compared to the first (2.3 MET-hr/day)[96].

Increasing gestational age is just one of the factors associated with decreased LTPA participation during pregnancy. Studies have shown that women decrease LTPA while pregnant due to time constraints, nausea, physical discomfort, and fatigue[98-101]. Some studies have also reported that women fear that exercise might harm their babies and perceive vigorous activities as unsafe during pregnancy[99]. Specific maternal characteristics that are consistently associated with lower levels of pregnancy LTPA include young maternal age, Hispanic race/ethnicity, parity, overweight/obese pre-pregnancy BMI, and low self-efficacy[94, 97, 102]. Conversely there are also several maternal characteristics that have been found to be associated with initial engagement and maintenance of LTPA during pregnancy. In general, Non-Hispanic white race/ethnicity, college educated, nulliparous, non-smoking, habitually active women older than 25 years have increased odds of participating in LTPA during pregnancy[93, 94, 96, 103].

*Health Benefits of Pregnancy LTPA*

While concerns of harm to the maternal-fetal unit have discouraged pregnant women from engaging in LTPA, more recent research indicates that most women recognize the health benefits of this behavior[104]. While evidence from randomized trials and Cochrane reviews are mixed[105, 106], a plethora of observational studies and literature reviews have been published in the past 25 years. Evidence suggests that LTPA participation prior to and during pregnancy is associated with decreased risk of gestational diabetes, preeclampsia, and preterm delivery[87-89, 107-109]. The belief is that any discrepancy in conclusions is partly due to the fact that few investigators have attempted to randomize exercise programs in pregnant women. Furthermore, the available randomized trials have utilized relatively small sample sizes (n < 40). Therefore, well-designed randomized trials that utilize larger sample sizes are needed in order to have adequate statistical power to determine whether structured exercise during pregnancy is protective against gestational diabetes, preeclampsia, and preterm delivery, as well as other adverse outcomes.

Although most evidence for a protective effect of pregnancy LTPA is limited to observational studies, the proposed biological mechanisms for maternal LTPA on the prevention of gestational diabetes, preeclampsia, and pre-term delivery are reduced oxidative stress and inflammation, and improved endothelial function[87, 89]. In addition to these biological mechanisms associated with risk reduction, most women who are active during pregnancy also have a lower pre-pregnancy BMI levels, increased fitness, and possibly lower GWG, compared to those who are not active. These factors may confound LTPA relationships by contributing independently to risk reduction. However, studies have not prospectively tracked LTPA levels prior to pregnancy through gestation, while simultaneously monitoring and accounting for aerobic fitness, GWG, and incidence of gestational diabetes, preeclampsia, and preterm birth. This shortcoming in previous research is most problematic when investigators attempt to tease out the association between pre-pregnancy body size and pregnancy LTPA participation.

*Maternal Pre-pregnancy Body Size and Physical Activity*

In general, BMI and LTPA participation have been found to be inversely associated in non-pregnant populations[110-114]. Although many investigators have examined prevalence and patterns of pre-pregnancy and pregnancy LTPA[92, 115-117], most have not investigated differences in pregnancy LTPA among pre-pregnancy BMI categories. Daily step counts have been found to be lower in obese versus normal weight pregnant women[118], but studies to corroborate this finding are lacking. In a sample of nulliparous women, Hegaard et al. evaluated LTPA participation during pregnancy via questionnaire. Clear inverse associations were found between pre-pregnancy BMI and pre-pregnancy LTPA. However, differences in pregnancy LTPA among pre-pregnancy BMI categories were small, and not significant. The authors' only significant finding related to BMI and pregnancy LTPA was that continuation of moderate-to-heavy LTPA from pre-pregnancy into the first trimester was more common among women with a normal pre-pregnancy BMI compared to those in the other BMI categories[115].

In another recent study, McParlin et al. assessed physical activity levels of overweight and obese pregnant British women with accelerometry. On average, moderate-to-vigorous physical activity was 35 minutes per day, and was achieved by more than 60% of the sample[119]. Although not directly comparable, this estimate is similar to the ~57% of pregnant women in the United States who report engaging in any moderate-to-vigorous activity[92]. Results of these studies indicate that in contrast to the non-pregnant population, pregnancy LTPA may not differ according to pre-pregnancy body size.

**LEISURE-TIME PHYSICAL ACTIVITY AND GESTATIONAL WEIGHT GAIN**

According to data from the National Health and Nutrition Examination Survey, Evenson and Wen reported recently that approximately 57% of pregnant women in the United States reported engaging in some form of moderate or vigorous LTPA[92]. This prevalence statistic is encouraging, since exercise/physical activity was not always viewed as safe for a woman experiencing a low-risk pregnancy. Additionally, LTPA participation during pregnancy could help women achieve GWG within IOM recommended ranges, since physical activity plays a significant role in energy balance. However, research on this topic has yielded mixed results.

Several observational studies have been designed to investigate the association between regular LTPA and GWG. For example, Clapp and Little studied habitual exercising women during pregnancy. One group continued their pre-pregnancy exercise regimen (n=44) while the other ceased or reduced their exercise regimen after becoming pregnant (n=35)[120]. Both groups experienced similar gains in weight and subcutaneous fat mass (assessed via skinfolds) in the first and second trimesters, but the group who continued exercising during pregnancy accrued less weight and subcutaneous fat mass in the third trimester. Specifically, women who continued to exercise gained ~3 kg less than those who did not exercise. Additionally, Haakstad et al.[121] assessed pregnancy LTPA of Norwegian women (n=467) level via questionnaire at 36 weeks gestation and their findings supported those of Clapp and Little[120]. Women who exercised regularly during pregnancy ($\geq$ 4 times per week) gained significantly less weight in the third trimester than those who exercised less regularly. The average pre-pregnancy BMI of both investigations was, on average, within the normal range.

Other observational studies investigating the association between pregnancy LTPA and GWG utilizing samples with wider pre-pregnancy BMI ranges have shown mixed results. Olson and Strawderman[49] asked women at mid-pregnancy, "How does the amount of physical activity you are getting now compare with your physical activity level before you got pregnant?" Response options were: much less active, a little less active, about the same, a little more active, and much more active. In their sample of 622 women, a decrease in pregnancy physical activity (as compared to pre-pregnancy) resulted in significantly greater GWG (2.74 lbs), compared to women who maintained or increased their activity levels. Pre-pregnancy BMI did not modify this relationship. In a more recent study, Althuizen et al. assessed LTPA in a sample of pregnant Dutch women at 30 weeks gestation (n=144) via questionnaire and found that overall, meeting Dutch PA guidelines (30 minutes per day, 5 days per week) did not reduce risk for excess GWG[15]. However, the authors reported that women who judged themselves less physically active than other pregnant women gained almost 2 kg more than women who perceived themselves as being at least as physically active[15].

*Efficacy of LTPA in Preventing Excess GWG*

The notion that physical activity may assist in attenuating GWG has led investigators to conduct randomized controlled trials to evaluate the efficacy of interventions aiming to increase physical activity during pregnancy, instead of relying solely on observational data. Many research groups have attempted to test the hypothesis that physical activity during pregnancy might help avoid excess GWG with varying methodology and inclusion criteria. Aside from the methodological quality being inconsistent across trials, interventions have also differed in the type, frequency, and intensity of exercise programs. Furthermore, GWG is often not the primary outcome measure in many trials and is sometimes collected via self-report in the postpartum period.

While measurement issues complicate across trial comparisons, two recent meta-analyses included pooled data from intervention trials that sought to investigate the efficacy of pregnancy physical activity/exercise in preventing excess GWG[8, 122]. Each meta-analysis used slightly different inclusion criteria and arrived at different pooled results. Streuling et al. included randomized controlled trials with increased physical activity as the only behavioral intervention[8]. Their results indicated that women who participated in a physical activity intervention while pregnant experienced less GWG than non-exercising controls (although considerable heterogeneity was observed). After pooling the results, the difference between intervention and control groups in 12 studies (n=459) was only 0.6 kg, but was statistically significant[8]. Although the observed difference of 0.6 kg between intervention and control groups may not be a clinically significant for an individual, any attempt to reduce GWG may be relevant on a population level. Eight of the 12 included studies reported an average pre-pregnancy BMI within the normal weight range. Furthermore, the authors did not comment on whether physical activity participation in the pooled results was associated with a decreased likelihood of excess GWG in the intervention groups. Consequently, conclusions and generalizations based on the results of this meta-analysis are limited.

The other recently published meta-analysis aimed to analyze behavior-based interventions that modified diet and/or physical activity to prevent excess GWG[122]. The goal of Gardner et al. was to deconstruct aspects of intervention trials that targeted behavior change, and explore moderators of intervention effectiveness. As a result, the authors investigated the moderating effect of pre-pregnancy BMI and intervention effectiveness. Twelve intervention trials were included (n=1656). Eleven trials targeted both diet and PA during pregnancy, while one focused on diet only. Physical activity in each trial was measured via questionnaire and reported as exercise class attendance frequency or exercise sessions per week (expressed as MET minutes per week). Pooled results indicated that interventions with a PA component were effective, with intervention groups experiencing significantly less GWG than control groups (-1.19 kg). Furthermore, pre-pregnancy BMI had a moderating effect on intervention effectiveness, but only in overweight samples. Significantly greater GWG reduction (-2.26 kg vs. -0.77 kg) was observed among trials including only overweight women compared to samples with a range of BMI classifications. Unfortunately, since all trials included in this meta-analysis had a dietary intervention component, it is impossible to ascertain the effect of PA only interventions. Furthermore, the frequency, intensity, time and type of PA in each trial differed, which makes deconstructing effective aspects, and PA specifically, quite difficult.

*Methodological Issues*

As previously stated, a primary obstacle in reaching any sort of conclusion with strong evidence is that randomized controlled trials vary in methodology. Furthermore, replication of effective interventions depends on clear description of the intervention components and outcome measures, which have not always been described well or consistently included. Trials have been inconsistent with respect to the frequency, intensity, type and time of the intervention group's exercise program and the pre-pregnancy body size and LTPA patterns of included women. In addition, some have controlled for diet while others have not. While these points may seem troubling, a consistent shortcoming in these studies was the inability to accurately account for daily energy expenditure (TDEE) (outside of engaging in planned, purposeful exercise). It is important to consider activities of daily living that result in significant caloric expenditure since pregnant women may engage in a variety of these tasks. Several cohort and cross-sectional studies have assessed participation in LTPA during pregnancy via a variety of methods, but to our knowledge, none have reported TDEE. Nonetheless, available evidence suggests that women reporting LTPA participation may be more likely to experience an attenuation of GWG within recommended ranges[15, 17, 123]. Additionally, women reporting more LTPA were less likely to experience adverse offspring outcomes. While these encouraging outcomes hold great implications for future research, precision of LTPA measurement through self-report may have been less than optimal, particularly when data were obtained retrospectively.

With respect to GWG assessment, it is possible that data available across numerous studies may be prone to bias. This is partly due to the nature in which most studies obtain pre-pregnancy BMI, which is largely through self-report. This is an inherent limitation, since relying on self-reported data always introduces the possibility of significant measurement error. However, for reproductive-age women, self-reported height and weight have been found to represent BMI abstracted from medical records with acceptable validity, as 84% of women were classified into the appropriate BMI category[124]. Nevertheless, few studies have utilized GWG values from medical records or actual serial measurements during pregnancy. Instead, a common practice is to assess GWG by a woman's self-report in the postpartum period or calculate it by subtracting self-reported pre-pregnancy weight (often times reported in the postpartum period) from the last recorded weight in medical records. These commonly used measures lack the sensitivity to limit bias, which is problematic when attempting the synthesize results from observational studies.

*Limitations of LTPA assessment*

Part of the difficulty in comparing results across studies designed to investigate the association between pregnancy LTPA and GWG is due to inconsistency in methods used to assess physical activity during pregnancy. Most studies have relied on self-report measures, often collected in the postpartum period. The subjectivity of questionnaires and other self-report measures might result in misclassification, which could explain weak associations observed between LTPA and outcome measures (specifically GWG) in previous investigations[49, 121, 123, 125]. The potential for misclassification when using questionnaires is also heightened during pregnancy, since compared to their non-pregnant counterparts, pregnant women tend to engage in more activities of daily living and household tasks (compared to locomotor activity) for which precise energy expenditure estimates are not well established[126]. More importantly, previous investigations have assessed LTPA via questionnaire in the postpartum period, which may have resulted in recall bias. However, previous research suggests women's ability to recall factors related to pregnancy (including GWG) is very good, even 30 years postpartum[127]. Bauer et al. recently evaluated women's ability to recall pregnancy physical activity in the postpartum period. Physical activity was measured originally at 20 and 32 weeks gestation via physical activity diary and compared to LTPA recalled at six years postpartum using a Modifiable Activity Questionnaire. The results showed a positive relationship, with correlation coefficients of r = .57 and .85 for 20 and 32 week values, respectively[128]. These correlation coefficients are higher than those reported previously in research using non-pregnant populations[129, 130]. This finding suggests that awareness and memory of behaviors during pregnancy might be heightened compared to a non-pregnant state. As a result, it appears that recalled pregnancy LTPA estimates in the postpartum period can be at least equally, and possibly more valid than recalled LTPA in non-pregnant populations.

Despite possible previous study limitations, LTPA participation during pregnancy has the potential to attenuate GWG into recommended ranges and also improve infant anthropometric outcomes[131]. Nevertheless, there are several logical directions for future research. First, it is necessary for LTPA and TDEE to be measured both objectively and via survey in order to evaluate the potential for self-report bias. Studies validating objective monitoring in pregnancy are limited, so these must be done before researchers may place high confidence in using a particular PA measurement modality. More accurate measurement ability will allow researchers to better pinpoint where the LTPA threshold occurs for attenuation of GWG into recommended ranges and attainment of favorable offspring anthropometric outcomes.

**POSTPARTUM WEIGHT RETENTION: INFLUENCING FACTORS**

To date, most research on maternal GWG has focused on determinants and consequences during pregnancy or at delivery. However, with the rising prevalence of obesity among women of childbearing ages[1] and the high prevalence of women gaining too much weight during pregnancy[132], many researchers have shifted their focus to mother's postpartum health status. One area in which researchers have begun to investigate is maternal weight status, since one of the most common, long-term health issues women face is an increase in body weight after pregnancy. Excess body weight is problematic because of its positive association with the development of metabolic and cardiovascular disease later in life[19]. Weight in the postpartum period that is in excess of pre-pregnancy body weight has been termed "postpartum weight retention" (PPWR). In fact, it has been suggested that pregnancy is a potential risk factor for the development of obesity for women of childbearing age because of PPWR[10]. The amount of weight retained has been shown to be quite variable, ranging from 26.5 kg gained to a loss of 12 kg, as compared to pre-pregnancy body weight[133]. Many studies report an average PPWR of only 0.5 – 3.0 kg; however, ~20% of women may retain at least 5 kg at 6 – 18 months postpartum[134]. The cause of an increase in body weight is multi-factorial, however, it has been proposed that one potential pathway for PPWR is through excessive GWG[135].

*Gestational Weight Gain*

The primary long-term maternal health outcome considered when reviewing the evidence and developing GWG recommendations was PPWR, because of its potential link to obesity and its association with metabolic and cardiovascular diseases[5]. After reviewing the evidence it became apparent that one weight gain recommendation was not likely to benefit women of different body sizes. Therefore, one of the main goals of IOM recommendations of different GWG ranges for each pre-pregnancy BMI category was to reduce or eliminate PPWR. Since the release of the first IOM guidelines in 1990, researchers have conducted studies with the purpose of investigating the relationship between the appropriateness of GWG and magnitude of PPWR among women in different BMI categories.

In general, observational studies have provided evidence of a consistent relationship between GWG outside of the IOM recommendations and PPWR[18-21, 48, 132, 133, 136-139]. For example, Linne et al. demonstrated this relationships in a series of papers utilizing data from the Stockholm Pregnancy and Women's Nutrition (SPAWN) study[20, 21, 133]. Women from this prospective cohort were studied originally during pregnancy and followed up at 6 months, 1 year and 15 years postpartum (n=563). Two groups (normal and overweight) were formed based on the cut-off point for overweight (BMI > 25 kg/m$^2$). Overweight women gained less weight during pregnancy and retained less weight at all the postpartum time points, compared to normal weight women[21]. Regardless of pre-pregnancy BMI, women who experienced the highest GWG (>15.6 kg) retained more weight at each postpartum follow-up time point, even after controlling for the number of pregnancies after the index child. Furthermore, 15.1%, 23.1% and 43.8% of the low, intermediate, and high weight retainer group, respectively, shifted from normal to overweight at 15 years postpartum[21]. These percentages were significantly different, implying that high GWG is independently associated with overweight status later in life. Unfortunately, because of the way pre-pregnancy BMI was categorized, it is impossible to comment on these relationships in obese women.

Gunderson et al.[136] conducted a prospective cohort study (n=985) to investigate the relationship between pre-pregnancy body size and PPWR, and included subjects from all four potential BMI categories. Pre-pregnancy weight was obtained from antenatal medical records and postpartum body weights were measured at an "early" and "late" postpartum time point (6 weeks and 2 years postpartum, on average). Results indicated that early postpartum weight retention was similar for all pre-pregnancy BMI groups. However, weight retention differed at the 2-year postpartum time point and was 4 kg lower in the underweight and normal weight groups, compared to the overweight and obese groups[136]. These results suggest that weight measurement timing is important to consider when assessing postpartum weight status and highlights the importance of serial weight measurements in the postpartum period in order to properly capture weight changes.

Recently, a meta-analysis was published and addressed the issue of timing of weight measurements in the postpartum period and its association with the appropriateness of GWG[140]. A previously published meta-analysis demonstrated an association between pregnancy and risk of overweight, but did not consider the effect of GWG specifically on PPWR[10]. Therefore, Nehring et al.[140] sought to compare short- and long-term effects of GWG in accordance with the IOM recommendations on PPWR. Nine studies were included that met the following criteria: 1) singleton pregnancy; 2) published in English 3) GWG classified as above, within, or below IOM recommendations 4) term delivery 5) PPWR documented at 4 weeks postpartum and/or later as a continuous variable. Studies were grouped according to the time in which PPWR was assessed. Three time categories were created: 4 weeks-6 months, 6 months-1 year, and ≥ 15 years postpartum. The meta-analysis revealed that women who gained below IOM recommendations retained significantly less weight (~3 kg less) than women who gained within the recommended range at 6 months, 1 year and 3 years postpartum[140]. This association became non-significant after 15 years postpartum. Conversely, gaining above the recommended range was associated with a ~3 kg increase in PPWR at 3 years postpartum and a ~5 kg increase in PPWR after 15 years postpartum, compared to women who gained within the IOM recommendation. Therefore, it appears that women who experience excess GWG are at higher risk for PPWR, regardless of the postpartum time point in which the measurement occurred.

Several additional studies have corroborated the finding of excessive GWG being positively associated with PPWR in the short-[18, 19, 22, 141, 142] and long-term[18, 19, 22], but have not been successful in consistently establishing a relationship (if any) between pre-pregnancy BMI and GWG. Unfortunately, the results of Nehring et al. were meta-analyzed independent of pre-pregnancy BMI[140], so inferences cannot be made in relation to pre-pregnancy body size.

After reviewing the available evidence, it appears that GWG has a relationship with PPWR. Pre-pregnancy BMI is not strongly associated with PPWR, particularly with early postpartum weight measurements. Even though GWG explains a large part of the variance in PPWR, other lifestyle factors should be considered when attempting to explain the remaining variance. Since pre-pregnancy body size has not been shown to predict PPWR, other variables, such as breastfeeding and LTPA must be considered. These factors are particularly important to consider, as they are modifiable, and associated with long-term weight control.

*Breastfeeding*

A common belief is that breastfeeding facilitates weight loss in the postpartum period, since lactation is an energy-requiring process that has been estimated to increase maternal energy expenditure by ~500 kcal per day[143]. The additional ~500 kcal per day energy requirement can be met by increasing energy intake, decreasing energy expenditure and/or mobilizing maternal fat stores. However, maternal postpartum weight changes while breastfeeding are highly variable and the relationship between breastfeeding and PPWR is not well understood. Research findings are equivocal, as some studies suggest that lactation has a role in postpartum weight loss[144-148], while others have not found a relationship[149, 150]. It is possible that these inconsistent findings may be explained in part by differing lactate duration among the studies.

Many studies indicate a significant relationship between breastfeeding and PPWR only when women breastfed (i.e. did not feed any formula) exclusively until at least 6 months postpartum. For example, Baker et al.[147] investigated weight changes in 36,030 Danish women and reported weight loss of 0.06-0.09 kg for every week of exclusive breastfeeding and that breastfeeding was inversely associated with PPWR at 6 and 18 months postpartum in all women except for those whose pre-pregnancy was BMI > 35 $kg/m^2$. In a sample of 14,330 low-income, racially diverse U.S. women, Krause et al. reported similar results, but investigated PPWR at 3 and 6 months postpartum[148]. No association was reported at 3 months postpartum between breastfeeding and PPWR. However, at 6 months postpartum, weight retention was 1.38 kg lower in women who breastfed exclusively and 0.84 kg lower in women who combined breastfeeding with formula, compared to women who only formula fed their infants[148]. Both studies[147, 148] controlled for several factors that might affect PPWR (maternal age, pre-pregnancy BMI, GWG, ethnicity, and marital status) and still found significant negative relationships between breastfeeding and PPWR.

Although large, epidemiological studies have shown significant, inverse relationships between breastfeeding and PPWR, the effects are rather small and may not be significant in studies with low statistical power. Furthermore, many studies on this topic have relied on measures recalled in postpartum after cessation of lactation and imprecise measures of the exclusivity of breastfeeding. Pre-pregnancy body weight values recalled in the postpartum period might bias the PPWR estimate, but the direction of bias is not clear since it might differ among BMI categories[136]. Lastly, researchers should consider that the amount of PPWR is dependent on factors other than lactation status, such as changes in LTPA in the postpartum period.

*Postpartum LTPA*

Although GWG is a strong predictor of PPWR and lactation has the potential to influence body weight, PPWR is also affected by a change in lifestyle after pregnancy. Although there are general guidelines for PA during pregnancy from the ACOG[90], the specificity of these recommendations for the postpartum period are lacking. ACOG guidelines state that pre-pregnancy exercise routines may be resumed in the postpartum period gradually, after it is medically and physically safe to do so[90]. The reason for the recommendation of a gradual resumption of pre-pregnancy exercise is the morphological and physiological changes of pregnancy can persist up to 4-6 weeks postpartum. However, these recommendations do not give specific information regarding these changes or the approach and timing to safely resume PA. In 2008, the DHHS released Physical Activity Guidelines for Americans and included a recommendation for healthy pregnant and postpartum women of at least 150 minutes of moderate intensity aerobic activity spread throughout the week, but did not provide guidelines for when it is safe for women to resume activity[91]. This lack of clarity regarding resumption of PA in the postpartum period may lead to inconsistent or erroneous recommendations from health care providers to new mothers. Research indicates that, in general, U.S. women feel that resumption of LTPA is safe at three months postpartum, even if they continue to breastfeed[151], but many have difficulty initiating LTPA in the postpartum period.

In a prospective cohort study based on a sample of 559 women, Borodulin et al.[117] assessed physical activities using a 7-day recall. Their results indicated that women decreased their activities from pre-pregnancy values during pregnancy. However, the women appeared to increase their activity again to pre-pregnancy values during the postpartum period, with women reporting more care-giving and recreational activity than during pregnancy. Prevalence data regarding adherence to PA guidelines were not provided in the study. However, other studies investigating LTPA in the postpartum period report that many women are not meeting recommendations[97, 133].

Using a cohort study design, Pereira et al.[97] assessed LTPA via questionnaire pre-pregnancy (recalled in the first trimester), during the second trimester, and at six months postpartum in 1012 women enrolled in Project Viva. Compared to pre-pregnancy LTPA, women reported a decrease in LTPA at six months postpartum (9.6 vs. 8.2 hours per week), with the exception of walking, which remained similar to pre-pregnancy levels. Furthermore, the prevalence of not meeting PA recommendations (150 min/week of total activity) increased significantly from pre-pregnancy at six months postpartum (12.6% vs. 21.7%). Interestingly, for each 5 kg increase in PPWR, women increased their odds of becoming insufficiently active at six months postpartum (OR – 1.31; 95% CI = 1.05-1.58). The findings of 1423 women in The Stockholm Pregnancy and Weight Development Study[133] corroborated the findings of Pereira et al[97]. As such, women who retained at least 5 kg postpartum more than their pre-pregnancy weight reported less LTPA, as compared to women with less than 5 kg of PPWR at six months and one year postpartum[133]. Among those who retained at least 10 kg, 23% reported no LTPA compared to 4% of women who retained less weight[133]. The inverse relationship between postpartum LTPA and PPWR seems to be rather consistent in the available research, as several other observational studies have found similar results at one year postpartum[141, 152, 153]. Futhermore, the inverse relationship between LTPA and PPWR has also been found to be significant in studies investigating long-term body weight development at 8.5[18] and 10 years postpartum[19].

In addition to observational studies, several randomized trials have been published that investigate the influence of PPWR interventions. Thus far, results of trials in the postpartum period have generally shown more consistent and significant reductions in weight loss than those trials intending to reduce GWG in pregnancy[9, 154]. However, more trials have implemented combined interventions consisting of a low-energy diet and increased PA rather than increasing PA alone, so there is limited evidence to assess the independent role of PA in reducing PPWR. Furthermore, many studies utilize sample sizes comprising of less than 100 women. Although interventions are not consistent across trials, data can be pooled to determine the overall effect of lifestyle modification in the postpartum period.

A Cochrane Review that aimed to evaluate the effect of diet, exercise or both for weight reduction in women in the postpartum period identified and included six trials (n=245) in its analyses[155]. Their analyses revealed that women who took part in a diet or diet plus exercise program lost significantly more weight in the postpartum period than women who participated in an exercise only intervention, when comparing intervention groups to their respective control groups. It should be noted that their review included only one trial with an exercise only intervention, so power to detect differences may have been limited. Furthermore, a review published by Larson-Meyer[156] evaluated available literature with less stringent criteria and included both observational and randomized trials and came to the same conclusion as the Cochrane Review[155]; moderate exercise without caloric restriction did not result in postpartum weight loss. However, the review highlighted other potential benefits of postpartum LTPA that should not be overlooked when considering maternal health, such as improved aerobic fitness, high-density lipoprotein cholesterol, insulin sensitivity and psychological well-being[156]. In total, these results highlight the importance of proper consideration of the quality and density of energy intake, since postpartum weight loss is less likely to occur without some form of energy restriction.

**SUMMARY**

The prevalence of obesity in the U.S. is troubling, and women of childbearing age are not exempt. Entering pregnancy with a BMI that is considered overweight or obese increases risk for maladies of pregnancy such as gestational diabetes mellitus, preeclampsia, unplanned cesarean delivery, and preterm delivery. Research indicates that gaining too much weight during pregnancy is also associated with these same adverse outcomes, although the evidence for how pre-pregnancy body size modifies this relationship is equivocal. Although LTPA participation during pregnancy has not always been universally accepted as safe, a plethora of published studies have indicated that LTPA participation is safe in low-risk pregnancies, and has the potential to help attenuate both GWG and risk for the several adverse pregnancy outcomes. In addition to obesity prevalence rates, the number of women in the U.S. who gain weight in excess of IOM recommendations is also significant. Findings from research examining the relationship between pregnancy LTPA and appropriateness of GWG are mixed. Additionally, little information is available with regard to how these relationships vary among women of different pre-pregnancy body sizes, and the agreement of findings is poor.

Because of the increasing prevalence of obesity in U.S. women of childbearing age, research has recently shifted toward investigating determinants of PPWR. As such, excessive GWG has been proposed as a potential link to recent increases in maternal overweight and obesity in the postpartum period. However, studies have investigated the relationship between these variables and PPWR in women of varying body sizes, but few have considered or controlled for the influence of postpartum diet or duration of breastfeeding. The inter-relationships among the appropriateness of GWG, pre-pregnancy body size, LTPA participation during pregnancy and postpartum period, and PPWR requires more attention. If findings from future research confirm significant relationships among these variables, interventions during pregnancy and in the postpartum period can be designed and implemented in ways that might aid in successfully eliciting appropriate changes in body weight.

# REFERENCES

## References


1. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA.* Jan 20 2010;303(3):235-241.

2. Sebire NJ, Jolly M, Harris JP, et al. Maternal obesity and pregnancy outcome: a study of 287,213 pregnancies in London. *Int J Obes Relat Metab Disord.* Aug 2001;25(8):1175-1182.

3. Callaway LK, Prins JB, Chang AM, McIntyre HD. The prevalence and impact of overweight and obesity in an Australian obstetric population. *Med J Aust.* Jan 16 2006;184(2):56-59.

4. Oken E. Excess gestational weight gain amplifies risks among obese mothers. *Epidemiology.* Jan 2009;20(1):82-83.

5. Weight gain during pregnancy: reexamining the guidelines. Washington DC: Institute of Medicine; 2009.

6. Artal R, Lockwood CJ, Brown HL. Weight gain recommendations in pregnancy and the obesity epidemic. *Obstet Gynecol.* Jan 2010;115(1):152-155.

7. Olson CM. Achieving a healthy weight gain during pregnancy. *Annu Rev Nutr.* 2008;28:411-423.

8. Streuling I, Beyerlein A, Rosenfeld E, Hofmann H, Schulz T, von Kries R. Physical activity and gestational weight gain: a meta-analysis of intervention trials. *BJOG.* Feb 2011;118(3):278-284.

9. Melzer K, Schutz Y. Pre-pregnancy and pregnancy predictors of obesity. *Int J Obes (Lond).* Dec 2010;34 Suppl 2:S44-52.

10. Schmitt NM, Nicholson WK, Schmitt J. The association of pregnancy and the development of obesity - results of a systematic review and meta-analysis on the natural history of postpartum weight retention. *Int J Obes (Lond).* Nov 2007;31(11):1642-1651.

11. Chu SY, Kim SY, Bish CL. Prepregnancy obesity prevalence in the United States, 2004-2005. *Matern Child Health J.* Sep 2009;13(5):614-620.

12. Flick AA, Brookfield KF, de la Torre L, Tudela CM, Duthely L, Gonzalez-Quintero VH. Excessive weight gain among obese women and pregnancy outcomes. *Am J Perinatol.* Apr 2010;27(4):333-338.

13. Gunderson EP, Abrams B. Epidemiology of gestational weight gain and body weight changes after pregnancy. *Epidemiol Rev.* 2000;22(2):261-274.

14. Crane JM, White J, Murphy P, Burrage L, Hutchens D. The effect of gestational weight gain by body mass index on maternal and neonatal outcomes. *J Obstet Gynaecol Can.* Jan 2009;31(1):28-35.

15. Althuizen E, van Poppel MN, Seidell JC, van Mechelen W. Correlates of absolute and excessive weight gain during pregnancy. *J Womens Health (Larchmt).* Oct 2009;18(10):1559-1566.

16. Abrams B, Altman SL, Pickett KE. Pregnancy weight gain: still controversial. *Am J Clin Nutr.* May 2000;71(5 Suppl):1233S-1241S.

17. Weisman CS, Hillemeier MM, Downs DS, Chuang CH, Dyer AM. Preconception predictors of weight gain during pregnancy: prospective findings from the Central Pennsylvania Women's Health Study. *Womens Health Issues.* Mar-Apr 2010;20(2):126-132.

18. Rooney BL, Schauberger CW. Excess pregnancy weight gain and long-term obesity: one decade later. *Obstet Gynecol.* Aug 2002;100(2):245-252.

19. Rooney BL, Schauberger CW, Mathiason MA. Impact of perinatal weight change on long-term obesity and obesity-related illnesses. *Obstet Gynecol.* Dec 2005;106(6):1349-1356.

20. Linne Y, Dye L, Barkeling B, Rossner S. Weight development over time in parous women--the SPAWN study--15 years follow-up. *Int J Obes Relat Metab Disord.* Dec 2003;27(12):1516-1522.

21. Linne Y, Dye L, Barkeling B, Rossner S. Long-term weight development in women: a 15-year follow-up of the effects of pregnancy. *Obes Res.* Jul 2004;12(7):1166-1178.

22. Amorim AR, Rossner S, Neovius M, Lourenco PM, Linne Y. Does excess pregnancy weight gain constitute a major risk for increasing long-term BMI? *Obesity (Silver Spring).* May 2007;15(5):1278-1286.

23. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA.* Apr 5 2006;295(13):1549-1555.

24. Catalano PM, Nizielski SE, Shao J, Preston L, Qiao L, Friedman JE. Downregulated IRS-1 and PPARgamma in obese women with gestational diabetes: relationship to FFA during pregnancy. *Am J Physiol Endocrinol Metab.* Mar 2002;282(3):E522-533.

25. O'Sullivan J. Subsequent morbidity among gestational diabetic women. In: Sutherland HW SJ, ed. *Carbohydrate Metabolism in Pregnancy and the Newborn*. Edingburgh: Churchill Livingstone; 1984:174-180.

**26.** Ramsay JE, Ferrell WR, Crawford L, Wallace AM, Greer IA, Sattar N. Maternal obesity is associated with dysregulation of metabolic, vascular, and inflammatory pathways. *J Clin Endocrinol Metab.* Sep 2002;87(9):4231-4237.

**27.** Ramsay JE, Simms RJ, Ferrell WR, et al. Enhancement of endothelial function by pregnancy: inadequate response in women with type 1 diabetes. *Diabetes Care.* Feb 2003;26(2):475-479.

**28.** O'Brien TE, Ray JG, Chan WS. Maternal body mass index and the risk of preeclampsia: a systematic overview. *Epidemiology.* May 2003;14(3):368-374.

**29.** Frederick IO, Rudra CB, Miller RS, Foster JC, Williams MA. Adult weight change, weight cycling, and prepregnancy obesity in relation to risk of preeclampsia. *Epidemiology.* Jul 2006;17(4):428-434.

**30.** Villamor E, Cnattingius S. Interpregnancy weight change and risk of adverse pregnancy outcomes: a population-based study. *Lancet.* Sep 30 2006;368(9542):1164-1170.

**31.** Crane SS, Wojtowycz MA, Dye TD, Aubry RH, Artal R. Association between pre-pregnancy obesity and the risk of cesarean delivery. *Obstet Gynecol.* Feb 1997;89(2):213-216.

**32.** Sheiner E, Levy A, Menes TS, Silverberg D, Katz M, Mazor M. Maternal obesity as an independent risk factor for caesarean delivery. *Paediatr Perinat Epidemiol.* May 2004;18(3):196-201.

**33.** Rosenberg TJ, Garbers S, Chavkin W, Chiasson MA. Prepregnancy weight and adverse perinatal outcomes in an ethnically diverse population. *Obstet Gynecol.* Nov 2003;102(5 Pt 1):1022-1027.

**34.** Andreasen KR, Andersen ML, Schantz AL. Obesity and pregnancy. *Acta Obstet Gynecol Scand.* Nov 2004;83(11):1022-1029.

**35.** Wolfe HM, Gross TL. Obesity in pregnancy. *Clin Obstet Gynecol.* Sep 1994;37(3):596-604.

**36.** Perlow JH, Morgan MA. Massive maternal obesity and perioperative cesarean morbidity. *Am J Obstet Gynecol.* Feb 1994;170(2):560-565.

**37.** Bianco AT, Smilen SW, Davis Y, Lopez S, Lapinski R, Lockwood CJ. Pregnancy outcome and weight gain recommendations for the morbidly obese woman. *Obstet Gynecol.* Jan 1998;91(1):97-102.

**38.** Cedergren MI. Maternal morbid obesity and the risk of adverse pregnancy outcome. *Obstet Gynecol.* Feb 2004;103(2):219-224.

**39.** Gross T, Sokol RJ, King KC. Obesity in pregnancy: risks and outcome. *Obstet Gynecol.* Oct 1980;56(4):446-450.

**40.** Hendler I, Goldenberg RL, Mercer BM, et al. The Preterm Prediction Study: association between maternal body mass index and spontaneous and indicated preterm birth. *Am J Obstet Gynecol.* Mar 2005;192(3):882-886.

**41.** Abrams B. Prenatal weight gain and postpartum weight retention: a delicate balance. *Am J Public Health.* Aug 1993;83(8):1082-1084.

**42.** Eastman NJ, Jackson E. Weight relationships in pregnancy. I. The bearing of maternal weight gain and pre-pregnancy weight on birth weight in full term pregnancies. *Obstet Gynecol Surv.* Nov 1968;23(11):1003-1025.

**43.** Medicine Io. Nutrition during pregnancy. Part I. Weight gain. Washington D.C.: National Academy Press; 1990.

**44.** Rodrigues PL, de Oliveira LC, Brito Ados S, Kac G. Determinant factors of insufficient and excessive gestational weight gain and maternal-child adverse outcomes. *Nutrition.* Jun 2010;26(6):617-623.

**45.** Savitz DA, Stein CR, Siega-Riz AM, Herring AH. Gestational weight gain and birth outcome in relation to prepregnancy body mass index and ethnicity. *Ann Epidemiol.* Feb 2011;21(2):78-85.

**46.** Deierlein AL, Siega-Riz AM, Adair LS, Herring AH. Effects of pre-pregnancy body mass index and gestational weight gain on infant anthropometric outcomes. *J Pediatr.* Feb 2011;158(2):221-226.

**47.** Schieve LA, Cogswell ME, Scanlon KS. An empiric evaluation of the Institute of Medicine's pregnancy weight gain guidelines by race. *Obstet Gynecol.* Jun 1998;91(6):878-884.

**48.** Mamun AA, Kinarivala M, O'Callaghan MJ, Williams GM, Najman JM, Callaway LK. Associations of excess weight gain during pregnancy with long-term maternal overweight and obesity: evidence from 21 y postpartum follow-up. *Am J Clin Nutr.* May 2010;91(5):1336-1341.

**49.** Olson CM, Strawderman MS. Modifiable behavioral factors in a biopsychosocial model predict inadequate and excessive gestational weight gain. *J Am Diet Assoc.* Jan 2003;103(1):48-54.

**50.** Oken E, Taveras EM, Kleinman KP, Rich-Edwards JW, Gillman MW. Gestational weight gain and child adiposity at age 3 years. *Am J Obstet Gynecol.* Apr 2007;196(4):322 e321-328.

**51.** Dahlgren J. Pregnancy and insulin resistance. *Metab Syndr Relat Disord.* Summer 2006;4(2):149-152.

**52.** Viswanathan M, Siega-Riz AM, Moos MK, et al. Outcomes of maternal weight gain. *Evid Rep Technol Assess (Full Rep).* May 2008(168):1-223.

**53.** Edwards LE, Hellerstedt WL, Alton IR, Story M, Himes JH. Pregnancy complications and birth outcomes in obese and normal-weight women: effects of gestational weight change. *Obstet Gynecol.* Mar 1996;87(3):389-394.

**54.** Kabiru W, Raynor BD. Obstetric outcomes associated with increase in BMI category during pregnancy. *Am J Obstet Gynecol.* Sep 2004;191(3):928-932.

**55.** Kieffer EC, Carman WJ, Gillespie BW, Nolan GH, Worley SE, Guzman JR. Obesity and gestational diabetes among African-American women and Latinas in Detroit: implications for disparities in women's health. *J Am Med Womens Assoc.* Fall 2001;56(4):181-187, 196.

**56.** Saldana TM, Siega-Riz AM, Adair LS, Suchindran C. The relationship between pregnancy weight gain and glucose tolerance status among black and white women in central North Carolina. *Am J Obstet Gynecol.* Dec 2006;195(6):1629-1635.

**57.** Brennand EA, Dannenbaum D, Willows ND. Pregnancy outcomes of First Nations women in relation to pregravid weight and pregnancy weight gain. *J Obstet Gynaecol Can.* Oct 2005;27(10):936-944.

**58.** Kieffer EC, Tabaei BP, Carman WJ, Nolan GH, Guzman JR, Herman WH. The influence of maternal weight and glucose tolerance on infant birthweight in Latino mother-infant pairs. *Am J Public Health.* Dec 2006;96(12):2201-2208.

**59.** Thorsdottir I, Torfadottir JE, Birgisdottir BE, Geirsson RT. Weight gain in women of normal weight before pregnancy: complications in pregnancy or delivery and birth outcome. *Obstet Gynecol.* May 2002;99(5 Pt 1):799-806.

**60.** Hackmon R, James R, O'Reilly Green C, Ferber A, Barnhard Y, Divon M. The impact of maternal age, body mass index and maternal weight gain on the glucose challenge test in pregnancy. *J Matern Fetal Neonatal Med.* Mar 2007;20(3):253-257.

**61.** Murakami M, Ohmichi M, Takahashi T, et al. Prepregnancy body mass index as an important predictor of perinatal outcomes in Japanese. *Arch Gynecol Obstet.* Apr 2005;271(4):311-315.

**62.** Seghieri G, De Bellis A, Anichini R, Alviggi L, Franconi F, Breschi MC. Does parity increase insulin resistance during pregnancy? *Diabet Med.* Nov 2005;22(11):1574-1580.

**63.** Catalano PM. Increasing maternal obesity and weight gain during pregnancy: the obstetric problems of plentitude. *Obstet Gynecol.* Oct 2007;110(4):743-744.

**64.** Sibai BM, Ewell M, Levine RJ, et al. Risk factors associated with preeclampsia in healthy nulliparous women. The Calcium for Preeclampsia Prevention (CPEP) Study Group. *Am J Obstet Gynecol.* Nov 1997;177(5):1003-1010.

**65.** Young BC, Levine RJ, Karumanchi SA. Pathogenesis of preeclampsia. *Annu Rev Pathol.* 2010;5:173-192.

66. DeVader SR, Neeley HL, Myles TD, Leet TL. Evaluation of gestational weight gain guidelines for women with normal prepregnancy body mass index. *Obstet Gynecol.* Oct 2007;110(4):745-751.

67. Kiel DW, Dodson EA, Artal R, Boehmer TK, Leet TL. Gestational weight gain and pregnancy outcomes in obese women: how much is enough? *Obstet Gynecol.* Oct 2007;110(4):752-758.

68. Ogunyemi D, Hullett S, Leeper J, Risk A. Prepregnancy body mass index, weight gain during pregnancy, and perinatal outcome in a rural black population. *J Matern Fetal Med.* Jul-Aug 1998;7(4):190-193.

69. Cedergren M. Effects of gestational weight gain and body mass index on obstetric outcome in Sweden. *Int J Gynaecol Obstet.* Jun 2006;93(3):269-274.

70. Wataba K, Mizutani T, Wasada K, Morine M, Sugiyama T, Suehara N. Impact of prepregnant body mass index and maternal weight gain on the risk of pregnancy complications in Japanese women. *Acta Obstet Gynecol Scand.* 2006;85(3):269-276.

71. Joseph KS, Young DC, Dodds L, et al. Changes in maternal characteristics and obstetric practice and recent increases in primary cesarean delivery. *Obstet Gynecol.* Oct 2003;102(4):791-800.

72. Rosenberg TJ, Garbers S, Lipkind H, Chiasson MA. Maternal obesity and diabetes as risk factors for adverse pregnancy outcomes: differences among 4 racial/ethnic groups. *Am J Public Health.* Sep 2005;95(9):1545-1551.

73. Shepard MJ, Saftlas AF, Leo-Summers L, Bracken MB. Maternal anthropometric factors and risk of primary cesarean delivery. *Am J Public Health.* Oct 1998;88(10):1534-1538.

74. Sherrard A, Platt RW, Vallerand D, Usher RH, Zhang X, Kramer MS. Maternal anthropometric risk factors for caesarean delivery before or after onset of labour. *BJOG.* Sep 2007;114(9):1088-1096.

75. Witter FR, Caulfield LE, Stoltzfus RJ. Influence of maternal anthropometric status and birth weight on the risk of cesarean delivery. *Obstet Gynecol.* Jun 1995;85(6):947-951.

76. Druet C, Ong KK. Early childhood predictors of adult body composition. *Best Pract Res Clin Endocrinol Metab.* Jun 2008;22(3):489-502.

77. Freedman DS, Khan LK, Serdula MK, Dietz WH, Srinivasan SR, Berenson GS. The relation of childhood BMI to adult adiposity: the Bogalusa Heart Study. *Pediatrics.* Jan 2005;115(1):22-27.

78. Sorensen HT, Sabroe S, Rothman KJ, Gillman M, Fischer P, Sorensen TI. Relation between weight and length at birth and body mass index in young adulthood: cohort study. *BMJ.* Nov 1 1997;315(7116):1137.

**79.** Cogswell ME, Serdula MK, Hungerford DW, Yip R. Gestational weight gain among average-weight and overweight women--what is excessive? *Am J Obstet Gynecol.* Feb 1995;172(2 Pt 1):705-712.

**80.** Hedderson MM, Weiss NS, Sacks DA, et al. Pregnancy weight gain and risk of neonatal complications: macrosomia, hypoglycemia, and hyperbilirubinemia. *Obstet Gynecol.* Nov 2006;108(5):1153-1161.

**81.** Siega-Riz AM, Viswanathan M, Moos MK, et al. A systematic review of outcomes of maternal weight gain according to the Institute of Medicine recommendations: birthweight, fetal growth, and postpartum weight retention. *Am J Obstet Gynecol.* Oct 2009;201(4):339 e331-314.

**82.** Bodnar LM, Siega-Riz AM, Simhan HN, Himes KP, Abrams B. Severe obesity, gestational weight gain, and adverse birth outcomes. *Am J Clin Nutr.* Jun 2010;91(6):1642-1648.

**83.** Margerison Zilko CE, Rehkopf D, Abrams B. Association of maternal gestational weight gain with short- and long-term maternal and child health outcomes. *Am J Obstet Gynecol.* Jun 2010;202(6):574 e571-578.

**84.** Heude B, Thiebaugeorges O, Goua V, et al. Pre-Pregnancy Body Mass Index and Weight Gain During Pregnancy: Relations with Gestational Diabetes and Hypertension, and Birth Outcomes. *Matern Child Health J.* Jan 22 2011.

**85.** Reynolds RM, Osmond C, Phillips DI, Godfrey KM. Maternal BMI, parity, and pregnancy weight gain: influences on offspring adiposity in young adulthood. *J Clin Endocrinol Metab.* Dec 2010;95(12):5365-5369.

**86.** ACOG. *Technical Bulletin: Exercise during pregnancy and the postnatal period.* Washington DC: American College of Obstetricians and Gynecologists;1985.

**87.** Impact of physical activity during pregnancy and postpartum on chronic disease risk. *Med Sci Sports Exerc.* 2006;38(5):989-1006.

**88.** Hegaard HK, Pedersen BK, Nielsen BB, Damm P. Leisure time physical activity during pregnancy and impact on gestational diabetes mellitus, pre-eclampsia, preterm delivery and birth weight: a review. *Acta Obstet Gynecol Scand.* 2007;86(11):1290-1296.

**89.** Weissgerber TL, Wolfe LA, Davies GA, Mottola MF. Exercise in the prevention and treatment of maternal-fetal disease: a review of the literature. *Appl Physiol Nutr Metab.* Dec 2006;31(6):661-674.

**90.** ACOG. Exercise during pregnancy and the postpartum period. Number 267. *Int J Gynaecol Obstet.* April 2002 2002;77(1):79-81.

**91.** U.S. Physical Activity Guidelines for Americans. U.S. Department of Health and Human Services. 2008. http://www.health.gov/paguidelines.

**92.** Evenson KR, Wen F. National trends in self-reported physical activity and sedentary behaviors among pregnant women: NHANES 1999-2006. *Prev Med.* Mar 2010;50(3):123-128.

**93.** Fell DB, Joseph KS, Armson BA, Dodds L. The impact of pregnancy on physical activity level. *Matern Child Health J.* Sep 2009;13(5):597-603.

**94.** Mottola MF, Campbell MK. Activity patterns during pregnancy. *Can J Appl Physiol.* Aug 2003;28(4):642-653.

**95.** Rousham EK, Clarke PE, Gross H. Significant changes in physical activity among pregnant women in the UK as assessed by accelerometry and self-reported activity. *Eur J Clin Nutr.* Mar 2006;60(3):393-400.

**96.** Schmidt MD, Pekow P, Freedson PS, Markenson G, Chasan-Taber L. Physical activity patterns during pregnancy in a diverse population of women. *J Womens Health (Larchmt).* Oct 2006;15(8):909-918.

**97.** Pereira MA, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Peterson KE, Gillman MW. Predictors of change in physical activity during and after pregnancy: Project Viva. *Am J Prev Med.* Apr 2007;32(4):312-319.

**98.** Albright C, Maddock JE, Nigg CR. Physical activity before pregnancy and following childbirth in a multiethnic sample of healthy women in Hawaii. *Women Health.* 2005;42(3):95-110.

**99.** Evenson KR, Moos MK, Carrier K, Siega-Riz AM. Perceived barriers to physical activity among pregnant women. *Matern Child Health J.* May 2009;13(3):364-375.

**100.** Symons Downs D, Hausenblas HA. Women's exercise beliefs and behaviors during their pregnancy and postpartum. *J Midwifery Womens Health.* Mar-Apr 2004;49(2):138-144.

**101.** Symons Downs D, Ulbrecht JS. Understanding exercise beliefs and behaviors in women with gestational diabetes mellitus. *Diabetes Care.* Feb 2006;29(2):236-240.

**102.** Hinton PS, Olson CM. Predictors of pregnancy-associated change in physical activity in a rural white population. *Matern Child Health J.* Mar 2001;5(1):7-14.

**103.** Petersen AM, Leet TL, Brownson RC. Correlates of physical activity among pregnant women in the United States. *Med Sci Sports Exerc.* Oct 2005;37(10):1748-1753.

**104.** Clarke PE, Gross H. Women's behaviour, beliefs and information sources about physical exercise in pregnancy. *Midwifery.* Jun 2004;20(2):133-141.

**105.** Ceysens G, Rouiller D, Boulvain M. Exercise for diabetic pregnant women. *Cochrane Database Syst Rev.* 2006;3:CD004225.

**106.** Meher S, Duley L. Exercise or other physical activity for preventing pre-eclampsia and its complications. *Cochrane Database Syst Rev.* 2006(2):CD005942.

**107.** Damm P, Breitowicz B, Hegaard H. Exercise, pregnancy, and insulin sensitivity--what is new? *Appl Physiol Nutr Metab.* Jun 2007;32(3):537-540.

**108.** Dempsey JC, Butler CL, Williams MA. No need for a pregnant pause: physical activity may reduce the occurrence of gestational diabetes mellitus and preeclampsia. *Exerc Sport Sci Rev.* Jul 2005;33(3):141-149.

**109.** Morris SN, Johnson NR. Exercise during pregnancy: a critical appraisal of the literature. *J Reprod Med.* Mar 2005;50(3):181-188.

**110.** Kaleta D, Makowiec-Dabrowska T, Jegier A. Occupational and leisure-time energy expenditure and body mass index. *Int J Occup Med Environ Health.* 2007;20(1):9-16.

**111.** Hemmingsson E, Ekelund U. Is the association between physical activity and body mass index obesity dependent? *Int J Obes (Lond).* Apr 2007;31(4):663-668.

**112.** Ball K, Owen N, Salmon J, Bauman A, Gore CJ. Associations of physical activity with body weight and fat in men and women. *Int J Obes Relat Metab Disord.* Jun 2001;25(6):914-919.

**113.** Tudor-Locke C, Ainsworth BE, Whitt MC, Thompson RW, Addy CL, Jones DA. The relationship between pedometer-determined ambulatory activity and body composition variables. *Int J Obes Relat Metab Disord.* Nov 2001;25(11):1571-1578.

**114.** Cooper AR, Page A, Fox KR, Misson J. Physical activity patterns in normal, overweight and obese individuals using minute-by-minute accelerometry. *Eur J Clin Nutr.* Dec 2000;54(12):887-894.

**115.** Hegaard HK, Damm P, Hedegaard M, et al. Sports and leisure time physical activity during pregnancy in nulliparous women. *Matern Child Health J.* Aug 2011;15(6):806-813.

**116.** Liu J, Blair SN, Teng Y, Ness AR, Lawlor DA, Riddoch C. Physical activity during pregnancy in a prospective cohort of British women: results from the Avon longitudinal study of parents and children. *Eur J Epidemiol.* Mar 2011;26(3):237-247.

**117.** Borodulin K, Evenson KR, Herring AH. Physical activity patterns during pregnancy through postpartum. *BMC Womens Health.* 2009;9:32.

**118.** Renault K, Norgaard K, Andreasen KR, Secher NJ, Nilas L. Physical activity during pregnancy in obese and normal-weight women as assessed by pedometer. *Acta Obstet Gynecol Scand.* Jul 2010;89(7):956-961.

**119.** McParlin C, Robson SC, Tennant PW, et al. Objectively measured physical activity during pregnancy: a study in obese and overweight women. *BMC Pregnancy Childbirth.* 2010;10:76.

**120.** Clapp JF, 3rd, Little KD. Effect of recreational exercise on pregnancy weight gain and subcutaneous fat deposition. *Med Sci Sports Exerc.* Feb 1995;27(2):170-177.

**121.** Haakstad LA, Voldner N, Henriksen T, Bo K. Physical activity level and weight gain in a cohort of pregnant Norwegian women. *Acta Obstet Gynecol Scand.* 2007;86(5):559-564.

**122.** Gardner B, Wardle J, Poston L, Croker H. Changing diet and physical activity to reduce gestational weight gain: a meta-analysis. *Obes Rev.* Jul 2011;12(7):e602-620.

**123.** Stuebe AM, Oken E, Gillman MW. Associations of diet and physical activity during pregnancy with risk for excessive gestational weight gain. *Am J Obstet Gynecol.* Jul 2009;201(1):58 e51-58.

**124.** Huber LRB. Validity of self-reported height and weight in women of reproductive age. *Maternal and Child Health Journal.* 2007;11:137-144.

**125.** Lof M, Hilakivi-Clarke L, Sandin S, Weiderpass E. Effects of pre-pregnancy physical activity and maternal BMI on gestational weight gain and birth weight. *Acta Obstet Gynecol Scand.* 2008;87(5):524-530.

**126.** Chasan-Taber L, Freedson PS, Roberts DE, Schmidt MD, Fragala MS. Energy expenditure of selected household activities during pregnancy. *Res Q Exerc Sport.* Mar 2007;78(2):133-137.

**127.** Tomeo CA, Rich-Edwards JW, Michels KB, et al. Reproducibility and validity of maternal recall of pregnancy-related events. *Epidemiology.* Nov 1999;10(6):774-777.

**128.** Bauer PW, Pivarnik JM, Feltz DL, Paneth N, Womack CJ. Validation of an historical physical activity recall tool in postpartum women. *J Phys Act Health.* Sep 2010;7(5):658-661.

**129.** Bowles HR, FitzGerald SJ, Morrow JR, Jr., Jackson AW, Blair SN. Construct validity of self-reported historical physical activity. *Am J Epidemiol.* Aug 1 2004;160(3):279-286.

**130.** Blair SN, Dowda M, Pate RR, et al. Reliability of long-term recall of participation in physical activity by middle-aged men and women. *Am J Epidemiol.* Feb 1 1991;133(3):266-275.

**131.** Mudd LM, Pivarnik J, Holzman CB, Paneth N, Pfeiffer K, Chung H. Leisure-time Physical Activity in Pregnancy and the Birth Weight Distribution: Where is the effect? *J Phys Act Health.* Dec 27 2011.

**132.** Chu SY, Callaghan WM, Bish CL, D'Angelo D. Gestational weight gain by body mass index among US women delivering live births, 2004-2005: fueling future obesity. *Am J Obstet Gynecol.* Mar 2009;200(3):271 e271-277.

**133.** Linne Y, Barkeling B, Rossner S. Long-term weight development after pregnancy. *Obes Rev.* May 2002;3(2):75-83.

**134.** Lovelady C. Balancing exercise and food intake with lactation to promote post-partum weight loss. *Proc Nutr Soc.* May 2011;70(2):181-184.

**135.** Siega-Riz AM, Evenson KR, Dole N. Pregnancy-related weight gain--a link to obesity? *Nutr Rev.* Jul 2004;62(7 Pt 2):S105-111.

**136.** Gunderson EP, Abrams B, Selvin S. Does the pattern of postpartum weight change differ according to pregravid body size? *Int J Obes Relat Metab Disord.* Jun 2001;25(6):853-862.

**137.** Huang TT, Wang HS, Dai FT. Effect of pre-pregnancy body size on postpartum weight retention. *Midwifery.* Apr 2010;26(2):222-231.

**138.** Nohr EA, Vaeth M, Baker JL, Sorensen TI, Olsen J, Rasmussen KM. Pregnancy outcomes related to gestational weight gain in women defined by their body mass index, parity, height, and smoking status. *Am J Clin Nutr.* Nov 2009;90(5):1288-1294.

**139.** Ostbye T, Peterson BL, Krause KM, Swamy GK, Lovelady CA. Predictors of Postpartum Weight Change Among Overweight and Obese Women: Results from the Active Mothers Postpartum Study. *J Womens Health (Larchmt).* Nov 17 2011.

**140.** Nehring I, Schmoll S, Beyerlein A, Hauner H, von Kries R. Gestational weight gain and long-term postpartum weight retention: a meta-analysis. *Am J Clin Nutr.* Nov 2011;94(5):1225-1231.

**141.** Olson CM, Strawderman MS, Hinton PS, Pearson TA. Gestational weight gain and postpartum behaviors associated with weight change from early pregnancy to 1 y postpartum. *Int J Obes Relat Metab Disord.* Jan 2003;27(1):117-127.

**142.** Walker LO. Predictors of weight gain at 6 and 18 months after childbirth: a pilot study. *J Obstet Gynecol Neonatal Nurs.* Jan 1996;25(1):39-48.

**143.** Medicine Io. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fatty Acids, Cholesterol, Protein, Amino Acids (Macronutrients). Washington, DC: National Academies Press; 2002.

**144.** Dewey KG, Heinig MJ, Nommsen LA. Maternal weight-loss patterns during prolonged lactation. *Am J Clin Nutr.* Aug 1993;58(2):162-166.

**145.** Janney CA, Zhang D, Sowers M. Lactation and weight retention. *Am J Clin Nutr.* Nov 1997;66(5):1116-1124.

**146.** Kramer FM, Stunkard AJ, Marshall KA, McKinney S, Liebschutz J. Breast-feeding reduces maternal lower-body fat. *J Am Diet Assoc.* Apr 1993;93(4):429-433.

**147.** Baker JL, Gamborg M, Heitmann BL, Lissner L, Sorensen TI, Rasmussen KM. Breastfeeding reduces postpartum weight retention. *Am J Clin Nutr.* Dec 2008;88(6):1543-1551.

**148.** Krause KM, Lovelady CA, Peterson BL, Chowdhury N, Ostbye T. Effect of breast-feeding on weight retention at 3 and 6 months postpartum: data from the North Carolina WIC Programme. *Public Health Nutr.* Dec 2010;13(12):2019-2026.

**149.** Johnston EM. Weight changes during pregnancy and the postpartum period. *Prog Food Nutr Sci.* 1991;15(3):117-157.

**150.** Potter S, Hannum S, McFarlin B, Essex-Sorlie D, Campbell E, Trupin S. Does infant feeding method influence maternal postpartum weight loss? *J Am Diet Assoc.* Apr 1991;91(4):441-446.

**151.** Evenson KR, Aytur SA, Borodulin K. Physical activity beliefs, barriers, and enablers among postpartum women. *J Womens Health (Larchmt).* Dec 2009;18(12):1925-1934.

**152.** Althuizen E, van Poppel MN, de Vries JH, Seidell JC, van Mechelen W. Postpartum behaviour as predictor of weight change from before pregnancy to one year postpartum. *BMC Public Health.* 2011;11:165.

**153.** Oken E, Taveras EM, Popoola FA, Rich-Edwards JW, Gillman MW. Television, walking, and diet: associations with postpartum weight retention. *Am J Prev Med.* Apr 2007;32(4):305-311.

**154.** Walker LO. Managing excessive weight gain during pregnancy and the postpartum period. *J Obstet Gynecol Neonatal Nurs.* Sep-Oct 2007;36(5):490-500.

**155.** Amorim AR, Linne YM, Lourenco PM. Diet or exercise, or both, for weight reduction in women after childbirth. *Cochrane Database Syst Rev.* 2007(3):CD005627.

**156.** Larson-Meyer DE. Effect of postpartum exercise on mothers and their offspring: a review of the literature. *Obes Res.* Aug 2002;10(8):841-853.

# CHAPTER THREE:

# GESTATIONAL WEIGHT GAIN AND PREGNANCY LEISURE-TIME PHYSICAL ACTIVITY IN RELATION TO PRE-PREGNANCY BODY SIZE

## ABSTRACT

The purposes of the study were to 1) examine the proportion of women who experience excess gestational weight gain (GWG) and determine its relationship with pre-pregnancy body mass index (BMI), 2) determine the relationship between pregnancy leisure-time physical activity (LTPA) and GWG categorization, and 3) determine whether pre-pregnancy BMI moderates the relationship between pregnancy LTPA and GWG categorization. **METHODS:** Our sample consisted of a subset of women who participated in the Archive for Research on Child Health (ARCH) study (n=135). Subjects were enrolled prior to 14 weeks gestation. Pre-pregnancy weight was obtained via questionnaire at enrollment and abstracted from each woman's birth certificate after delivery. Moderate and vigorous LTPA was self-reported via enrollment questionnaire and women were dichotomized as "active" or "not active", depending on whether any LTPA was reported. GWG was calculated by subtracting pre-pregnancy weight (self-reported at study enrollment or abstracted from birth certificates) from weight at delivery (abstracted from birth certificates) and classified as "excess" or "not excess" using the upper limit of the 2009 IOM recommended range. Logistic regression was used to examine the relationships between moderate and vigorous pregnancy LTPA and pre-pregnancy BMI with the outcome of appropriateness of GWG. **RESULTS:** Overall, 56-60% of our sample experienced excess GWG, depending on the measure of pre-pregnancy BMI that was used to calculate GWG. Overweight and obese women had significantly higher odds of excess GWG (compared to normal weight women; OR=2.48-5.34). LTPA participation did not differ among pre-pregnancy

BMI categories and was not related to the appropriateness of GWG. Due to inadequate sample size, we were unable to determine whether pre-pregnancy BMI moderated the relationship between pregnancy LTPA and GWG categorization. **CONCLUSION:** Regardless of the source of pre-pregnancy weight, overweight and obese women were more likely to experience excess GWG (compared to normal weight women) and LTPA was not significantly related to the appropriateness of GWG. Prospective studies with larger samples and objective measures of LTPA are needed to determine the relationships among pre-pregnancy BMI, LTPA, and GWG. Additionally, more research is needed to investigate changes in these associations according to the way in which pre-pregnancy BMI and GWG are calculated.

## INTRODUCTION

As the prevalence of adult obesity continues to increase in the United States, more women are entering pregnancy overweight or obese[1]. Research suggests that as pre-pregnancy body mass index (BMI) increases, risk for adverse maternal pregnancy-related health outcomes (such as gestational diabetes, preeclampsia, and cesarean delivery) also increases[2-9]. In addition, the incidence of pregnancy-related maladies is often exacerbated by the amount of weight a woman gains during pregnancy[10-16]. In order to evaluate the appropriateness of gestational weight gain (GWG), one must consult the 2009 Institute of Medicine (IOM) guidelines that recommend GWG vary according to pre-pregnancy BMI[17]. In general, the recommended range of GWG decreases with each increasing pre-pregnancy BMI category (Table 3.1). These recommendations were developed to vary in this fashion because, to date, peer-reviewed evidence suggests that one GWG recommendation is not appropriate for women of all body sizes. In fact, recent findings indicate that obese women optimize positive maternal and offspring health outcomes with more restricted GWG[15, 18, 19].

Unfortunately, the number of U.S. women who exceed the IOM pregnancy weight gain guidelines is significant. In a nationally representative sample of U.S. women, almost 50% of U.S. women gain weight in excess of the recommended amount[20]. Therefore, it is important to identify modifiable factors that might help women achieve an appropriate amount of GWG. One such behavior is participation in leisure-time physical activity (LTPA) during pregnancy. Observational studies and intervention trials investigating the association between LTPA participation and appropriateness of GWG have generally yielded promising results with respect to weight gain control[21-26]. However, less is known about how attenuation of GWG into recommended ranges via LTPA participation varies among women in different pre-pregnancy BMI categories. It is important that the association between GWG and LTPA be investigated within specific BMI categories in order to appropriately identify at-risk sub-groups and tailor interventions properly to elicit positive results. Therefore, the purposes of this study were to 1) examine the proportion of women who experience excess GWG and determine its relationship with pre-pregnancy BMI, 2) determine the relationship between pregnancy LTPA and GWG categorization, and 3) determine whether pre-pregnancy BMI moderates the relationship between pregnancy LTPA and GWG categorization.

**METHODS**

*Study Population and Recruitment*

Our sample consisted of a subset of women who participated in the Archive for Research on Child Health (ARCH) study. The initial purpose of the prospective ARCH study was to develop a system to collect and store pregnancy and perinatal biological specimens (urine, blood, placenta) and data collected from maternal report via interview/questionnaires. Therefore, results from biological specimens and other prospectively reported participant data were stored in a database. The intent was for these data to be used for future research questions, in the event that a health condition arises in the postpartum period (instead of relying on maternal recall of the perinatal period after an event occurred). Women were recruited and enrolled prior to 14 weeks gestation from local prenatal clinics. Inclusion criteria for the ARCH study were maternal age $\geq$ 18 years and proficiency in English. Women included in our analyses had self-reported pregnancy LTPA, and birth certificate data needed to calculate GWG. In addition, participants included delivered a live, singleton, term (>37 weeks) infant.

Subject recruitment occurred at three Midwestern U.S. prenatal clinics. These clinics included a university faculty obstetric clinic, hospital residency clinic, and county health department clinic. When a woman first called one of these clinics to schedule a prenatal appointment, she was informed that a brochure would be mailed to her describing the ARCH project. Brochures were also available in the clinic waiting room when women arrived for their appointments. At the first appointment, the health care provider sought pregnant patients' permission to talk with the ARCH staff in the clinic. Interested women then met with a trained member of the ARCH staff in the clinic immediately following their appointments. Women interested in the study had the opportunity to ask questions and complete the consent form, in order to become enrolled (Appendix A). Women who consented to participate allowed routinely collected prenatal specimens to be forwarded to a data repository for storage, abstraction from medical records and access to their children's birth certificates for research purposes. After consenting, women were asked to complete a brief questionnaire at the time of enrollment. ARCH researchers also asked permission to contact the women at varying time points (until five years postpartum) to obtain maternally-reported health information. Study participants were compensated with a $10 gift card to a local grocery store after enrolling in the study and completing the prenatal questionnaire.

*Demographic Variables*

Information obtained at enrollment was collected via self-reported maternal questionnaire (Appendix B). Maternal age was determined from reported date of birth. Basic demographic information such as ethnic/racial category, education level, and marital status were collected using categorical variables. Women were also asked to specify if they have ever been told by a healthcare provider that they had any of the following conditions: periodontal disease, depression or other psychiatric conditions, seizure disorder, epilepsy or other neurological conditions, and high cholesterol. Additionally, women reported family history of autism, mental retardation, cerebral palsy, or any other severe child disability.

*Pre-pregnancy Anthropometrics*

In order to obtain a measure of pre-pregnancy body size, women were asked, via questionnaire at enrollment, to report their heights and weights (without shoes) just prior to becoming pregnant. Pre-pregnancy body weight was also abstracted from each woman's birth certificate after delivery. The validity of the birth certificate pre-pregnancy weight value in the State of Michigan has not yet been determined and the origin of the value recorded is not consistent, as practices vary across and within hospitals. Some hospitals abstract pre-pregnancy weight from medical records, while others record a value that is self-reported by the patient after delivery. For this dissertation, the research team calculated pre-pregnancy body mass index (BMI) as weight in kilograms divided by height in meters squared, using both measures of pre-pregnancy body weight. These variables were termed "Enrollment pre-pregnancy BMI" and "Birth certificate pre-pregnancy BMI." Women were categorized as underweight, normal weight, overweight or obese, according to the classifications developed by the World Health Organization and adopted by the Institutes of Medicine (IOM) for GWG recommendations[17, 27] (Underweight: <18.5 kg/m$^2$; Normal: 18.5-24.99 kg/m$^2$; Overweight: 25-29.99 kg/m$^2$; Obese: $\geq$30 kg/m$^2$).

*Pregnancy Leisure-Time Physical Activity*

Women were also asked to report LTPA participation during pregnancy. They were asked to think about any physical activity, exercise, and sports in which they took part during their free time and reported activities according to whether they were moderate or vigorous. Moderate activities were described as ones that cause a small increase in breathing or heart rate, while vigorous activities were described as ones that cause an increase in breathing or heart rate. Examples of both moderate and vigorous activities were provided to assist women in distinguishing intensity level. If women checked “yes” for participation in either moderate or vigorous activity, they were asked to report days per week and typical time (hours and minutes) spent doing moderate and vigorous activities in one day. Minutes per day of moderate and vigorous LTPA were each multiplied by the number of days per week to obtain minutes per week of moderate and vigorous LTPA. Moderate and vigorous pregnancy LTPA were each dichotomized as “not active” if a women did not report any moderate or vigorous LTPA and “active” if a woman reported any moderate or vigorous LTPA. LTPA data not within three standard deviations of the mean were excluded as outliers.

*Gestational Weight Gain*

For this dissertation, gestational weight gain (GWG) was calculated in two ways. Values for GWG were calculated by subtracting pre-pregnancy weight (self-reported at study enrollment or abstracted from birth certificates) from weight at delivery (abstracted from birth certificates), and were referred to as “enrollment GWG” and “birth certificate GWG.” For each participant, adequacy of GWG (via both calculation methods) was evaluated based on pre-pregnancy BMI-specific 2009 IOM recommendations. In order to maximize statistical power and focus on predicting excess GWG, values were categorized as “excess” or “not excess”, using the upper limit of the 2009 IOM recommended range in a given BMI category as a cut-point[17].

*Other Pregnancy Variables*

Variables abstracted from medical records and birth certificate data served as important covariates to consider when evaluating the relationships between exposures and outcomes of interest. The following variables were obtained in the postpartum period from birth certificate abstraction: parity, birth weight, gestational age, smoking status, alcohol use, method of delivery, enrollment in WIC, and diagnosis of gestational diabetes or gestational hypertension. Each variable was evaluated for potential confounding according to procedures described in our statistical analyses.

*Statistical Analyses*

Descriptive statistics (means, standard deviations, and proportions) were calculated for all variables of interest. The analytic sample was compared to the non-analytic sample (women enrolled in ARCH who did not have variables of interest collected) to examine differences among demographic variables using a chi-square test. Women's pre-pregnancy BMI was categorized as either normal weight, overweight, or obese, for both enrollment and birth certificate pre-pregnancy BMI, and GWG was categorized as either "not excess" or "excess", for enrollment and birth certificate GWG. LTPA was evaluated categorically using self-reported moderate and vigorous LTPA. Moderate and vigorous LTPA were both dichotomized as "active" or "not active." One-way analysis of variance was used to determine whether method of determining pre-pregnancy weight produced different results according to pre-pregnancy BMI category and LTPA participation, and a kappa statistic was calculated to express percent agreement between pre-pregnancy BMI calculation methods. Logistic regression was used to examine the relationships between moderate and vigorous pregnancy LTPA and pre-pregnancy BMI (calculated via enrollment and birth certificate) with the outcome of appropriateness of GWG (enrollment and birth certificate). To determine whether pre-pregnancy BMI moderates the relationship between pregnancy LTPA and GWG categorization, an interaction term was created and entered into the model to examine its relationship with GWG categorization, net of the main effects of BMI and LTPA. Odds ratios (OR) and 95% confidence intervals were calculated by using normal BMI, "not active" moderate and vigorous LTPA, and "not excess" GWG as referent categories.

A conceptual model was constructed to evaluate potentially important covariates (e.g., maternal descriptive characteristics and delivery outcomes). Criteria for covariate inclusion in the analytic models were as follows: 1) does not function as a mediator or collider; 2) biologic rationale for potential confounding based on previous literature; and 3) a statistically significant association with appropriateness of GWG, or alters other main effect estimates by more than 10 percent in the current dataset. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

**RESULTS**

Since very few women had a pre-pregnancy BMI that was classified as underweight (n=7), they were excluded from our analyses. In addition, women with self-reported pregnancy LTPA that was $\geq$ 3 standard deviations above the mean (self-reported estimates not within reason) were excluded (n=5). Final sample size included in statistical analyses was 135. A flow chart of included/excluded participants can be seen in Figure 3.1.

Overall, women not included in our analytic sample were older (M±SD; 26 $\pm$ 6.9 years), of higher socio-economic status (indicated by WIC enrollment), and were more likely to be married. Furthermore, a lower percentage of the non-analytic sample was obese prior to becoming pregnant, of non-white race/ethnicity, and experienced excess GWG according to self-reported GWG comparisons among the analytic and non-analytic ARCH samples (more detailed descriptive data can be found in Table 3.2).

Among the analytic sample, maternal age at enrollment was 25 $\pm$ 5.7 years and gestational age at delivery was 39.9 $\pm$ 1.8 weeks. Additionally, maternal height averaged 163.6 $\pm$ 7.9 centimeters and maternal weight according to birth certificate and enrollment questionnaire were 75.3 $\pm$ 18.5 and 74.8 $\pm$ 20.5 kilograms, respectively. Overall, 43% of women were nulliparous, 57% were white, 54% reported having more than 12 years of education, 27% were married, and 24% reported smoking during pregnancy.

The percentage of women classified as normal weight, overweight, and obese (according to pre-pregnancy BMI) varied according to the source of pre-pregnancy body weight (Table 3.2). More women were classified as normal weight when enrollment weight was used, compared to birth certificate abstracted pre-pregnancy weight (39.6% vs. 34.1%). Conversely, slightly fewer women were classified as overweight and obese when enrollment weight was used (overweight: 30.6% vs. 32.6%; obese: 29.9% vs. 33.3%). Agreement between pre-pregnancy BMI calculation methods was 74%. The difference between self-reported pre-pregnancy weight and birth certificate pre-pregnancy weight did not vary by pre-pregnancy BMI categories (p=0.62) or participation in moderate (p=0.95) or vigorous LTPA (p=0.11).

According to maternal self-report, time spent in moderate LTPA ranged from 0-2100 minutes per week and averaged 198 $\pm$ 379 minutes per week, and time spent in vigorous LTPA ranged from 0-450 minutes per week and averaged 29 $\pm$ 85 minutes per week. Among our sample, 32% reported participating in at least 150 minutes of moderate and vigorous LTPA per week. Overall, 56% of women reported participating in any moderate activity and 18% reported participating in any vigorous activity at enrollment (Table 3.2). Although the proportion of active women varied among pre-pregnancy BMI categories, differences in proportions among categories did not reach statistical significance, regardless of how pre-pregnancy weight was estimated (Table 3.3).

The percentage of women who experienced excess GWG differed according to the measure of pre-pregnancy BMI that was used to calculate GWG. When evaluating enrollment GWG, 60.4% of the sample gained excess weight, while 56.3% of the sample was considered to have excess GWG according to birth certificate GWG. Additionally, the proportion of women who experienced excess GWG varied within each BMI category (Table 3.3). Compared to normal weight women, overweight women had significantly higher odds of having excess GWG, regardless of how pre-pregnancy weight was estimated (Table 3.4). Odds ratios ranged from 3.47 to 5.13, depending on the source of pre-pregnancy BMI and calculation of GWG. Higher odds of excess GWG (compared to normal weight women) were also observed among obese women, but only when obesity was classified according to birth certificate pre-pregnancy BMI

Due to inadequate sample size, we were unable to determine whether pre-pregnancy BMI moderated the relationship between pregnancy LTPA and GWG categorization. After separating each BMI category according to appropriateness of GWG and participation in LTPA, numbers of participants in some cells were very small ($<5$) and did not support estimation of the interaction.

Evaluation for potential confounding revealed that parity and enrollment in WIC were significantly related to the appropriateness of both self-reported and birth certificate GWG in the total sample ($p<0.05$). After entering parity and WIC into regression models with pre-pregnancy BMI and moderate and vigorous LTPA, enrollment in WIC was the only covariate that remained statistically significant ($p<0.05$; Women enrolled in WIC had lower odds of excess GWG) and met our inclusion criteria for confounding. Therefore, we retained WIC enrollment in final adjusted main effect regression models. Main effect estimates were altered by more than 10 percent in fewer than half the models, as adjusted Odds Ratios indicate in Table 3.5.

**DISCUSSION**

Our purposes were to 1) examine the proportion of women who experienced excess GWG and determine its relationship with pre-pregnancy BMI, 2) determine the relationship between pregnancy LTPA and GWG categorization, and 3) determine whether pre-pregnancy BMI moderates the relationship between pregnancy LTPA and GWG categorization. Our findings indicated that odds of experiencing excess GWG varied among pre-pregnancy BMI categories, but the magnitude of the odds depended on how pre-pregnancy weight was estimated (self-reported at study enrollment or abstracted from birth certificate). Furthermore, we found that moderate and vigorous LTPA during pregnancy were not associated with GWG categorization in the total sample and that the proportion of women within each BMI category who reported moderate or vigorous LTPA was not significantly different. Unfortunately, we were unable to determine whether pre-pregnancy BMI moderated the relationship between pregnancy LTPA and GWG categorization, due to our small sample size.

According to classifications based on pre-pregnancy BMI, our sample consisted of ~35-40% normal weight and ~60-65% overweight or obese women. These prevalence estimates differed according to the source of pre-pregnancy weight (self-reported at enrollment or abstracted from birth certificate), as fewer women were classified as overweight and obese and more women were classified as normal weight according to enrollment pre-pregnancy weight. This finding suggests that self-reported enrollment pre-pregnancy weight tended to be lower than pre-pregnancy weight values abstracted from birth certificates. Previous research investigating the validity of self-reported weight in women of childbearing age have consistently found that women tend to under-report their body weight[28, 29]. However, to our knowledge, this is the only study to use more than one method to estimate pre-pregnancy weight when evaluating the relationship between pre-pregnancy BMI and GWG. The difference between pre-pregnancy weight self-reported at study enrollment and abstracted from birth certificates, and its implication in BMI classification and evaluation of GWG appropriateness is important to recognize when attempting to compare results among studies utilizing pre-pregnancy weight values obtained in varying ways. Our findings indicate that the method utilized to obtain pre-pregnancy weight may contribute to estimates of risk status for a subset of the sample. Furthermore, the potential for women to be misclassified by BMI category may lead to increased measurement error and attenuation of significant findings.

Within the total sample, ~56% and ~60% of women gained weight in excess of the 2009 IOM recommendations according to birth certificate and enrollment GWG, respectively. It is plausible that the slightly higher prevalence estimate of excess GWG obtained via self-reported GWG calculation was partly due to women self-reporting lower pre-pregnancy weights at enrollment compared to pre-pregnancy weight abstracted from a birth certificate. However, it is important to recognize that birth certificate pre-pregnancy weight, even when abstracted from medical records, is most likely not a measured value of pre-pregnancy weight, and is often self-reported at the first prenatal visit. Therefore, our varying estimates may simply be a comparison of self-reported pre-pregnancy weight at different time points. Data have not yet been published regarding the validity of this record in the state of Michigan and we found very little information from any state regarding the validity of birth certificate GWG. However, one recent study conducted in Pennsylvania compared birth certificate GWG to GWG recorded in electronic medical records, which was used as the criterion measure [30]. The authors indicated that GWG in medical records was not calculated with a measured value of pre-pregnancy weight. Rather, it was calculated by subtracting antenatal self-reported pre-pregnancy weight from weight at delivery. The authors found that compared to normal weight women with adequate GWG, normal weight and overweight/obese women with excess GWG were more likely to under-report GWG. However, overweight/obese women with excess GWG were also more likely to over-report GWG, compared to normal weight women. Accurate reporting was defined as a birth certificate value within 10 pounds of medical records[30]. Consequently, these findings suggest that there might be systematic bias in birth certificate GWG when birth certificate GWG is obtained after delivery. Our conversations with the director of Vital Records and Health Statistics at the Michigan Department of Community Health revealed that hospitals often rely on maternal self-report after delivery and that practices within and across hospitals are not consistent (personal communication, Glenn Copeland)[51]. Before the use of birth certificate abstracted GWG may be utilized with confidence, more studies are needed to validate birth certificate GWG, particularly in hospitals with varying birth certificate recording processes.

Regardless of the method of pre-pregnancy BMI calculation, we found that the appropriateness of GWG varied among pre-pregnancy BMI categories. Compared to normal weight women, overweight and obese women had significantly higher odds of experiencing excess GWG. Our finding of overweight women having significantly higher odds of excess GWG highlights the need for health care providers to be certain that they are communicating effectively the recommended amount of GWG to their overweight patients. However, to date, a plethora of observational studies and intervention trials have been published that focus solely on minimizing GWG in obese patients[10, 15, 18, 21, 31-34]. In fact, Bish et al. found that women who were advised to lose weight by their health care providers were nine times more likely to report trying to lose weight during pregnancy[35]. Additionally, Bish et al.'s results indicated that obesity (and not other BMI classifications) was independently associated with trying to lose weight during pregnancy, suggesting that obese women may be more likely to be told to maintain or lose weight than overweight women. However, we do not have information regarding weight gain advice received during prenatal care for the women in our sample so further inference is speculative. Nevertheless, it seems there is a need for health care providers to distribute concern and advice aimed at preventing excess GWG to both overweight and obese women, particularly since the association between risk for adverse pregnancy outcomes and excess GWG has been observed in women from all pre-pregnancy BMI categories[21, 36-38].

Encouraging LTPA during pregnancy is one approach that health care providers might utilize to help patients achieve GWG within recommended ranges. However, in our sample, participation in moderate or vigorous LTPA did not predict odds of excess GWG. There are many potential explanations for these findings. The first is that, due to our small sample size, we were underpowered to detect differences among LTPA categories and GWG categorizations. Post-hoc analyses revealed that our power to detect differences between LTPA categories and GWG appropriateness was 0.1. In addition, the direction of our non-significant estimates showed that odds ratios for excess GWG were higher for the active women. It is possible that the questions we used to assess moderate and vigorous LTPA may have led women to report more time in each LTPA intensity than they might have if we had asked them to report duration of specific activities. In addition, it is possible that many activities of daily living are more difficult and cause a greater increase in breathing and heart rate for overweight and obese pregnant women, as compared to normal weight pregnant women. According to our estimates, 32% of our sample met U.S. physical activity recommendations (≥ 150 minutes per week), which is greater than the estimate of 23% obtained using data from the National Health and Nutrition Examination Survey[39]. Regardless of pre-pregnancy body size, women may have had difficulty in separating LTPA from activities of daily living, which also may have resulted in over-report of LTPA. In addition to the phrasing of our questions, null findings could also be due to the timing of our LTPA measure. Pregnancy LTPA was assessed at the time of enrollment (prior to 14 weeks gestation) via self-report. The major weakness of the timing of assessment was that it was obtained in early pregnancy and might not be representative of overall pregnancy LTPA. Previous reports indicate that LTPA levels decline as pregnancy progresses[39-41]. Therefore, it is likely that some study participants decreased LTPA or stopped exercising altogether later in pregnancy. In contrast, it is unlikely that women reported not participating in LTPA and then became active later in pregnancy. In order to minimize the influence of changing LTPA during pregnancy and eliminate measurement error associated with LTPA obtained via questionnaire, we chose to classify moderate and vigorous as "not active" or "active" for our analyses. By classifying LTPA in this way, we made it unlikely for women to be misclassified as being sedentary and were able to group women together that reported participating in any LTPA during pregnancy. Although we carefully considered how to best utilize our LTPA variables, it is possible that our measures lacked sufficient sensitivity to determine significant differences in the appropriateness of GWG.

An alternative explanation for LTPA not being associated with GWG among varying BMI categories is that the propensity for women to engage in LTPA while pregnant, particularly among women who are not highly active, is simply not associated with body size prior to becoming pregnant. Although average minutes per week of moderate LTPA in our sample were above recommended ranges and higher than estimates obtained from larger cohorts[39, 42], the majority of our sample was not highly active. As such, we found that, compared to normal weight women, odds of overweight and obese women engaging in moderate or vigorous pregnancy LTPA were not significantly different. Although there is a clear inverse association between BMI and LTPA in non-pregnant adult populations[43-46], less is known about the nature of this relationship during pregnancy. Lower daily step counts have been observed in obese versus normal weight pregnant women[47], but results to corroborate this finding or assess differences from overweight pregnant women are lacking. Hegaard et al. evaluated physical activity among nulliparous women in different BMI categories and found that differences across categories were not significant[48]. We performed another study (under review) that also supports the findings of Hegaard et al. [49]. In a racially and economically diverse sample, we found that differences in retrospective self-reported pregnancy LTPA levels did not differ significantly among women of different pre-pregnancy body sizes. Although more data from varying populations are needed to confirm these findings, preliminary results from these studies indicate that in contrast to non-pregnant populations, participation in pregnancy LTPA may not differ among women of different pre-pregnancy body sizes.

After evaluating potential confounders, the only covariate retained in our adjusted models was enrollment in WIC. Our data indicated that women who were enrolled in WIC were less likely to experience excess GWG. Funded by the United States Department of Agriculture, WIC provides referrals to health and social services, supplemental foods of high nutrient content, nutrition education and breastfeeding support to low-income pregnant and postpartum women[50].

Implemented properly, WIC programming has the potential to assist women in gaining a healthy amount of weight during pregnancy. According to the report released by the IOM (in conjunction with their revised GWG guidelines), data are needed that investigate the appropriateness of GWG in racial and ethnic minority groups and women on food assistance programs, such as WIC, as this is a very understudied area[17]. Although it was not our purpose to investigate the association between WIC enrollment and GWG, our data suggest that the programming provided through WIC to our sample (in which 42% consisted of racial and ethnic minority groups and 78% were enrolled in WIC) may be effective in helping women achieve GWG within recommended ranges.

Study limitations include the self-reported nature of our LTPA variable and our relatively small sample size. As a result, we were unable to explore the interaction between pre-pregnancy BMI and LTPA. In spite of these limitations, study strengths included our racially and economically diverse sample, prospectively measured moderate and vigorous pregnancy LTPA, and consideration of covariates. Additionally, to our knowledge, we are the first group to evaluate pre-pregnancy BMI and LTPA in relation to GWG calculated via two different sources of pre-pregnancy weight. Prospective studies should be performed on larger samples with more objective measures of LTPA (such as accelerometry) and diversity with respect levels of LTPA to further explore the relationships among pre-pregnancy BMI, LTPA, and GWG. Additionally, more research is needed to investigate changes in these associations according to the method by which pre-pregnancy BMI and GWG are calculated.

**Figure 3.1. Flow chart of women included in analyses for Aims 1, 2 and 3 (n=135)**

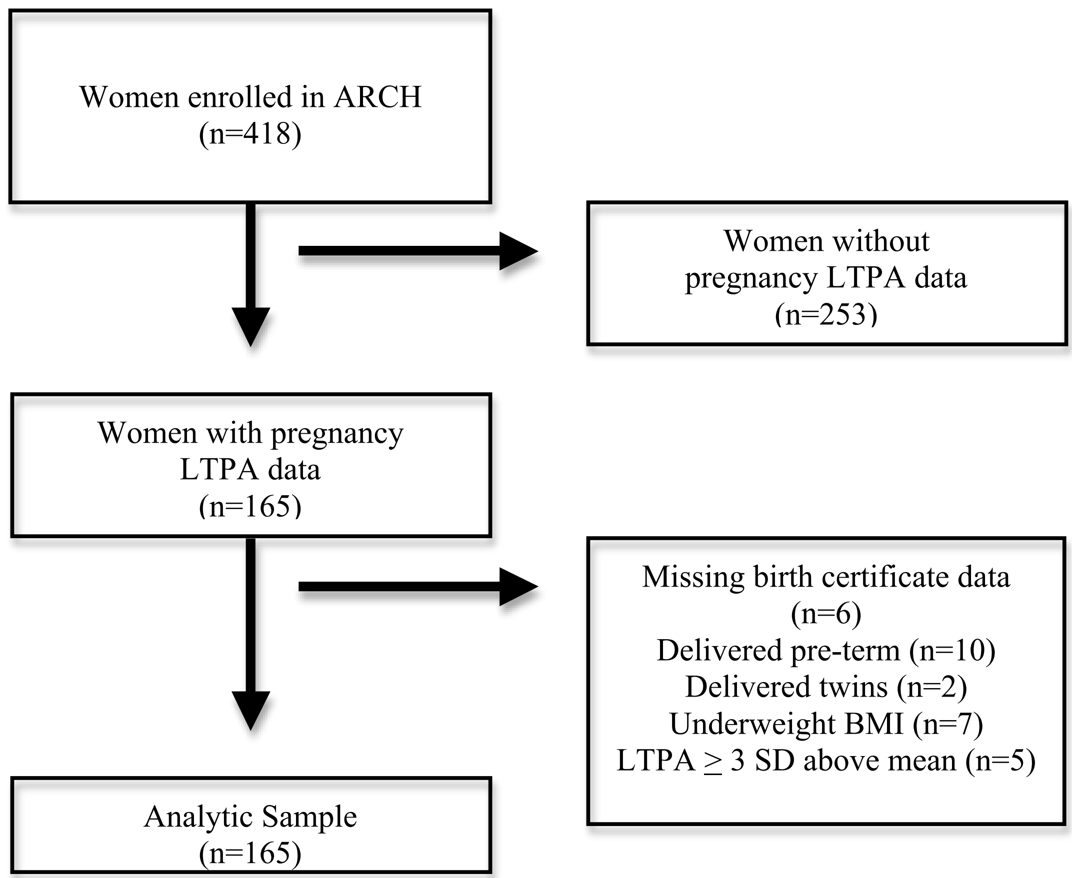

**Table 3.1. Institute of Medicine gestational weight gain recommendations (2009).**

| Pre-pregnancy BMI category ($kg/m^2$) | Recommended gestational weight gain (lbs) |
|---|---|
| <18.5 (Underweight) | 28-40 |
| 18.5-24.9 (Normal weight) | 25-35 |
| 25.0-29.9 (Overweight) | 15-25 |
| >30.0 (Obese) | 11-20 |

**Table 3.2. Comparison of maternal characteristics for the ARCH analytic and non-analytic samples.**

| | Analytic Sample (N=129-135) | | Non-Analytic Sample (N=265-280) | | |
|---|---|---|---|---|---|
| | N | (%) | N | (%) | p-value; ϕ |
| **Education (years)** | | | | | |
| <12 | 20 | (15.5) | 36 | (13.0) | 0.43; 0.08 |
| 12 | 40 | (31.0) | 97 | (35.0 | |
| >12 | 69 | (53.5) | 144 | (52.0) | |
| **Race/Ethnicity** | | | | | |
| White | 77 | (57.0) | 199 | (71.6) | 0.02*; 0.18 |
| African American | 41 | (30.4) | 59 | (21.2) | |
| Others | 17 | (12.6) | 20 | (7.2) | |
| **Smoking** | | | | | |
| Yes | 32 | (23.7) | 46 | (16.8) | 0.20; 0.09 |
| No | 103 | (76.3) | 226 | (82.8) | |
| **Alcohol** | | | | | |
| Yes | 0 | (0) | 1 | (0.4) | 0.69; 0.04 |
| No | 134 | (100) | 272 | (99.6) | |
| **Parity** | | | | | |
| 0 | 57 | (42.2) | 117 | (42.4) | 0.32; 0.16 |
| ≥ 1 | 75 | (57.8) | 159 | (57.6) | |
| **WIC Recipient** | | | | | |
| Yes | 100 | (77.5) | 94 | (34.1) | < 0.001*; 0.39 |
| No | 29 | (22.4) | 178 | (64.5) | |
| **Marital Status** | | | | | |
| Married | 36 | (26.9) | 102 | (36.4) | 0.05*; 0.10 |
| Unmarried | 98 | (73.1) | 178 | (63.6) | |
| **Enrollment Pre-pregnancy Body Mass Index (BMI; $kg/m^2$)** | | | | | |
| Normal Weight (≥18.5, <25) | 53 | (39.6) | 114 | (46.3) | 0.05*; 0.14 |
| Overweight (≥ 25, <30) | 41 | (30.6) | 60 | (24.4) | |
| Obese (>30) | 40 | (29.9) | 72 | (29.3) | |
| **Birth Certificate Pre-pregnancy BMI ($kg/m^2$)** | | | | | |
| Normal Weight (≥18.5, <25) | 46 | (34.1) | 118 | (46.5) | 0.005*; 0.18 |
| Overweight (≥ 25, <30) | 44 | (32.6) | 78 | (30.7) | |
| Obese (>30) | 45 | (33.3) | 58 | (22.8) | |

**Table 3.2. (cont'd)**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Pregnancy Leisure-time Physical Activity (LTPA): Moderate Intensity** | | | | | | |
| Yes | 73 | (55.7) | | N/A | | |
| No | 58 | (44.3) | | | | |
| **Pregnancy LTPA: Vigorous Intensity** | | | | | | |
| Yes | 23 | (17.8) | | N/A | | |
| No | 106 | (82.2) | | | | |
| **Enrollment Gestational Weight Gain (GWG)** | | | | | | |
| Not Excess | 53 | (39.6) | | 141 | (53.2) | 0.01*; 0.13 |
| Excess | 81 | (60.4) | | 124 | (46.8) | |
| **Birth Certificate GWG** | | | | | | |
| Not Excess | 59 | (43.7) | | 143 | (53.2) | 0.07; 0.09 |
| Excess | 76 | (56.3) | | 126 | (46.8) | |

* Indicates a statistically significant difference between analytic and non-analytic samples ($p \leq 0.05$).

**Table 3.3. Gestational weight gain categorization and LTPA according to pre-pregnancy BMI (n=135).**

| | **Enrollment GWG N (%*)** | | **Birth certificate GWG N (%*)** | | **Moderate LTPA N (%*)** | | **Vigorous LTPA N (%*)** | |
|---|---|---|---|---|---|---|---|---|
| | **Not excess** | **Excess** | **Not Excess** | **Excess** | **Not Active** | **Active** | **Not Active** | **Active** |
| **Enrollment BMI** | | | | | | | | |
| Normal | 28 (52.8) | 25 (47.2) | 30 (56.6) | 23 (43.4) | 26 (51.0) | 25 (49.0) | 42 (80.8) | 10 (19.2) |
| Overweight | 10 (24.4) | 31 (75.6) [a] | 11 (26.8) | 30 (73.2) [a] | 14 (35.0) | 26 (65.0) | 29 (78.4) | 8 (21.6) |
| Obese | 15 (37.5) | 25 (62.5) | 15 (37.5) | 25 (62.5) | 17 (43.6) | 22 (56.4) | 34 (87.2) | 23 (12.8) |
| **Birth certificate BMI** | | | | | | | | |
| Normal | 28 (60.9) | 18 (39.1) | 28 (60.9) | 18 (39.1) | 23 (51.1) | 22 (48.9) | 36 (80.0) | 9 (20.0) |
| Overweight | 10 (23.3) | 33 (76.7) [a] | 11 (25.0) | 33 (75.0) [a] | 16 (38.1) | 26 (61.9) | 30 (75.0) | 10 (25.0) |
| Obese | 15 (33.3) | 30 (66.7) [a] | 18 (40.0) | 27 (60.0) [a] | 19 (43.2) | 25 (56.8) | 40 (90.9) | 4 (9.1) |

* % are calculated as percentage within each BMI category

[a] Significantly different from the normal weight category ($p \leq 0.05$)

**Table 3.4. Associations among GWG categorization, pre-pregnancy BMI, and pregnancy LTPA (n=135).**

| | **Excess Enrollment GWG OR (95% CI)** | **Excess Birth Certificate GWG OR (95% CI)** |
|---|---|---|
| **Main Effects Models** | | |
| **Enrollment Pre-pregnancy BMI** *(ref: Normal weight)* | | |
| Overweight | 3.47 (1.42, 8.49)* | 3.56 (1.48, 8.57)* |
| Obese | 1.87 (0.81, 4.31) | 2.17 (0.94, 5.03) |
| **Birth certificate Pre-pregnancy BMI** *(ref: Normal weight)* | | |
| Overweight | 5.13 (2.04, 12.91)* | 4.67 (1.89, 11.52)* |
| Obese | 3.11 (1.32, 7.33)* | 2.33 (1.01, 5.41)* |
| **Moderate LTPA** *(ref: Not Active)* | | |
| Active | 1.52 (0.75, 3.08) | 1.40 (0.70, 2.82) |
| **Vigorous LTPA** *(ref: Not Active)* | | |
| Active | 1.30 (0.51, 3.34) | 1.49 (0.58, 3.82) |

***** $p \leq 0.05$
Referent (ref) categories were: normal weight BMI and "not active" moderate and vigorous LTPA

**Table 3.5. Main effect models adjusted for WIC enrollment (n=135).**

| | **Excess Enrollment GWG aOR (95% CI)#** | **Excess Birth Certificate GWG aOR (95% CI)#** |
|---|---|---|
| **Main Effects Models** | | |
| **Enrollment Pre-pregnancy BMI** *(ref: Normal weight)* | | |
| Overweight | 3.38 (1.32, 8.64)* | 3.73 (1.49, 9.37)* |
| Obese | 1.81 (0.76, 4.36) | 2.31 (0.96, 5.56) |
| **Birth certificate Pre-pregnancy BMI** *(ref: Normal weight)* | | |
| Overweight | 5.34 (2.03, 14.11)* | 5.30 (2.05, 13.72)* ‡ |
| Obese | 3.11 (1.27, 7.63)* | 2.48 (1.03, 6.00)* |
| **Moderate LTPA** *(ref: Not Active)* | | |
| Active | 1.22 (0.58, 2.58) | 1.23 (0.59, 2.57) ‡ |
| **Vigorous LTPA** *(ref: Not Active)* | | |
| Active | 1.10 (0.41, 2.91) ‡ | 1.33 (0.51, 3.51) ‡ |

"aOR"=Adjusted odds ratio
Referent (ref) categories were: normal weight BMI and "not active" moderate and vigorous LTPA
# Models adjusted for WIC enrollment (ref: not enrolled).
* $p \leq 0.05$
‡ ≥10% change from unadjusted model.

**REFERENCES**

## References


1. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA.* Jan 20 2010;303(3):235-241.

2. Sebire NJ, Jolly M, Harris JP, et al. Maternal obesity and pregnancy outcome: a study of 287,213 pregnancies in London. *Int J Obes Relat Metab Disord.* Aug 2001;25(8):1175-1182.

3. Callaway LK, Prins JB, Chang AM, McIntyre HD. The prevalence and impact of overweight and obesity in an Australian obstetric population. *Med J Aust.* Jan 16 2006;184(2):56-59.

4. O'Brien TE, Ray JG, Chan WS. Maternal body mass index and the risk of preeclampsia: a systematic overview. *Epidemiology.* May 2003;14(3):368-374.

5. Frederick IO, Rudra CB, Miller RS, Foster JC, Williams MA. Adult weight change, weight cycling, and prepregnancy obesity in relation to risk of preeclampsia. *Epidemiology.* Jul 2006;17(4):428-434.

6. Villamor E, Cnattingius S. Interpregnancy weight change and risk of adverse pregnancy outcomes: a population-based study. *Lancet.* Sep 30 2006;368(9542):1164-1170.

7. Crane SS, Wojtowycz MA, Dye TD, Aubry RH, Artal R. Association between pre-pregnancy obesity and the risk of cesarean delivery. *Obstet Gynecol.* Feb 1997;89(2):213-216.

8. Sheiner E, Levy A, Menes TS, Silverberg D, Katz M, Mazor M. Maternal obesity as an independent risk factor for caesarean delivery. *Paediatr Perinat Epidemiol.* May 2004;18(3):196-201.

9. Rosenberg TJ, Garbers S, Chavkin W, Chiasson MA. Prepregnancy weight and adverse perinatal outcomes in an ethnically diverse population. *Obstet Gynecol.* Nov 2003;102(5 Pt 1):1022-1027.

10. Oken E. Excess gestational weight gain amplifies risks among obese mothers. *Epidemiology.* Jan 2009;20(1):82-83.

11. Siega-Riz AM, Viswanathan M, Moos MK, et al. A systematic review of outcomes of maternal weight gain according to the Institute of Medicine recommendations: birthweight, fetal growth, and postpartum weight retention. *Am J Obstet Gynecol.* Oct 2009;201(4):339 e331-314.

12. Viswanathan M, Siega-Riz AM, Moos MK, et al. Outcomes of maternal weight gain. *Evid Rep Technol Assess (Full Rep).* May 2008(168):1-223.

**13.** Edwards LE, Hellerstedt WL, Alton IR, Story M, Himes JH. Pregnancy complications and birth outcomes in obese and normal-weight women: effects of gestational weight change. *Obstet Gynecol.* Mar 1996;87(3):389-394.

**14.** Saldana TM, Siega-Riz AM, Adair LS, Suchindran C. The relationship between pregnancy weight gain and glucose tolerance status among black and white women in central North Carolina. *Am J Obstet Gynecol.* Dec 2006;195(6):1629-1635.

**15.** Kiel DW, Dodson EA, Artal R, Boehmer TK, Leet TL. Gestational weight gain and pregnancy outcomes in obese women: how much is enough? *Obstet Gynecol.* Oct 2007;110(4):752-758.

**16.** Cedergren M. Effects of gestational weight gain and body mass index on obstetric outcome in Sweden. *Int J Gynaecol Obstet.* Jun 2006;93(3):269-274.

**17.** Weight gain during pregnancy: reexamining the guidelines. Washington DC: Institute of Medicine; 2009.

**18.** Artal R, Lockwood CJ, Brown HL. Weight gain recommendations in pregnancy and the obesity epidemic. *Obstet Gynecol.* Jan 2010;115(1):152-155.

**19.** Claesson IM, Brynhildsen J, Cedergren M, Jeppsson A, Sydsjo A, Josefsson A. Weight gain restriction during pregnancy is safe for both the mother and neonate. *Acta Obstet Gynecol Scand.* 2009;88(10):1158-1162.

**20.** Olson CM. Achieving a healthy weight gain during pregnancy. *Annu Rev Nutr.* 2008;28:411-423.

**21.** Althuizen E, van Poppel MN, Seidell JC, van Mechelen W. Correlates of absolute and excessive weight gain during pregnancy. *J Womens Health (Larchmt).* Oct 2009;18(10):1559-1566.

**22.** Streuling I, Beyerlein A, Rosenfeld E, Hofmann H, Schulz T, von Kries R. Physical activity and gestational weight gain: a meta-analysis of intervention trials. *BJOG.* Feb 2011;118(3):278-284.

**23.** Gardner B, Wardle J, Poston L, Croker H. Changing diet and physical activity to reduce gestational weight gain: a meta-analysis. *Obes Rev.* Jul 2011;12(7):e602-620.

**24.** Clapp JF, 3rd, Little KD. Effect of recreational exercise on pregnancy weight gain and subcutaneous fat deposition. *Med Sci Sports Exerc.* Feb 1995;27(2):170-177.

**25.** Haakstad LA, Voldner N, Henriksen T, Bo K. Physical activity level and weight gain in a cohort of pregnant Norwegian women. *Acta Obstet Gynecol Scand.* 2007;86(5):559-564.

**26.** Stuebe AM, Oken E, Gillman MW. Associations of diet and physical activity during pregnancy with risk for excessive gestational weight gain. *Am J Obstet Gynecol.* Jul 2009;201(1):58 e51-58.

**27.** Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser.* 2000;894:i-xii, 1-253.

**28.** Merrill RM, Richardson JS. Validity of self-reported height, weight, and body mass index: findings from the National Health and Nutrition Examination Survey, 2001-2006. *Prev Chronic Dis.* Oct 2009;6(4):A121.

**29.** Brunner Huber LR. Validity of self-reported height and weight in women of reproductive age. *Matern Child Health J.* Mar 2007;11(2):137-144.

**30.** Wright CS, Weiner M, Localio R, Song L, Chen P, Rubin D. Misreport of gestational weight gain (GWG) in birth certificate data. *Matern Child Health J.* Jan 2012;16(1):197-202.

**31.** Bodnar LM, Siega-Riz AM, Simhan HN, Himes KP, Abrams B. Severe obesity, gestational weight gain, and adverse birth outcomes. *Am J Clin Nutr.* Jun 2010;91(6):1642-1648.

**32.** Flick AA, Brookfield KF, de la Torre L, Tudela CM, Duthely L, Gonzalez-Quintero VH. Excessive weight gain among obese women and pregnancy outcomes. *Am J Perinatol.* Apr 2010;27(4):333-338.

**33.** Skouteris H, Hartley-Clark L, McCabe M, et al. Preventing excessive gestational weight gain: a systematic review of interventions. *Obes Rev.* Nov 2010;11(11):757-768.

**34.** Streuling I, Beyerlein A, von Kries R. Can gestational weight gain be modified by increasing physical activity and diet counseling? A meta-analysis of interventional trials. *Am J Clin Nutr.* Oct 2010;92(4):678-687.

**35.** Bish CL, Chu SY, Shapiro-Mendoza CK, Sharma AJ, Blanck HM. Trying to lose or maintain weight during pregnancy-United States, 2003. *Matern Child Health J.* Mar 2009;13(2):286-292.

**36.** Gunderson EP, Abrams B. Epidemiology of gestational weight gain and body weight changes after pregnancy. *Epidemiol Rev.* 2000;22(2):261-274.

**37.** Crane JM, White J, Murphy P, Burrage L, Hutchens D. The effect of gestational weight gain by body mass index on maternal and neonatal outcomes. *J Obstet Gynaecol Can.* Jan 2009;31(1):28-35.

**38.** Abrams B, Altman SL, Pickett KE. Pregnancy weight gain: still controversial. *Am J Clin Nutr.* May 2000;71(5 Suppl):1233S-1241S.

**39.** Evenson KR, Wen F. National trends in self-reported physical activity and sedentary behaviors among pregnant women: NHANES 1999-2006. *Prev Med.* Mar 2010;50(3):123-128.

**40.** Mottola MF, Campbell MK. Activity patterns during pregnancy. *Can J Appl Physiol.* Aug 2003;28(4):642-653.

**41.** Pereira MA, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Peterson KE, Gillman MW. Predictors of change in physical activity during and after pregnancy: Project Viva. *Am J Prev Med.* Apr 2007;32(4):312-319.

**42.** Borodulin K, Evenson KR, Herring AH. Physical activity patterns during pregnancy through postpartum. *BMC Womens Health.* 2009;9:32.

**43.** Kaleta D, Makowiec-Dabrowska T, Jegier A. Occupational and leisure-time energy expenditure and body mass index. *Int J Occup Med Environ Health.* 2007;20(1):9-16.

**44.** Hemmingsson E, Ekelund U. Is the association between physical activity and body mass index obesity dependent? *Int J Obes (Lond).* Apr 2007;31(4):663-668.

**45.** Ball K, Owen N, Salmon J, Bauman A, Gore CJ. Associations of physical activity with body weight and fat in men and women. *Int J Obes Relat Metab Disord.* Jun 2001;25(6):914-919.

**46.** Cooper AR, Page A, Fox KR, Misson J. Physical activity patterns in normal, overweight and obese individuals using minute-by-minute accelerometry. *Eur J Clin Nutr.* Dec 2000;54(12):887-894.

**47.** Renault K, Norgaard K, Andreasen KR, Secher NJ, Nilas L. Physical activity during pregnancy in obese and normal-weight women as assessed by pedometer. *Acta Obstet Gynecol Scand.* Jul 2010;89(7):956-961.

**48.** Hegaard HK, Damm P, Hedegaard M, et al. Sports and leisure time physical activity during pregnancy in nulliparous women. *Matern Child Health J.* Aug 2011;15(6):806-813.

**49.** Schlaff RA, Holzman C, Mudd LM, Pfeiffer KA, Pivarnik JM. Gestational weight gain, pre-pregnancy body mass index, and leisure-time physical activity during pregnancy.2012.

**50.** United States Department of Agriculture. Nutrition and food service. 2005; www.fns.usda.gov/wic/.

**51.** Personal Communication with Glenn Copeland: Michigan Department of Community Health. May 18, 2012

## CHAPTER FOUR:

## POSTPARTUM WEIGHT RETENTION: IS THERE AN ASSOCIATION WITH LEISURE-TIME PHYSICAL ACTIVITY AND GESTATIONAL WEIGHT GAIN?


### ABSTRACT

The purpose of this study was to prospectively examine the separate and combined effects of gestational weight gain (GWG), and pregnancy and postpartum leisure-time physical activity (LTPA) on postpartum weight retention (PPWR) at six months postpartum. **METHODS:** Our sample consisted of a subset of women who participated in the Archive for Research on Child Health (ARCH) study and were successfully contacted in the postpartum period (n=68). Pre-pregnancy weight was obtained via questionnaire at enrollment and abstracted from each woman's birth certificate after delivery. Pregnancy LTPA was self-reported via enrollment questionnaire and six month postpartum LTPA was self-reported via phone interview. Both were dichotomized as "not meeting recs" or "meeting recs," based on achievement of 150 minutes of moderate and/or vigorous LTPA per week. GWG was calculated by subtracting pre-pregnancy weight (self-reported at study enrollment or abstracted from birth certificates) from weight at delivery (abstracted from birth certificates) and classified as "excess" or "not excess" using the upper limit of the 2009 IOM recommended range. Pre-pregnancy weight (self-reported at enrollment and abstracted from birth certificates) was subtracted from self-reported postpartum weight to calculate two different values of six month PPWR. Linear regression was used to examine independent and combined associations among GWG, pregnancy LTPA, and postpartum LTPA on the outcome of PPWR. **RESULTS:** Mean six month PPWR was 2-4 kg, depending on PPWR calculation. Excess GWG was independently associated with increased PPWR. After adjusting for covariates, excess GWG was the only variable that remained significant.  The magnitude and statistical significance of associations varied among GWG and PPWR calculation methods.  **CONCLUSION:** In conclusion, our findings highlight the importance of appropriate GWG in decreasing PPWR.  In order to better inform interventions and clinical practice, research with improved methodology (particularly with regard to LTPA assessment) is needed to test and refine our findings while continuing to explore the interrelationships among GWG, pregnancy LTPA, postpartum LTPA, and PPWR.

## INTRODUCTION

To date, most research on the appropriateness of maternal gestational weight gain (GWG) has focused on determinants and consequences during pregnancy or at delivery. However, with the rising prevalence of obesity among women of childbearing ages[1] and the high prevalence of women gaining excess weight during pregnancy[2], many researchers have shifted their foci to mother's postpartum health status. Researchers have begun to investigate postpartum weight status, since one of the most common, long-term health issues women face is an increase in body weight after pregnancy. Excess body weight is problematic because of its positive association with metabolic and cardiovascular disease development later in life[3]. Weight in the postpartum period in excess of pre-pregnancy body weight has been termed "postpartum weight retention" (PPWR). In fact, researchers have suggested that pregnancy is a potential risk factor for obesity development in women of childbearing age because of PPWR[4]. The amount of weight retained has been shown to be quite variable, with one review paper reporting a range from 26.5 kg gained to 12 kg lost at one year postpartum, as compared to pre-pregnancy body weight[5]. Many studies report an average PPWR of only 0.5 – 3.0 kg; however, ~20% of women may retain at least 5 kg at 6 – 18 months postpartum[6]. The cause of PPWR is multi-factorial, however, it has been proposed that one potential pathway is through excessive GWG[7].

In general, results from observational studies have shown a consistent positive relationship between GWG in excess of the IOM recommendations and PPWR[2, 3, 5, 8-15]. Even though GWG explains a large part of the variance in PPWR, other lifestyle factors, such as leisure-time physical activity (LTPA) during pregnancy and postpartum, may play a role.

Unfortunately, researchers studying PPWR have not typically considered the influence of lifestyle behaviors, such as LTPA. Results from observational studies that have examined association between postpartum LTPA and PPWR have yielded consistent inverse relationships at varying postpartum time points (6 weeks to 10 years)[5, 14-18]. However, prospective studies that examine LTPA participation during pregnancy and postpartum on PPWR are lacking. Further, the combined effects of pregnancy LTPA, postpartum LTPA, and appropriateness of GWG on PPWR have not been examined. Gaining more insight into the inter-relationships among the appropriateness of GWG, LTPA participation during pregnancy and postpartum period, and PPWR could help inform future research and interventions designed to elicit appropriate maternal body weight changes. Therefore, the purpose of this study was to prospectively examine the separate and combined effects of GWG, and pregnancy and postpartum LTPA on PPWR at six months postpartum.

## METHODS

### *Study Population and Recruitment*

Our sample consisted of a subset of women who participated in the Archive for Research on Child Health (ARCH) study. The initial purpose of the prospective ARCH study was to develop a system to collect and store pregnancy and perinatal biological specimens (urine, blood, placenta) and data collected from maternal report via interview/questionnaires. Therefore, results from biological specimens and other prospectively reported participant data were stored in a database. The intent was for these data to be used for future research questions, in the event that a health condition arises in the postpartum period (instead of relying on maternal recall of the perinatal period after an event occurred).

Women were recruited and enrolled prior to 14 weeks gestation from local prenatal clinics. Inclusion criteria for the ARCH study were maternal age $\geq$ 18 years and proficiency in English. Women included in our analyses had self-reported pregnancy and postpartum LTPA, birth certificate data to calculate GWG, and six month postpartum body weight estimates. In addition, participants included delivered a live, singleton, term (>37 weeks) infant. Subject recruitment occurred at three Midwestern U.S. prenatal clinics. These clinics included a university faculty obstetric clinic, hospital residency clinic, and county health department clinic. When a woman first called one of these clinics to schedule a prenatal appointment, she was informed that a brochure would be mailed to her describing the ARCH project. Brochures were also available in the clinic waiting room when women arrived for their appointments. At the first appointment, the health care provider sought pregnant patients' permission to talk with ARCH staff in the clinic. Interested women then met with a trained member of the ARCH staff in the clinic immediately following their appointments. Women interested in the study had the opportunity to ask questions and complete the consent form, in order to become enrolled (Appendix A). Women who consented to participate allowed routinely collected prenatal specimens to be forwarded to a data repository for storage, abstraction from medical records and access to their children's birth certificate for research purposes. After consenting, women were asked to complete a brief questionnaire at enrollment. ARCH researchers also asked permission to contact the women at varying time points in the postpartum period to obtain maternally-reported health information. Study participants were compensated with a $10 gift card to a local grocery store after enrolling in the study and completing the prenatal questionnaire, and each time they completed a postpartum interview.

*Demographic Variables*

Information obtained at enrollment was collected via self-reported maternal questionnaire (Appendix B). Maternal age was determined from reported date of birth. Basic demographic information such as ethnic/racial category, education level, and marital status were collected using categorical variables. Women were also asked to specify if they have ever been told by a healthcare provider that they had any of the following conditions: periodontal disease, depression or other psychiatric conditions, seizure disorder, epilepsy or other neurological conditions, and high cholesterol. Additionally, women reported family history of autism, mental retardation, cerebral palsy, or any other severe child disability.

*Pre-pregnancy Anthropometrics*

In order to obtain a measure of pre-pregnancy body size, women were asked, via questionnaire at enrollment, to report their heights and weights (without shoes) just prior to becoming pregnant. Pre-pregnancy body weight was also abstracted from each woman's birth certificate after delivery. For this dissertation, the research team calculated pre-pregnancy body mass index (BMI) as weight in kilograms divided by height in meters squared, using both measures of pre-pregnancy body weight. These variables were termed "Enrollment pre-pregnancy BMI" and "Birth certificate pre-pregnancy BMI." Women were categorized as underweight, normal weight, overweight or obese, according to the classifications developed by the World Health Organization and adopted by the Institutes of Medicine (IOM) for GWG recommendations[19, 20] (Underweight: <18.5 kg/m$^2$; Normal: 18.5-24.99kg/m$^2$; Overweight: 25-29.99kg/m$^2$; Obese: $\geq$30kg/m$^2$).

*Pregnancy Leisure-time Physical Activity*

Women were asked to report LTPA participation during pregnancy at study enrollment (prior to 14 weeks gestation) via questionnaire (Appendix C). They were asked to think about any physical activity, exercise, and sports that they took part in during their free time. Moderate activities were described as ones that cause a small increase in breathing or heart rate, while vigorous activities were described as ones that cause an increase in breathing or heart rate. Examples of both moderate and vigorous activities were provided to assist women in distinguishing intensity level. If women reported participating in either moderate or vigorous LTPA, they were asked to report days per week and typical time (hours and minutes) spent doing moderate and/or vigorous activities in one day. Minutes per day of moderate and vigorous LTPA were multiplied by the number of days per week to obtain minutes per week of moderate and vigorous LTPA. Pregnancy LTPA was dichotomized as "not meeting recs" if a woman reported less than 150 minutes of moderate and vigorous LTPA per week during pregnancy or "meeting recs" if a woman reported participating in at least 150 minutes of moderate and/or vigorous LTPA during pregnancy, in accordance with guidelines published by the American College of Obstetricians and Gynecologists (ACOG)[21].

*Gestational Weight Gain*

For this dissertation, gestational weight gain (GWG) was calculated in two ways. Values for GWG were calculated by subtracting pre-pregnancy weight (self-reported at study enrollment or abstracted from birth certificates) from weight at delivery (abstracted from birth certificates), and were referred to as "enrollment GWG" and "birth certificate GWG." For each participant, adequacy of GWG (via both calculation methods) was evaluated based on pre-pregnancy BMI-specific 2009 IOM recommendations. In order to maximize statistical power and focus on predicting excess GWG, values were categorized as "excess" or "not excess", using the upper limit of the 2009 IOM recommended range in a given BMI category as a cut-point[20] (Table 4.1).

*Postpartum Follow-up Phone Interview*

Participants enrolled in the ARCH study received follow-up phone calls at six months and one year postpartum by a trained member of the ARCH staff. The purpose of these calls was to obtain relevant information regarding the overall health of the mother and child. Responses from a questionnaire related to maternal weight status and LTPA were utilized for analyses (Appendix D). Since we had data for very few women at one year postpartum (<20), only six month postpartum data were included this paper. Therefore, women contacted at six months postpartum were asked to report weight and LTPA at the current time-point, and women contacted at one year postpartum were asked to recall weight and LTPA from six months postpartum.

*Postpartum Weight Retention*

Pre-pregnancy weight (self-reported at enrollment and abstracted from birth certificates) was subtracted from self-reported postpartum weight to calculate two different values of six month PPWR for each subject, which were termed "Enrollment PPWR" and "Birth certificate PPWR."

*Postpartum Leisure-Time Physical Activity*

Women were asked to report LTPA participation at six months postpartum via questions asked during a postpartum phone interview. They were asked to think about any physical activity, exercise, and sports that they took part in during their free time and reported activities according to whether they were moderate or vigorous. Moderate activities were described as ones that cause a small increase in breathing or heart rate, while vigorous activities were described as ones that cause an increase in breathing or heart rate. Examples of both moderate and vigorous activities were provided to assist women in distinguishing intensity level. If women reported participating in either moderate or vigorous LTPA, they were asked to report days per week and typical time (hours and minutes) spent doing moderate and/or vigorous activities in one day. Time per day spent in moderate and vigorous LTPA were each multiplied by the number of reported days per week to obtain minutes per week of moderate and vigorous LTPA. Six month postpartum LTPA was categorized as “not meeting recs” or “meeting recs,” depending on whether either moderate or vigorous physical activity guidelines were achieved (moderate: 150 minutes per week; vigorous: 75 minutes per week[22]).

*Postpartum Covariates*

During the postpartum interview, women were asked if their infant has been breastfed. Information regarding this practice was available as a dichotomous variable (yes/no). Women were also asked about their fruit and vegetable intake. Servings of fruits and vegetables per day were combined and available as a continuous variable (servings per day).

*Statistical Analyses*

Descriptive statistics (means, standard deviations, and proportions were calculated for all variables of interest. Women lost to follow-up were compared to women in our analytic sample to assess differences from the original cohort using a chi-square test. Postpartum weight retention (measured as a continuously-valued variable) was normally distributed, so linear regression was used to test for main effects between GWG, and pregnancy and postpartum LTPA on the outcome measure of six month PPWR. Multiple linear regression was used to examine the combined effect of GWG, pregnancy LTPA, and postpartum LTPA on six month PPWR. GWG was expressed as a binary variable (“not excess” or “excess”) and LTPA was expressed categorically during pregnancy and at six months postpartum (“not meeting recs” or “meeting recs”). LTPA data not within three standard deviations of the mean were excluded as outliers. “Not-excess” GWG and “not meeting recs” for pregnancy and postpartum LTPA were referent categories. 95% confidence intervals for the regression coefficient were calculated. Covariates were investigated for their potential roles as confounders. Criteria for covariate inclusion in the analytic models were as follows: 1) does not function as a mediator or collider; 2) biologic rationale for potential confounding based on previous literature; and 3) a statistically significant association with PPWR, or alters other main effect estimates by more than 10 percent in the current dataset. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

**RESULTS**

Since very few women had a pre-pregnancy BMI that was classified as underweight (n=7), they were excluded from our analyses. Women with self-reported pregnancy LTPA that was ≥ 3 standard deviations above the mean (self-reported estimates not within reason) were excluded (n=5). In addition, 67 women were unable to be contacted in the postpartum period. Attempts to contact women occurred via telephone, email, and postal mail. Women were called at various times of the day at all numbers traceable to her name, including those found in the white pages. Since postpartum weight and LTPA were not available for these women, they were not included in our analyses. Therefore, final sample size included in our analyses was 68. A flow chart of included/excluded participants can be seen in Figure 4.1.

Overall, women who did not meet our pregnancy inclusion criteria were older (M±SD; 26 ± 6.9 years), of higher socio-economic status (indicated by WIC enrollment), and more were married. Furthermore, a lower percentage of the women not meeting pregnancy inclusion criteria were obese prior to becoming pregnant, of non-white race/ethnicity, and experienced excess GWG (Table 4.2). On average, women who were unavailable for follow-up in the postpartum period (and met our pregnancy inclusion criteria above) were less educated and fewer met LTPA guidelines during pregnancy. Although differences were not statistically significant in pre-pregnancy BMI and GWG, more women in our follow-up sample were normal weight and fewer had excess GWG, compared to our non-follow-up sample. More detailed comparisons and effect sizes can be found in Table 4.3.

At study enrollment, average (Mean$\pm$SD) maternal age was 25.5$\pm$5.3 years. The majority of our sample reported an education level that included at least some college, were of white ethnicity, unmarried, enrolled in WIC, and did not smoke during pregnancy (Table 4.3). Pre-pregnancy BMI according to birth certificate and self-report at enrollment were 27.8$\pm$6.6 kg/m$^2$ and 27.5$\pm$7.0 kg/m$^2$, respectively. The percentage of normal weight, overweight, and obese women in our sample (via pre-pregnancy BMI) varied according to the estimate of pre-pregnancy weight used (normal weight: 42-47%, overweight: 22-25%, obese: 29-32%; Table 4.3). Furthermore, average six month PPWR differed slightly according to which estimate of pre-pregnancy weight was utilized in calculation. As such, PPWR was 2.66$\pm$9.71 (range: -20 to +43) kg when using pre-pregnancy weight abstracted from the birth certificate and 3.59$\pm$8.73 (range: -22 to +27) kilograms according to enrollment pre-pregnancy weight. PPWR estimation methods did not differ by pre-pregnancy BMI category (p=0.29) or LTPA participation (p=0.43).

The percentage of women who experienced excess GWG varied slightly between calculation methods of GWG, with enrollment (56.7%) being higher than birth certificate (52.9%). Results of linear regression showed that birth certificate excess GWG was associated with PPWR ($R^2$=0.12-0.21; Table 4.4). However, the magnitude of this association varied among estimations of PPWR and GWG, and enrollment GWG did not significantly predict birth certificate PPWR.

Among our sample, the average amount of moderate and vigorous LTPA in which women reported performing during pregnancy was 293±378 (range: 0-1500) minutes per week. Additionally, we found that 45% of our sample reported participating in the recommended amount of LTPA during pregnancy. The average amount of moderate and vigorous LTPA at six months postpartum averaged 410±593 (range 0-2400) minutes per week and 52% of the sample met national recommendations. When we investigated the association between adequacy of pregnancy LTPA participation and six month PPWR, we found that pregnancy LTPA did not significantly predict weight retained at six months postpartum. Additionally, meeting LTPA recommendations at six months postpartum was not significantly related to PPWR (Table 4.4).

Finally, we examined the combined association of GWG category, pregnancy LTPA and postpartum LTPA on the outcome of six month PPWR. Excess GWG was the only significant predictor in the combined model. The variance that was explained by the combined effect of these predictors differed according to estimates of GWG and PPWR, but ranged from 6.2-22.6% (Table 4.5).

Among the covariates considered for confounding (race, parity, WIC enrollment, smoking, gestational age, birth certificate and enrollment pre-pregnancy BMI, fruits/vegetable consumption, and breastfeeding), only enrollment pre-pregnancy BMI (categorically valued) was significantly related to PPWR ($P<0.05$; overweight and obese women retained less weight than normal weight women). Enrollment pre-pregnancy BMI remained significant when modeled with GWG (enrollment and birth certificate), pregnancy LTPA, and postpartum LTPA with the outcome of enrollment PPWR. The amount of variance each model explained after adjusting for enrollment pre-pregnancy BMI category increased from 15-18% to 25-27% (Tables 4.5 and 4.6). Although breastfeeding was not significantly related to PPWR, it altered some main effect estimates by more than 10 percent when predicting enrollment PPWR (Table 4.6). After further adjusting for breastfeeding, the amount of explained variance in enrollment PPWR increased from 25-27% to 29-33%.

**DISCUSSION**

Our purposes were to examine if a) the appropriateness of GWG, b) pregnancy LTPA, and c) postpartum LTPA were associated with six month PPWR using pre-pregnancy weight estimates determined via self-report at enrollment and abstracted from birth certificate. Additionally, we sought to determine whether the combination of these variables was associated with six month PPWR. Our findings indicated that GWG in excess of IOM recommendations was significantly associated with an increase in PPWR. LTPA participation during pregnancy and at six months postpartum was not associated with PPWR. When we modeled GWG, pregnancy LTPA and postpartum LTPA together, excess GWG was the only variable that remained significant, even after adjusting for pre-pregnancy BMI category and breastfeeding. For all analyses, the magnitude of associations depended on the estimate of pre-pregnancy weight that was used to estimate GWG and PPWR.

Since two different estimates of pre-pregnancy weight were available, we calculated two different values for pre-pregnancy BMI, GWG, and PPWR. Consequently, our prevalence estimates of excess GWG, BMI categorizations, and mean PPWR varied slightly according to the source of pre-pregnancy weight estimate (self-reported at enrollment or abstracted from birth certificate). On average, values for enrollment pre-pregnancy weight were lower than values abstracted from birth certificates. This resulted in average enrollment PPWR being slightly higher than average birth certificate PPWR, but the difference between PPWR measures did not differ significantly as a function of pre-pregnancy BMI category or LTPA participation.

Furthermore, main effect estimates from our linear regression analyses varied among GWG, pre-pregnancy BMI, and PPWR estimations. These findings indicate that methodology utilized to obtain pre-pregnancy weight is an important factor to consider when attempting to explain variance in PPWR within and across research studies. However, to our knowledge, we are the first study to utilize two different estimates of pre-pregnancy weight to calculate GWG, pre-pregnancy BMI, and PPWR.

To date, evidence is not available to comment on the validity of pre-pregnancy weight on the birth certificate in the state of Michigan. Communication with the director of Vital Records and Health Statistics at the Michigan Department of Community Health revealed that the origin of birth certificate pre-pregnancy weight is somewhat ambiguous, as practices within and across hospitals are not consistent (personal communication, Glenn Copeland)[23]. Ideally, pre-pregnancy weight is abstracted from medical records, but conversations with hospital staff revealed that they often rely on maternal self-report after delivery. However, even when pre-pregnancy weight is abstracted from medical records, it is likely an estimate that was self-reported at the first prenatal visit. Before birth certificate abstracted pre-pregnancy weight may be used with confidence in future studies, research is needed to validate birth certificate pre-pregnancy weight, particularly in hospitals with varying birth certificate recording processes. Therefore, for our analyses, we chose to calculate our outcome measure of PPWR with both self-reported enrollment (prior to 14 weeks gestation) and birth certificate pre-pregnancy weight to explore its effect on our estimates.

In addition to pre-pregnancy weight being self-reported, six month postpartum weight status was also assessed via self-report, with women who were at one year postpartum at the time of their interview recalling their body weight from six months prior. An actual measurement of weight at six months postpartum would have been ideal, but was not feasible. Previous research has validated the use of self-reported weight in women of reproductive age, with an average underestimation of 4.6 pounds (2.1 kg) [24]. Furthermore, it does not appear that the bias in self-report changes according to the duration of recall, since research utilizing samples of young and middle-aged adults demonstrate that recall of past body weight (1 – 10 years) may be accomplished with acceptable accuracy, with women tending to underestimate weight by 1 – 3 kg, on average[25, 26]. This is comparable to underestimation of current self-reported body weight.

Regardless of which pre-pregnancy weight estimate was used, we found a consistent, positive association between GWG in excess of IOM recommendations and PPWR at six months. Moreover, excess GWG explained more variance in PPWR than any other predictor in our simple linear and multiple regression models. This finding has been observed consistently in several observational studies[2, 3, 5, 8, 10-15]. For example, Linne et al. demonstrated this relationship in a series of papers utilizing data from the Stockholm Pregnancy and Women's Nutrition (SPAWN) study[5, 10, 11]. Women from SPAWN were studied originally during pregnancy and followed up at six months, one year and 15 years postpartum. Regardless of pre-pregnancy BMI, women who experienced excess GWG retained more weight at each postpartum follow-up time point, even after controlling for the number of pregnancies after the index child. In addition, a recent meta-analysis supported our findings and those from other observational studies and found that women with GWG in excess of IOM recommendations retained significantly more weight at a range of postpartum time points (six months through 15 years postpartum)[27]. The positive association between excess GWG and PPWR is so strong and consistent, that it has been suggested that excess GWG is likely the strongest predictor of PPWR[28].

When we investigated whether self-reported LTPA participation during pregnancy or at six months postpartum was associated with PPWR, we found that LTPA participation at both time points was not significantly associated with six month PPWR. However, an association between postpartum LTPA and PPWR has been consistently found in existing literature, which has demonstrated an inverse relationship at time points ranging from six months to 10 years postpartum[5, 15-18, 29]. Although postpartum LTPA was not significantly associated with PPWR, our linear regression estimates were in the expected direction. Specifically, women who met recommendations retained less weight than women who did not (Birth certificate PPWR: 1.5 vs. 4.0 kg; Enrollment PPWR: 3.2 vs. 3.9). However, our model explained a very small portion of the variance in PPWR ($R^2 = 0.002 – 0.015$). Therefore, our linear regression model did not fit the data well and the average PPWR value among women meeting guidelines was not significantly lower than those who did not meet guidelines at six months postpartum. Post-hoc testing revealed that our power to detect differences in PPWR between postpartum LTPA categories was 0.064. Consequently, our small sample size likely limited our ability to detect a significant difference between LTPA categories.

Compared to postpartum LTPA, the role of pregnancy LTPA in reducing PPWR is less studied. In fact, we are among the first to prospectively investigate self-reported minutes per week of moderate and vigorous LTPA during pregnancy in relation to PPWR. Pereira et al. examined change in LTPA from pre-pregnancy through six months postpartum by utilizing a prospective cohort design[18]. They assessed LTPA at each trimester and found that a decline in

LTPA levels during pregnancy was associated with increased body weight retention during the first six months of the postpartum period. In our sample, LTPA was assessed only at one time point, which was early in pregnancy (<14 weeks gestation). Therefore, it is likely that some women decreased LTPA or stopped exercising altogether later in pregnancy, and our measure lacked sensitivity to properly investigate the association between changes in pregnancy LTPA across trimesters and PPWR. Change in activity volume is important to consider, since continuation of LTPA throughout pregnancy may be associated with the likelihood of women engaging in LTPA during the postpartum period. In our sample, total minutes of pregnancy and postpartum LTPA were not significantly correlated ($\rho=0.19$). However, if we had obtained a measure of pregnancy LTPA representative of all trimesters, we may have observed higher, significant correlation coefficients, which suggests that engaging in pregnancy LTPA is important because of its potential to predict postpartum behavior. In addition, investigating the association between LTPA across pregnancy and the appropriateness of GWG is also imperative, since GWG might mediate the relationship between pregnancy LTPA and PPWR. Although we did not find significant associations between pregnancy LTPA or postpartum LTPA and PPWR, the importance of LTPA in eliciting body weight change should not be ignored by researchers or health care providers.

Although there are general guidelines for LTPA participation during pregnancy from the ACOG[21], specificity regarding the approach and timing to safely resume LTPA in the postpartum period are lacking. This lack of clarity regarding resumption of PA in the postpartum period may lead to inconsistent or erroneous recommendations from health care providers to new mothers. Research indicates that, in general, U.S. women feel that resumption of LTPA is safe at three months postpartum, even if they continue to breastfeed[30]. However, many women have difficulty initiating LTPA in the postpartum period[5, 18]. Therefore, it is important that health care providers strive to effectively communicate the benefits of LTPA at a time in the postpartum period that is safe to do so, and are receptive to their patients' concerns.

Finally, we sought to determine the combined effect of GWG, pregnancy LTPA, and postpartum LTPA on the outcome of six month PPWR. When these variables were modeled together, excess GWG remained significant, even after further adjusting for pre-pregnancy BMI category and breastfeeding. This finding reinforces the importance of women striving to gain weight during pregnancy that is coincident with IOM recommendations. In addition, our adjusted models indicate that women who reported breastfeeding (compared to not breastfeeding) and were overweight or obese (compared to normal weight women) retained less weight at six months postpartum. These findings have important public health implications. First, it is important that health care providers effectively communicate GWG guidelines to their patients and encourage a healthy weight gain over the course of pregnancy. However, encouraging appropriate GWG in all BMI categories, and not only women in the highest BMI category, is also essential. This is supported by our findings of PPWR being significantly and inversely related to BMI category. Studies show that regardless of pre-pregnancy BMI, women who do not return to their pre-pregnancy weight within the first year after delivery tend to retain significantly more weight over time (up to 15 years postpartum)[3, 15, 31]. Furthermore, increases in body weight, due to PPWR, have been observed after each subsequent pregnancy in multiparous women[7, 28]. Since many women gain excess weight while pregnant and retain much of it after each delivery, pregnancy has been proposed as a potential risk factor for obesity[7]. Therefore, it is important for health care providers to not only encourage appropriate

GWG, but also be open to discuss postpartum behaviors that may help their patients return to pre-pregnancy weight. Behaviors that may assist in achieving a negative energy balance, such as LTPA and breastfeeding, should be encouraged to women of all body sizes, and particularly those with PPWR. Additionally, since guidelines for resumption or initiation of LTPA in the postpartum period are somewhat ambiguous, health care providers must take time to implement individualized patient approaches, since LTPA recommendations in the early postpartum period will likely vary among new mothers.

There are several study limitations worth noting. Our inability to obtain postpartum follow-up data on our entire cohort is our most significant limitation. Women lost to follow-up differed from those in our analytic sample with regard to several descriptive characteristics. For example, women not included in our analyses were less active during pregnancy, and therefore, may have also been less active at six months postpartum. Consequently, our findings were likely affected and the influence of LTPA may have been obscured. Other limitations include the self-reported and recalled nature of body weight and LTPA, small sample size and inability to follow our entire cohort farther into the postpartum period. Additionally, we were not able to include serial measures of postpartum body weight in this study. This is an important variable for future researchers to consider, particularly since some studies have shown PPWR to continue to decrease up until one year postpartum[8, 27]. Although we collected data on postpartum diet quality (fruits/vegetable consumption) and breastfeeding, future research should expand these measures when possible, to obtain estimates of caloric intake and duration/exclusivity of breastfeeding. Additionally, prospective studies with larger sample sizes are needed that carefully quantify energy intake vs. expenditure and include serial measurements of body weight (pre-pregnancy through postpartum).

In spite of these limitations, study strengths include a prospective design, consideration of covariates for confounding, and a racially and economically diverse sample. In addition, we are one of only a few studies to consider the combined effect of GWG, pregnancy LTPA, and postpartum LTPA, and, to our knowledge, the first to utilize two estimates of PPWR as our outcome measure. However, validation studies are needed to assess the validity of pre-pregnancy weight abstracted from the birth certificate.

In conclusion, our findings highlight the importance of appropriate GWG, since we found that gaining weight during pregnancy in excess of IOM guidelines was independently associated with increased weight retention at six months postpartum. Additionally, after adjusting for covariates, excess GWG remained significant. The magnitude of these associations and estimates of PPWR varied according to the source of pre-pregnancy weight estimate. In order to better inform interventions and clinical practice, research with improved methodology is needed to test and refine our findings while continuing to explore the interrelationships among GWG, pregnancy LTPA, postpartum LTPA, and PPWR.

**Figure 4.1. Flow chart of women included in the analytic sample for Aims 4, 5 and 6 (n=68).**

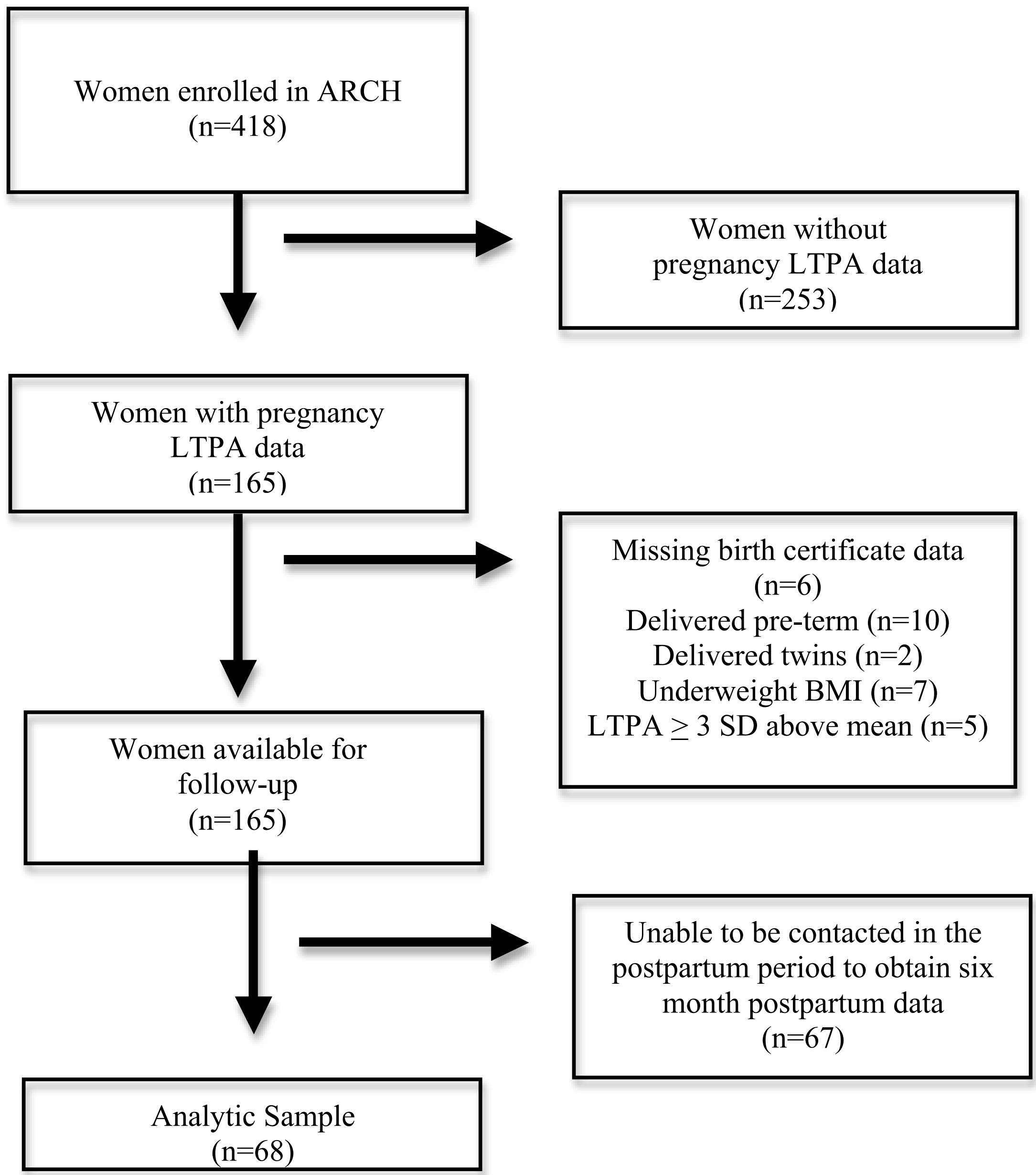

**Table 4.1. Categorization of gestational weight gain.**

| Pre-Pregnancy BMI | Not Excess | Excess |
|---|---|---|
| Normal Weight (18.5 – 24.9 kg/m$^2$) | ≤ 35 lbs. | > 35 lbs. |
| Overweight (25 – 29.9 kg/m$^2$) | ≤ 25 lbs. | > 25 lbs. |
| Obese (≥ 30 kg/m$^2$) | ≤ 20 lbs. | > 20 lbs. |

**Table 4.2. Comparison of maternal characteristics for ARCH participants meeting pregnancy inclusion criteria and participants not meeting pregnancy inclusion criteria.**

| | Met Pregnancy Criteria (N=127-135) | | Did not meet criteria (N=265-280) | | |
|---|---|---|---|---|---|
| | N | (%) | N | (%) | p-value; ϕ |
| **Education (years)** | | | | | |
| <12 | 20 | (15.5) | 36 | (13.0) | 0.43; 0.08 |
| 12 | 40 | (31.0) | 97 | (35.0 | |
| >12 | 69 | (53.5) | 144 | (52.0) | |
| **Race/Ethnicity** | | | | | |
| White | 77 | (57.0) | 199 | (71.6) | 0.02*; 0.18 |
| African American | 41 | (30.4) | 59 | (21.2) | |
| Others | 17 | (12.6) | 20 | (7.2) | |
| **Smoking** | | | | | |
| Yes | 32 | (23.7) | 46 | (16.8) | 0.20; 0.09 |
| No | 103 | (76.3) | 226 | (82.8) | |
| **Alcohol** | | | | | |
| Yes | 0 | (0) | 1 | (0.4) | 0.69; 0.04 |
| No | 134 | (100) | 272 | (99.6) | |
| **Parity** | | | | | |
| 0 | 57 | (42.2) | 117 | (42.4) | 0.32; 0.16 |
| ≥ 1 | 75 | (57.8) | 159 | (57.6) | |
| **WIC Recipient** | | | | | |
| Yes | 100 | (77.5) | 94 | (34.1) | < 0.001*; 0.39 |
| No | 29 | (22.4) | 178 | (64.5) | |
| **Marital Status** | | | | | |
| Married | 36 | (26.9) | 102 | (36.4) | 0.05*; 0.10 |
| Unmarried | 98 | (73.1) | 178 | (63.6) | |
| **Enrollment Pre-pregnancy Body Mass Index (BMI; kg/m$^2$)** | | | | | |
| Normal Weight (≥18.5, <25) | 53 | (39.6) | 114 | (46.3) | 0.05*; 0.14 |
| Overweight (≥ 25, <30) | 41 | (30.6) | 60 | (24.4) | |
| Obese (>30) | 40 | (29.9) | 72 | (29.3) | |
| **Birth Certificate Pre-pregnancy BMI (kg/m$^2$)** | | | | | |
| Normal Weight (≥18.5, <25) | 46 | (34.1) | 118 | (46.5) | 0.005*; 0.18 |
| Overweight (≥ 25, <30) | 44 | (32.6) | 78 | (30.7) | |
| Obese (>30) | 45 | (33.3) | 58 | (22.8) | |

**Table 4.2 (cont'd)**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Pregnancy Leisure-time Physical Activity (LTPA)** | | | | | | |
| Not Meeting Recs | 84 | (66.1) | | N/A | | |
| Meeting Recs | 43 | (33.9) | | | | |
| **Enrollment Gestational Weight Gain (GWG)** | | | | | | |
| Not Excess | 53 | (39.6) | | 141 | (53.2) | 0.01*; 0.13 |
| Excess | 81 | (60.4) | | 124 | (46.8) | |
| **Birth Certificate GWG** | | | | | | |
| Not Excess | 59 | (43.7) | | 143 | (53.2) | 0.07; 0.09 |
| Excess | 76 | (56.3) | | 126 | (46.8) | |

* Indicates a statistically significant difference between analytic and non-analytic samples (p≤0.05).

**Table 4.3. Comparison of maternal characteristics for the ARCH participants included in the follow-up and non-follow-up samples.**

| | Follow-up Sample (N=63-68) | | | Non-follow-up Sample (N=60-67) | | |
|---|---|---|---|---|---|---|
| | N | (%) | | N | (%) | p-value; ϕ |
| **Education (years)** | | | | | | |
| <12 | 6 | (9.0) | | 14 | (22.6) | 0.04*; 0.25 |
| 12 | 18 | (26.8) | | 22 | (35.5) | |
| >12 | 43 | (64.2) | | 26 | (42.0) | |
| **Race/Ethnicity** | | | | | | |
| White | 43 | (64.2) | | 34 | (54.0) | 0.16; 0.23 |
| African American | 21 | (31.3) | | 20 | (31.7) | |
| Others | 3 | (4.5) | | 9 | (14.3) | |
| **Smoking** | | | | | | |
| Yes | 18 | (26.5) | | 14 | (20.9) | 0.45; 0.07 |
| No | 50 | (73.5) | | 53 | (79.1) | |
| **Alcohol** | | | | | | |
| Yes | 0 | (0) | | 0 | (0) | - |
| No | 68 | (100) | | 66 | (100) | |
| **Parity** | | | | | | |
| 0 | 31 | (45.6) | | 26 | (40.6) | 0.37; 0.24 |
| ≥ 1 | 37 | (54.4) | | 38 | (59.4) | |
| **WIC Recipient** | | | | | | |
| Yes | 52 | (78.8) | | 48 | (76.2) | 0.72; 0.03 |
| No | 14 | (21.2) | | 15 | (23.8) | |
| **Marital Status** | | | | | | |
| Married | 20 | (29.4) | | 16 | (24.2) | 0.50; 0.06 |
| Unmarried | 48 | (70.6) | | 50 | (75.8) | |

**Table 4.3. (cont'd)**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Enrollment Pre-pregnancy BMI (kg/m$^2$)** | | | | | | |
| Normal Weight (≥18.5, <25) | 32 | (47.8) | | 21 | (31.3) | 0.07; 0.20 |
| Overweight (≥ 25, <30) | 15 | (22.4) | | 26 | (38.8) | |
| Obese (>30) | 20 | (29.9) | | 20 | (29.9) | |
| **Birth Certificate Pre-pregnancy BMI (kg/m$^2$)** | | | | | | |
| Normal Weight (≥18.5, <25) | 29 | (42.6) | | 17 | (25.4) | 0.07; 0.20 |
| Overweight (≥ 25, <30) | 17 | (25.0) | | 27 | (40.3) | |
| Obese (>30) | 22 | (32.4) | | 23 | (34.3) | |
| **Pregnancy LTPA** | | | | | | |
| Not Meeting Recs | 37 | (55.2) | | 47 | (78.3) | 0.006*; 0.25 |
| Meeting Recs | 30 | (44.8) | | 13 | (21.7) | |
| **Postpartum LTPA** | | | | | | |
| Not Meeting Recs | 33 | (48.5) | | N/A | | |
| Meeting Recs | 35 | (51.5) | | | | |
| **Enrollment GWG** | | | | | | |
| Not Excess | 29 | (43.3) | | 24 | (35.8) | 0.38; 0.08 |
| Excess | 38 | (56.7) | | 43 | (64.2) | |
| **Birth Certificate GWG** | | | | | | |
| Not Excess | 32 | (47.1) | | 25 | (37.3) | 0.25; 0.10 |
| Excess | 36 | (52.9) | | 42 | (62.7) | |

* Indicates a statistically significant difference between follow-up and non-follow-up samples ($p \leq 0.05$).

**Table 4.4. Linear regression analyses for associations among GWG category, pregnancy LTPA, and postpartum LTPA on the outcome of six month PPWR (n=68).**

| | **Birth Certificate PPWR (kg)** β (95% C.I.) | **Enrollment PPWR (kg)** β (95% C.I.) |
|---|---|---|
| Excess BC-GWG | 8.86 (4.64, 13.07)* ($R^2$=0.21) | 6.10 (2.07, 10.13)* ($R^2$=0.12) |
| | | |
| Excess E-GWG | 3.27 (-1.47, 8.02) ($R^2$=0.03) | 6.92 (2.94, 10.89)* ($R^2$=0.16) |
| | | |
| Meeting Recs Pg-LTPA | 0.37 (-4.44, 5.19) ($R^2$=0.001) | 1.61 (-2.74, 5.95) ($R^2$=0.01) |
| | | |
| Meeting Recs PP-LTPA | -2.37 (-7.07, 2.33) ($R^2$=0.02) | -0.76 (-5.05, 3.53) ($R^2$=0.002) |

*p-value ≤ 0.05
BC-GWG = Birth Certificate GWG; E-GWG=Enrollment GWG; Pg-LTPA=Pregnancy LTPA; PP-LPTA=Postpartum LTPA.
Referent categories were "Not Excess" GWG, "Not Meeting Recs" pregnancy LTPA, "Not Meeting Recs" postpartum LTPA.

**Table 4.5. Multiple linear regression analysis examining the combined relationship among GWG category, pregnancy LTPA, and postpartum LTPA on the outcome of six month PPWR (n=68).**

| | **Birth Certificate PPWR (kg)** β (95% C.I.) | **Enrollment PPWR (kg)** β (95% C.I.) |
|---|---|---|
| **Model 1: $R^2$** | **0.23** | **0.15** |
| Excess BC-GWG | 8.91 (4.61, 13.21)* | 6.48 (2.39, 10.57)* |
| Meeting Recs PP-LTPA | -2.83 (-7.23, 1.58) | -1.57 (-5.74, 2.61) |
| Meeting Recs Pg-LTPA | 1.08 (-7.23, 1.58) | 2.09 (-2.10, 6.28) |
| **Model 2: $R^2$** | **0.06** | **0.18** |
| Excess E-GWG | 4.13 (-0.74, 8.99) | 7.31 (3.22, 11.40)* |
| Meeting Recs PP-LTPA | -3.45 (-8.40, 1.50) | -2.69 (-6.86, 1.47) |
| Meeting Recs Pg-LTPA | 0.80 (-4.09, 5.69) | 2.10 (-2.00, 6.22) |

*p-value ≤ 0.05
BC-GWG = Birth Certificate GWG; E-GWG=Enrollment GWG; Pg-LTPA=Pregnancy LTPA; PP-LPTA=Postpartum LTPA.
Referent categories were "Not Excess" GWG, "Not Meeting Recs" pregnancy LTPA, "Not Meeting Recs" postpartum LTPA.

**Table 4.6. Adjusted multiple linear regression analyses examining the combined relationship among GWG category, pregnancy LTPA, and postpartum LTPA on the outcome of six month PPWR (n=68).**

| | **Birth Certificate PPWR (kg)** β (95% C.I.) | **Enrollment PPWR (kg)** β (95% C.I.) |
|---|---|---|
| **Model 1: $R^2$** | **0.23** | **0.25** |
| Excess BC-GWG | 9.14 (4.70, 13.58)* | 7.58 (3.63, 11.52)* |
| Meeting Recs PP-LTPA | -3.00 (-7.40, 1.49) | -1.50 (-5.44, 2.45) |
| Meeting Recs Pg-LTPA | 0.82 (-3.65, 5.28) | 1.79 (-2.17, 5.76) |
| E-BMI | -1.30 (-3.85, 1.25) | -3.25 (-5.51, -0.99)* |
| **Model 2: $R^2$** | **0.07** | **0.27** |
| Excess E-GWG | 4.27 (-0.58, 9.21) | 8.01 (4.08, 11.94)* |
| Meeting Recs PP-LTPA | -3.46 (-8.44, 1.53) | -2.72 (-6.69, 1.24) |
| Meeting Recs Pg-LTPA | 0.74 (-4.19, 5.67) | 1.83 (-2.10, 5.75) |
| E-BMI | -0.60 (-3.38, 2.18) | -3.00 (-5.21, -0.79)* |
| **Model 3: $R^2$** | **0.25** | **0.29** |
| Excess BC-GWG | 9.70 (5.17, 14.23)* | 8.33 (4.36, 12.30)* |
| Meeting Recs PP-LTPA | -3.0 (-7.43, 1.44) | -1.55 (-5.43, 2.33) |
| Meeting Recs Pg-LTPA | 0.87 (-3.59, 5.32) | 1.86 (-2.04, 5.76) |
| E-BMI | -1.66 (-4.23, 0.95) | -3.74 (-6.03, -1.45)* |
| Breastfeeding | -2.71 (-7.36, 1.94) | -3.64 (-7.71, 0.44) |
| **Model 4: $R^2$** | **0.07** | **0.33** |
| Excess E-GWG | 4.85 (-0.34, 10.04) | 9.33 (0.35, 13.31)* |
| Meeting Recs PP-LTPA | -3.58 (-8.59, 1.43) | -3.01 (-6.85, 0.84) |
| Meeting Recs Pg-LTPA | 10.78 (-4.17, 5.73) | 1.91 (-1.88, 5.71) |
| E-BMI | -0.87 (-3.75, 2.01) | -3.61 (-5.82, -1.40)* |
| Breastfeeding | -2.04 (-7.32, 3.24) | -4.60 (-8.65, -0.55)* |

*p-value $\leq$ 0.05

BC-GWG = Birth Certificate GWG; E-GWG=Enrollment GWG; Pg-LTPA=Pregnancy LTPA; PP-LPTA=Postpartum LTPA; E-BMI=Enrollment Pre-pregnancy BMI.

Referent categories: “Not Excess” GWG, “Not Meeting Recs” pregnancy LTPA, “Not Meeting Recs” postpartum LTPA, Normal weight BMI, No Breastfeeding.

# REFERENCES

## References


**1.** Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA.* Jan 20 2010;303(3):235-241.

**2.** Chu SY, Callaghan WM, Bish CL, D'Angelo D. Gestational weight gain by body mass index among US women delivering live births, 2004-2005: fueling future obesity. *Am J Obstet Gynecol.* Mar 2009;200(3):271 e271-277.

**3.** Rooney BL, Schauberger CW, Mathiason MA. Impact of perinatal weight change on long-term obesity and obesity-related illnesses. *Obstet Gynecol.* Dec 2005;106(6):1349-1356.

**4.** Schmitt NM, Nicholson WK, Schmitt J. The association of pregnancy and the development of obesity - results of a systematic review and meta-analysis on the natural history of postpartum weight retention. *Int J Obes (Lond).* Nov 2007;31(11):1642-1651.

**5.** Linne Y, Barkeling B, Rossner S. Long-term weight development after pregnancy. *Obes Rev.* May 2002;3(2):75-83.

**6.** Lovelady C. Balancing exercise and food intake with lactation to promote post-partum weight loss. *Proc Nutr Soc.* May 2011;70(2):181-184.

**7.** Siega-Riz AM, Evenson KR, Dole N. Pregnancy-related weight gain--a link to obesity? *Nutr Rev.* Jul 2004;62(7 Pt 2):S105-111.

**8.** Gunderson EP, Abrams B, Selvin S. Does the pattern of postpartum weight change differ according to pregravid body size? *Int J Obes Relat Metab Disord.* Jun 2001;25(6):853-862.

**9.** Huang TT, Wang HS, Dai FT. Effect of pre-pregnancy body size on postpartum weight retention. *Midwifery.* Apr 2010;26(2):222-231.

**10.** Linne Y, Dye L, Barkeling B, Rossner S. Weight development over time in parous women--the SPAWN study--15 years follow-up. *Int J Obes Relat Metab Disord.* Dec 2003;27(12):1516-1522.

**11.** Linne Y, Dye L, Barkeling B, Rossner S. Long-term weight development in women: a 15-year follow-up of the effects of pregnancy. *Obes Res.* Jul 2004;12(7):1166-1178.

**12.** Mamun AA, Kinarivala M, O'Callaghan MJ, Williams GM, Najman JM, Callaway LK. Associations of excess weight gain during pregnancy with long-term maternal overweight and obesity: evidence from 21 y postpartum follow-up. *Am J Clin Nutr.* May 2010;91(5):1336-1341.

**13.** Nohr EA, Vaeth M, Baker JL, Sorensen TI, Olsen J, Rasmussen KM. Pregnancy outcomes related to gestational weight gain in women defined by their body mass index, parity, height, and smoking status. *Am J Clin Nutr.* Nov 2009;90(5):1288-1294.

**14.** Ostbye T, Peterson BL, Krause KM, Swamy GK, Lovelady CA. Predictors of Postpartum Weight Change Among Overweight and Obese Women: Results from the Active Mothers Postpartum Study. *J Womens Health (Larchmt).* Nov 17 2011.

**15.** Rooney BL, Schauberger CW. Excess pregnancy weight gain and long-term obesity: one decade later. *Obstet Gynecol.* Aug 2002;100(2):245-252.

**16.** Althuizen E, van Poppel MN, de Vries JH, Seidell JC, van Mechelen W. Postpartum behaviour as predictor of weight change from before pregnancy to one year postpartum. *BMC Public Health.* 2011;11:165.

**17.** Olson CM, Strawderman MS, Hinton PS, Pearson TA. Gestational weight gain and postpartum behaviors associated with weight change from early pregnancy to 1 y postpartum. *Int J Obes Relat Metab Disord.* Jan 2003;27(1):117-127.

**18.** Pereira MA, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Peterson KE, Gillman MW. Predictors of change in physical activity during and after pregnancy: Project Viva. *Am J Prev Med.* Apr 2007;32(4):312-319.

**19.** Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser.* 2000;894:i-xii, 1-253.

**20.** Weight gain during pregnancy: reexamining the guidelines. Washington DC: Institute of Medicine; 2009.

**21.** ACOG. Exercise during pregnancy and the postpartum period. Number 267. *Int J Gynaecol Obstet.* April 2002 2002;77(1):79-81.

**22.** U.S. Physical Activity Guidelines for Americans. U.S. Department of Health and Human Services. 2008. http://www.health.gov/paguidelines.

**23.** Personal Communication with Glenn Copeland: Michigan Department of Community Health. May 18, 2012.

**24.** Brunner Huber LR. Validity of self-reported height and weight in women of reproductive age. *Matern Child Health J.* Mar 2007;11(2):137-144.

**25.** Olivarius NF, Andreasen AH, Loken J. Accuracy of 1-, 5- and 10-year body weight recall given in a standard questionnaire. *Int J Obes Relat Metab Disord.* Jan 1997;21(1):67-71.

**26.** Troy LM, Hunter DJ, Manson JE, Colditz GA, Stampfer MJ, Willett WC. The validity of recalled weight among younger women. *Int J Obes Relat Metab Disord.* Aug 1995;19(8):570-572.

**27.** Nehring I, Schmoll S, Beyerlein A, Hauner H, von Kries R. Gestational weight gain and long-term postpartum weight retention: a meta-analysis. *Am J Clin Nutr.* Nov 2011;94(5):1225-1231.

**28.** Melzer K, Schutz Y. Pre-pregnancy and pregnancy predictors of obesity. *Int J Obes (Lond).* Dec 2010;34 Suppl 2:S44-52.

**29.** Oken E, Taveras EM, Popoola FA, Rich-Edwards JW, Gillman MW. Television, walking, and diet: associations with postpartum weight retention. *Am J Prev Med.* Apr 2007;32(4):305-311.

**30.** Evenson KR, Aytur SA, Borodulin K. Physical activity beliefs, barriers, and enablers among postpartum women. *J Womens Health (Larchmt).* Dec 2009;18(12):1925-1934.

**31.** Amorim AR, Rossner S, Neovius M, Lourenco PM, Linne Y. Does excess pregnancy weight gain constitute a major risk for increasing long-term BMI? *Obesity (Silver Spring).* May 2007;15(5):1278-1286.

# CHAPTER FIVE

# SUMMARY AND RECOMMENDATIONS

## SUMMARY OF RESULTS

The overall purpose of this dissertation was to prospectively examine the associations among gestational weight gain (GWG), leisure-time physical activity (LTPA; during pregnancy and postpartum), and postpartum weight retention (PPWR). We utilized data from the Archive for Research on Child Health (ARCH) Study to explore these relationships. Women were enrolled prior to 14 weeks gestation and were contacted at varying time points in the postpartum period. Two estimates of pre-pregnancy weight were available to utilize in analyses (self-reported at enrollment and abstracted from birth certificates). Therefore, we estimated two values each for pre-pregnancy body mass index (BMI), GWG, and PPWR, which were influenced somewhat by pre-pregnancy weight estimate.

### *Associations among LTPA, pre-pregnancy BMI, and GWG*

The first part of the dissertation involved an examination of the proportion of women who experienced excess GWG. In addition, we sought to determine whether the prevalence of excess GWG varied according to pre-pregnancy BMI. The result that 56-60% of our sample experienced excess GWG supported our hypothesis that at least half the women would exceed Institute of Medicine Guidelines for maternal weight gain. We also hypothesized that overweight women would be more likely to experience excess GWG, compared to normal weight and obese women. This hypothesis was not fully supported, as both overweight *and* obese women had significantly higher odds of excess GWG (compared to normal weight women; OR=2.48-5.34). However, differences between overweight and obese BMI categories did not reach statistical significance. It is possible that overweight and obese women generally do not differ in their propensity for excess GWG. Some researchers have concluded that the prevalence of excess GWG is highest in women who are obese prior to pregnancy[1-4], and others have suggested that excess GWG is an issue not exclusive to the highest BMI category, but rather, is more prevalent in overweight women[5-8]. Obesity and the negative health outcomes associated with it have become very well studied topics, including during pregnancy. Therefore, most researchers to date have focused their resources on designing intervention trials to attenuate GWG among obese women and health care providers seem to be most concerned with GWG in their obese patients, due to complications known to be associated with obesity. However, women who are overweight prior to becoming pregnancy are also at risk. Excess GWG was found to be highest (though not statistically significant) among overweight women in our sample and in previous studies. As a result, although our hypothesis was not fully supported, we believe it is important for overweight women to receive GWG counseling similar to obese women by their health care providers.

Since LTPA is a behavior that has been demonstrated to assist in weight control, many studies have focused on the role of pregnancy LTPA in attenuating GWG into recommended ranges. In fact, two recently published meta-analyses demonstrated an inverse relationship between physical activity during pregnancy and GWG[9, 10]. Consequently, we hypothesized that women who engaged in moderate or vigorous LTPA would be less likely to experience excess GWG. However, LTPA participation was not related to the appropriateness of GWG in our sample. Although some studies have found a significant inverse association between pregnancy LTPA and GWG, other researchers have failed to find this relationship [7, 11]. Limitations noted in many studies with null findings include sample size, timing of LTPA assessment, sensitivity of LTPA measurement, and inability to account for energy intake; all of which were methodological obstacles encountered in the present investigation, and likely contributed to our null findings. Additionally, the questions we used to assess LTPA may have resulted in misclassification. We did not have information about the types of activities women performed, which would have allowed us to better determine intensity level (based on MET values). Relying on women to gauge whether they were active based on questions that asked about time per day when breathing and heart rate were increased likely contributed to LTPA measurement error. In addition, had we assessed LTPA more precisely and in a larger sample with greater LTPA variability, we could have properly assessed whether a dose-response relationship with GWG was present.

Previous research has not identified whether the beneficial effect of LTPA in attenuating GWG varies among women in different pre-pregnancy BMI categories. If we were correct in our belief that overweight women would be most at risk for excess GWG, active women in this subgroup would have the greatest potential for GWG attenuation, compared to normal weight and obese women. Unfortunately, we were unable to determine whether pre-pregnancy BMI moderated the relationship between pregnancy LTPA and GWG categorization. The number of women within each pre-pregnancy BMI category in our sample was fairly evenly split. However, once BMI categories were separated according to appropriateness of GWG and participation in LTPA, groups became very small (n=2 in some categories), and the interaction results between pre-pregnancy BMI and LTPA were not interpretable (Appendix D).

*Associations among GWG, LTPA, and PPWR*

Part two of the dissertation was an analysis of associations among GWG categorization, pregnancy LTPA, and postpartum LTPA with the outcome measure of PPWR at six months, one year, and two years after delivery. Unfortunately, adequate sample was not available for longitudinal evaluation so analyses focused on results at six months. Since data collection for the ARCH study is ongoing, we plan to revisit and test our longitudinal hypotheses when more postpartum data are available.

A strong, inverse association between the appropriateness of GWG and PPWR has been observed consistently in several observational studies[6, 13-21]. As a result, we hypothesized that women who experienced excess GWG would retain more weight at six months postpartum compared to women who did not experience excess GWG. Our hypothesis was supported, as we found that women who gained weight in excess of IOM recommended ranges[12] retained significantly more weight at six months postpartum ($\beta$=6.1 – 8.9; $p<0.05$). Although a strong, inverse correlation has been observed consistently among studies, the degree of the relationship between PPWR associated with excess GWG has varied. Similarly, model estimates of PPWR change associated with excess GWG obtained in this dissertation varied slightly according to the estimate of pre-pregnancy weight used. Thus, the method used to estimate pre-pregnancy weight is an important factor to consider when comparing results across studies. To our knowledge, we are the first group to incorporate two different estimates of pre-pregnancy weight into one study and factor each into the calculation of pre-pregnancy BMI, GWG, and PPWR. Unfortunately, evidence is not yet available to comment on the validity of pre-pregnancy weight on the birth certificate in the state of Michigan.

Since previous research has demonstrated that LTPA plays a role in attenuating PPWR, we hypothesized that women who participated in any pregnancy and postpartum LTPA would retain the least amount of weight at six months postpartum. We proposed initially that a composite LTPA variable be created with four potential categories: 1) Active during pregnancy and postpartum, 2) Active during pregnancy not active postpartum, 3) Not active during pregnancy and active postpartum, and 4) Not active during pregnancy and postpartum. However, we were unable to test this hypothesis as specified because observations among categories were very uneven and did not support model estimation. Furthermore, it was not logical to combine categories, since making inferences about results would be difficult. Therefore, we tested the main effect of pregnancy and postpartum LTPA independently against PPWR and dichotomized each variable at current LTPA recommendations.

Our results indicated that pregnancy LTPA and postpartum LTPA were not significantly associated with PPWR. Although our postpartum LTPA results did not reach statistical significance, our estimates were in the expected direction (women who met recommendations at six months postpartum retained less weight than women who did not meet recommendations). Existing literature has demonstrated an inverse relationship at time points ranging from six months to 10 years postpartum[13, 15, 22-25]. Compared to postpartum LTPA, less is known about the role of pregnancy LTPA in reducing PPWR. However, one study assessed trimester specific LTPA and found that six month PPWR was significantly related to a decline in pregnancy LTPA[22]. Unfortunately, we did not assess LTPA during each trimester and could not examine the effect of LTPA over the course of pregnancy. Change in activity volume is important to consider, since continuation of LTPA throughout pregnancy may predict the likelihood of women achieving appropriate GWG and engaging in postpartum LTPA, both of which were related to PPWR in our sample. Therefore, it is possible that pregnancy LTPA, when measured appropriately, may be an antecedent to variables associated with postpartum weight change. However, prospective studies with larger samples, measured values of body weight change and objective measures that investigate change in LTPA during pregnancy and the postpartum period are needed to test this hypothesis. Although our hypotheses were not supported with respect to pregnancy LTPA or postpartum LTPA and PPWR, the potential importance of LTPA at both time points should not be ignored in future studies.

Finally, we sought to determine the combined relationship among GWG categorization, pregnancy LTPA, and postpartum LTPA on PPWR, since all three predictors have been shown to be independently associated with the outcome in previous research. Since we could not find these variables modeled together in published research, we did not know if the effect of one variable would be strong enough to negate or enhance the predictive power of another. As a result, we hypothesized that women who did not experience excess GWG and participated in pregnancy and postpartum LTPA would retain the least amount of weight at six months postpartum. When these variables were modeled together, the only predictor that was significantly associated with PPWR was GWG, even after further adjusting for pre-pregnancy BMI category and breastfeeding. This finding reinforces the importance of women striving to gain weight during pregnancy that is coincident with IOM recommended levels. The positive association between excess GWG and PPWR is so strong and consistent, even after controlling for confounding variables, that it has been suggested that excess GWG is likely the strongest predictor of PPWR, and may contribute to obesity among women of childbearing age[27, 28]. Although the strength of the relationship between GWG and PPWR cannot be argued, we believe that this finding (or any of our other results) should not discount the importance of LTPA participation in contributing to body weight change. As mentioned previously, several aspects of our assessment of LTPA during pregnancy and at six months postpartum limited our ability to properly investigate its association with our outcomes of interest.

Taken together, our results highlight the importance of identifying factors that assist women in achieving appropriate GWG. Striving to reduce the prevalence of excess GWG, regardless of pre-pregnancy BMI, is important because of its role in risk reduction during pregnancy and also because of its strong association with PPWR. Although we did not find a beneficial effect of pregnancy or postpartum LTPA, studies with improved methodologies should continue to explore the role of LTPA at both time points in attenuating body weight.

**RECOMMENDATIONS**

Future research is needed to study the role of LTPA and maternal weight control during, and after pregnancy. Prospective studies that investigate LTPA patterns across trimesters and into the postpartum period with objective measurement devices (e.g. accelerometry) are needed in order to determine the role of LTPA in achieving appropriate GWG and attenuating PPWR. Prospective studies that include large sample sizes should be designed, and include women with diverse LTPA behaviors. Utilizing large and diverse samples of women, with respect to LTPA volume and intensity, are necessary in order to a) appropriately examine main effects involving LTPA, b) evaluate dose-response relationships with GWG and PPWR, and c) appropriately investigate interactions (e.g. Pre-pregnancy BMI*LTPA). Future research should also investigate different modes of LTPA, such as strength training or yoga, and their relationship with PPWR and GWG. It is also important to consider other domains of physical activity, such as occupational and household tasks. This is particularly true in women who have jobs requiring significant physical activity. Additionally, researchers should consider the association between sedentary behaviors and weight change.

Diet is a fundamental variable that must be considered when attempting to explain variation in body weight change and energy balance. Although we assessed a proxy for diet quality (fruits/vegetable consumption) in this dissertation, we were not able to account for total energy intake. Future research should also strive to obtain information about the duration/exclusivity of breastfeeding, and sleep quality, since these factors may influence body weight change. Therefore, prospective studies are needed that carefully quantify energy intake vs. expenditure during pregnancy and postpartum period if the independent effect and relative importance of physical activity is to be quantified.

Two estimates of pre-pregnancy weight were collected for participants enrolled in the ARCH study. Consequently, we implemented a novel approach and calculated two estimates for several important variables of interest (GWG, pre-pregnancy BMI, and PPWR). Our results indicated that the magnitude and statistical significance of several associations varied among GWG, BMI, and PPWR estimates. However, since the validity of birth certificate abstracted pre-pregnancy weight is not known in the state of Michigan, researchers must first validate its use to ensure that it is an appropriate estimate of pre-pregnancy weight.

Since some studies have shown PPWR continues to decrease until one year postpartum, and the change in postpartum body weight may vary according to pre-pregnancy BMI, it is essential that future research include serial measures of body weight in the postpartum period[18, 26]. Obtaining several measures over time would allow researchers to examine the pattern of weight change over time to determine whether it has a linear or non-linear shape (e.g. rate of increase or decrease in body weight). Furthermore, these studies should follow women prospectively from the beginning of pregnancy through the postpartum period and obtain measured body weight, instead of relying on maternal self-report. Reducing misclassification (and the resulting measurement error) due to self-reported pre-pregnancy and postpartum body weight is essential if the interrelationships among GWG, LTPA, and PPWR are to be more clearly explained.

# APPENDICES

## Appendix A:

## Informed Consent

## APPENDIX A

**ARCHIVE FOR RESEACH ON CHILD HEALTH PATIENT CONSENT FORM FOR RESEARCH INVOLVING HUMAN STUDY PARTICIPANTS**
**Participant's Name**:

______________________________________________________________________

**Study Name: Investigator's Name: Investigator's Phone Number:**
**Archive for Research on Child Health**
Nigel Paneth, M.D. (517) 353-8623

**Background of the Study**- You have been asked to participate in a voluntary research study called ARCH (Archive for Research on Child Health). The idea behind the ARCH project is pretty simple. A lot of health conditions in mothers (e.g. preterm birth, pre-eclampsia) and in children (e.g. cerebral palsy, birth defects) clearly have some relationship to pregnancy. ARCH hopes to build a collection of maternal specimens from pregnancy that includes urine, blood, and placenta. Then it will be possible to go back and test for the presence of environmental agents, infectious agents, or anything else that might possibly explain health disorders that occur later on down the road. Thus, the idea of ARCH is to develop a biological record of pregnancy before health problems develop. This "record" of pregnancy can be used to study health problems if they develop.

This consent form tells you more about the study and the risks involved, so you can make an informed decision before you agree to be in the study. The form also lets you know how the information you have provided will be used. It is important that you read the entire form before you make a decision. If you decide to give your informed consent and authorize the use and release of your medical information for the study, please sign Page 4 of the form.

**Purpose of the Study**- The purpose of the study is to store biological specimens (urine, blood, placenta) and other health information that can be used in the future to help better understand the causes of problems in pregnancy and the health of children. The basic idea of ARCH is that if we collect biological material routinely, (material that is ordinarily just thrown away!) we should be able to reconstruct events that took place in pregnancy and compare findings in the mothers of children with, and without, developmental and/or health disorders.

**What happens if I am a part of the study?**- If you agree to be in the study, you will be asked to sign this consent and two authorization forms. A copy of the forms will be given to you after you sign them. Your participation is voluntary, and for that reason you may refuse to be in the study or stop the study at any time without penalty. You also have the option to participate in certain procedures or answer only certain questions without any type of consequence.

If you agree to be in the study, researchers at Michigan State University will collect and store the following samples and information.

• You will be asked to complete a brief questionnaire. • Urine from the samples you give to your doctor during your prenatal visits will be collected and
stored. • If you have prenatal screening for birth defects done, ARCH will have access to any leftover blood,
and to the results of the tests. Similarly, if you have an amniocentesis, ARCH will have access to any leftover amniotic fluid and to the results of the tests.

• A small piece of placenta and a small piece of the umbilical cord will be forwarded to Michigan State University, once not needed at Sparrow Hospital.

• Extra blood (2-4 teaspoons or 10-20ml) will be collected when you have your blood drawn

for your prenatal labs and sent to Michigan State University for storage.
• A small portion of your blood sample may be sent to Sparrow Hospital for cholesterol testing. • Researchers will collect medical information from your medical record and from your baby's medical
record. • Researchers will collect health and other information concerning the birth of my child as reported to
the Michigan Department of Community Health at the time of my child's birth. • You will be asked for permission to have access to leftover material from your baby's newborn
screening blood. • In order to locate your baby's birth certificate research staff will request your social security number • You will be granting the study permission to notify Sparrow Hospital that you are a part of the study. • You will be contacted once a year until your child is five to learn from you about you and your
baby's health. If researchers need to contact you after your child is five years old, your consent will be asked for at that time.

**What are the risks of being in this study?** There is no increase in physical, psychological, social, legal nor economic risks to you or your baby from being in this study.

**How will my confidentiality be protected?** All the information collected within the study is strictly confidential. Y*our confidentiality and that of your child will be protected to the maximum extent allowable by law.* The researchers will take many steps to protect the confidentiality of your information, including replacing your name with a study number in all computer files, storing paper records in locked file cabinets in locked rooms for the five years that you are committed to the project.

For your safety only the staff that manages the computer system or does data analysis will see your real name. There are staff members at MSU that oversee research (Institutional Review Board) and individuals who fund this research who may see your name if they need to ensure that the ARCH project is properly conducting the research. All others working on the study will only see a case number that cannot identify you. No one outside of the study will be permitted to have access to any part of the study records. Your information will not be released without your written consent.

**What are the likely benefits of being in this study?** You likely will not directly benefit from this study; however your participation may help scientists and doctors learn if there are ways to prevent pregnancy and childhood health problems. Also, a portion of the biological samples collected in the study will be set aside for use by you or your doctor should that information be useful to you.

**Will I be compensated for my participation?** You will receive compensation for the time and effort you spend participating in this study. A $10.00 gift card will be given to you upon completion of the initial questionnaire and enrollment into the project. $10.00 gift cards will also be offered at the time of delivery and annually for five years when you complete a health history update survey.

**How much time is required to participate?** If you choose to participate in ARCH you will be asked to fill out a questionnaire and sign this consent and that takes about 20 minutes. You will be contacted at least once a year for an approximately 20-minute phone interview to gather information about your child's health. If you choose to be involved with additional studies that may develop over time, then you may be asked to complete additional interviews and/or surveys. The samples that are needed will be collected at your regular doctors visits and therefore will require no extra time commitments from you.

**What are the costs?** There is no charge for any part of the study.
**Will I have access to the information in my study record?** You can have access to any of your own study data anytime by contacting the Principal Investigator, Dr. Nigel Paneth or Lynette Biery, at (517) 432-9828 or at 1-866-925-8758.
**How will I know if you will need to contact me after my child's fifth birthday?** If the principle investigator, Dr. Nigel Paneth, and his research team feels as though the information you and your child have provided has been extremely helpful, they may ask you to extend your participation. An extension of your participation will require no extra time or effort on your part; however an additional consent form will be needed so that your records can be updated.
**What if I decide not to be a part of this study?** It is completely voluntary to be a part of this study. You have the right to refuse to be in the study or to stop at any time without affecting your present or future medical care.
If you decide to stop the study, please contact the Principal Investigator of the study, Dr. Nigel Paneth, in writing, by phone, or by email and let him know that you want to stop the study. Send your letter to Dr. Nigel Paneth, Michigan State University, Department of Epidemiology, B636 West Fee Hall, East Lansing MI 48824. You can call (517) 432-9828 or 1-866-925-8758. You can also e-mail him at paneth@epi.msu.edu.
**How can I get more information regarding ARCH?** If you have any questions about this study, such as how will your samples or information be used, how to do any part of it, or to report an injury or complaint, please contact:
• • •
Dr. Paneth at (517) 432-9828 or 1-866-925-8758 for general issues Dr. Leach at (517) 364-5949 for issues related to the MSU faculty clinic Dr. Allsweade at (517) 364-2570 for issues related to the Sparrow residency clinic
**What if an injury results because of my participation?** Participating in the ARCH project does not involve any NEW procedures. ARCH is only storing specimens that are already collected as part of your prenatal and obstetric care.
If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Dr. Paneth at (517) 432-9828 or 1-866-925-8758 with any questions or to report an injury.
**Who can I contact about my rights/ role within the study?** If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at (517) 355-2180, FAX (517) 432-4503, or email irb@msu.edu, or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

**Statement of Consent**
You have read this form in full. You have been given the opportunity to ask questions and to discuss any concerns. If you have any other questions you may call the Principal Investigator,

Nigel Paneth or Lynette Biery at (517) 432-9828.
You may withdraw from this study at any time without affecting you or your baby in any way.
By signing below you will indicate your voluntary agreement to participate in this research and have your answers included in the data set by completing and returning the attached survey.
I voluntarily agree to participate in the study.

___________________________________

**(Signature of Participant)**

___________________________________

**(Person Obtaining Consent)**
**Date: ____________________**
**Date:____________ Time: ______ AM/PM**

**PATIENT AUTHORIZATION FOR DISCLOSURE OF HEALTH INFORMATION FOR RESEARCH**
**Patient's Name:_______________________________________________________________**

**Street Address:_______________________________________________________________**

**City/State/Zip:_______________________________________________________________ Date of Birth: ____________________Social Security Number: ______________________**

**I AUTHORIZE THE DISCLOSURE OF MY HEALTH INFORMATION FROM:**

___________________________________________________________

***(Agency Name)***
***TO: Archive for Research on Child Health (IRB #C07-1201)***
Michigan State University B636 West Fee Hall East Lansing, MI 48824 (517) 432-9828
**DESCRIPTION OF INFORMATION TO BE DISCLOSED ALL portions' of the mother's MSU Health Team electronic medical record**
The ARCH research team is asking permission to review all portions of your Health Team medical records.
Your information that is disclosed to the researcher(s) may no longer be protected by Federal privacy regulations if the researcher(s) is not a health care provider covered by the regulations; however the researcher(s) agrees to protect your information as required by law.
**RESEARCH STUDY FOR THIS DISCLOSURE:**
**Title of Study: Name of Research Leader: Affiliation of Researcher: IRB#: Name of IRB: EXPIRATION**:
**Archive for Research on Child Health**
Dr. Nigel Paneth Michigan State University, College of Human Medicine ***C07-1201***
MSU University Committee for Research Involving Human Subjects Your Authorization to disclose the above information **expires on**
_______________. *(Insert date 5 years from now or sooner)* **Authorization: [ ] Yes [ ] No**

___________________________________

**(Signature of Participant)**

________________________________________

**Person Obtaining Consent**

**REVOCATION, REFUSAL, REDISCLOSURE**: You may revoke this Authorization in writing at any time by contacting the: MSU HealthTeam Privacy Officer
A211 Clinical Center, East Lansing, MI 48824-1313 (517) 355-2180
**But it will not affect any information already released to the researcher(s).**
**␣PROVIDE COPY TO PATIENT**

**Date: ______________________________**
**Date:_______________ Time: ______ AM / PM**

**PATIENT AUTHORIZATION FOR DISCLOSURE OF HEALTH INFORMATION FOR RESEARCH**
**Patient's Name:_________________________________________________________________________**

**Street Address:_____________________________________________________________________**

**City/State/Zip__________________________________________________________________**
**_________ Date of Birth: ____________________Social Security Number: ______________________**

**I AUTHORIZE THE DISCLOSURE OF MY HEALTH INFORMATION FROM:**
**__________________________________________________________**
***(Agency Name)***
***TO: Archive for Research on Child Health (IRB # C07-1201)***
Michigan State University B636 West Fee Hall East Lansing, MI 48824 (517) 432-9828
**DESCRIPTION OF INFORMATION TO BE DISCLOSED • All portion's of the mother's Sparrow hospital medical record. • All portion's of the infant's Sparrow hospital medical record.**
The ARCH research team is asking permission to review all portions of your and your baby's hospital records related to this pregnancy, birth and postpartum period.
Your information that is disclosed to the researcher(s) may no longer be protected by Federal privacy regulations if the researcher(s) is not a health care provider covered by the regulations; however the researcher(s) agrees to protect your information as required by law.

**RESEARCH STUDY FOR THIS DISCLOSURE**:
**Title of Study: Name of Research Leader: Affiliation of Researcher:**
**Archive for Research on Child Health**
Dr. Nigel Paneth Michigan State University, College of Human Medicine
**IRB#: Name of IRB: EXPIRATION**:
***C07-1201***
MSU University Committee for Research Involving Human Subjects Your Authorization to disclose the above information **expires on**

_______________. *(Insert date 5 years from now or sooner.)* **Authorization: [ ] Yes [ ] No**

________________________________________

**(Signature of Participant)**

________________________________________

**Person Obtaining Consent**

**REVOCATION, REFUSAL, REDISCLOSURE**: You may revoke this Authorization in writing at any time by contacting the: MSU HealthTeam Privacy Officer
A211 Clinical Center, East Lansing, MI 48824-1313 (517) 355-2180
**But it will not affect any information already released to the researcher(s).**
**PROVIDE COPY TO PATIENT**

This consent form was approved by the Biomedical and Health Institutional Review Board (BIRB) at Michigan State University. Approved 1/21/11 – valid through 1/20/12 This version supersedes all previous versions. IRB # C07-1201.

# APPENDIX B:

## ARCH Enrollment Questionnaire

## APPENDIX B

## ARCH Self-Recorded Maternal Questionnaire

**Name (Last, First): __________________________**

**Date of Birth: __________________** **Your social security number:___________**

**Your baby's due date: _____________**

**Your racial category (check all that apply):**

__ American Indian/Alaskan __ Black or African American __ Native Hawaiian

__ Asian __ White

**Highest level of education you have completed?**

__ Did not finish high school __ High school graduate __ Some college

__ College graduate or more

**What is your current marital status?**

__ Married, living with baby's father __Married

__ Unmarried, living with baby's father __Unmarried

**What is your annual household income?**

__ Under $25,000 __$25,000-$49,999 __$50,000 to $74,999 __ $75,000 or above

**Do you own…**

**A home?** __Yes __No

**A car?** __Yes __No

**Any stocks or bonds?** __Yes __No

**How tall are you without shoes? ______** **Weight just before pregnancy: ______**

**Was this pregnancy planned?** __Yes __No

**Before this pregnancy, were you told by a healthcare provider that you had any of the following:**

Periodontal disease/infection of gums? __Yes Depression? __Yes

Psychiatric conditions? __Yes Seizure disorder or epilepsy? __Yes

Other neurological conditions? __Yes

High Cholesterol? __Yes (if yes) were you taking cholesterol lowering medication? __Yes

**Have any of the following blood relatives ever been diagnosed with any of the following conditions?**

| | | | |
|---|---|---|---|
| Autism | __My parent<br>__My child | __My brother/sister<br>__Other relative | __My grandparent |
| Mental Retardation | __My parent<br>__My child | __My brother/sister<br>__Other relative | __My grandparent |
| Cerebral Palsy | __My parent<br>__My child | __My brother/sister<br>__Other relative | __My grandparent |
| Severe child diability | __My parent<br>__My child | __My brother/sister<br>__Other relative | __My grandparent |
| Other childhood disability | __My parent<br>__My child | __My brother/sister<br>__Other relative | __My grandparent |

**Your Phone number: __________________**  **Your Email address: ________________**

**Alternate Contact Name: _______________**  **Alternate Contact Number: ____________**

**Your Maiden Name: ___________________**

**Your Mother's Full Maiden Name: ________________________**

**Your Father's Full Name: ________________________________**

**<u>These next set of questions are about physical activity, exercise, and sports that you take part in during your free time. If you have any questions or if you are not sure if the activity your partake in is moderate or vigorous, please ask and we can help you.</u>**

**<u>We will first ask about moderate activities. A moderate activity is one that causes a small increase in your breathing or heart rate. Some examples of moderate activities are brisk walking, bicycling, dancing, and yoga.</u>**

**During the past month, did you do any <u>moderate</u> activities for more than 10 minutes that caused a small increase in your breathing and heart rate?**

___Yes ___No ___Don't Know/Refuse

**If yes, how many days a week do you usually do these moderate activities?**

___ Days per week ___ Do not exercise at least 10 min a week ___Don't Know/Refuse

**How much time do you usually spend doing these moderate activities in one day?**

(Please fill in the blanks) ___Hours and ___Minutes

**<u>Now we will ask you about vigorous activities. A vigorous activity is one that causes an increase in your breathing or heart rate. Some activities of vigorous activities are running, jogging, and aerobics.</u>**

**During the past month, did you do any <u>vigorous</u> activities for more than 10 minutes that caused a large increase in your breathing and caused you to sweat?**

___Yes ___No ___Don't Know/Refuse

**If yes, how many days a week do you usually do these vigorous activities?**

___ Days per week ___ Do not exercise at least 10 min a week ___Don't Know/Refuse

**How much time do you usually spend doing these vigorous activities in one day?**

(Please fill in the blanks) ___Hours and ___Minutes

**<u>These next set of questions are about physical activity, exercise at work</u>**

**Do you currently work at least 30 hours a week?**

___Yes ___No ___Don't Know/Refuse

**If yes, how do you spend most of your time at work on a typical day? Are you mostly sitting, standing, walking or doing physical labor?**

**Please rank these activities from 1 to 4 in order of most (1) to least (4) time spent during a normal work day below. If there are any activities you do not normally do at work, please put a 0 next to it.**

**Please rank the following work activities using this scale:**

| 1 | 2 | 3 | 4 | 0 |
|---|---|---|---|---|
| **I do the most** | | | **I do the least** | **I never do** |

Sitting: ________ Standing: _______ Walking: _______

Physical labor (like lifting/moving things): _______

# APPENDIX C:

## ARCH Postpartum Phone Interview Questions

# APPENDIX C

***ARCH supplemental phone interview questions:***
*(** Offer $5 Meijer gift card for completing this portion)*

**Which postpartum time point is the participant currently at?**

_____ 6 months  _____ 1 year  _____ 2 years

***[**INTERVIEWER NOTE: Go through this script first pertaining to the time point you are calling (i.e. 6 months, 1 year, 2 years postpartum)]***

**1. About how much do you currently weigh without shoes?**

_______ Pounds

*"These next few questions are about physical activity, exercise, and sports that you take part in during your free time."*

**2. Moderate activities are ones that cause a small increase in your breathing or heart rate. Some examples are walking, dancing, and yoga. During the past month, did you do any moderate activities for more than 10 minutes?**

____ Yes or ____ No

**If No, skip to question #3**
**If Yes, proceed to question #2A:**

**2A. How many days a week do you usually do these moderate activities?**

_____ Days per week

**2B. How much time do you usually spend doing these activities in one day?**

_____ Hours and _____ Minutes

**3. Vigorous activities are ones that cause an increase in your breathing or heart rate. Some examples of vigorous activities are running, jogging, and aerobics. During the past month, did you do any vigorous activities for more than 10 minutes?**

_____ Yes or _____ No

**If No, skip to Section 2**
**If Yes, proceed to question #3A:**

**3A. How many days a week do you usually do these vigorous activities?**

_____ Days per week

**3B. How much time do you usually spend doing these activities in one day?**

_____ Hours and _____ Minutes

***(**INTERVIEWER NOTE: If you are calling at the 6 month postpartum time point, you do not need to proceed with anymore questions. If you are calling at 1 year or 2 years postpartum, continue with questions below: )***

*"If it's okay, I'd like to ask you to think about your weight, physical activity, exercise, and diet at a time closer to when your baby was born."*

***(**INTERVIEWER NOTE: If you are calling at 1 year postpartum, only ask about 6 months postpartum. If you are calling at 2 years postpartum, please ask about 6 months and 1 year.)***

**1. At 6 months postpartum, about how much did you weigh without shoes?**

_______ Pounds

**If the participant is at 1 year postpartum, skip to question #2**
**If the participant is at 2 years postpartum, proceed to question #1A:**

**1A. At 1 year postpartum, about how much did you weight without shoes?**

_______ Pounds

**2. Moderate activities are ones that cause a small increase in your breathing or heart rate. Some examples are walking, dancing, and yoga. Around 6 months postpartum, did you do any moderate activities for more than 10 minutes?**

____ Yes or ____ No

**If No AND 1 year postpartum, skip to question #4**
**If No AND 2 years postpartum, skip to question #3**
**If Yes, proceed to question #2A:**

**2A. How many days a week did you usually do these moderate activities?**

_____ Days per week

**2B. How much time did you usually spend doing these activities in one day?**

_____ Hours and _____ Minutes

**If at 1 year postpartum, skip to question #4**
**If at 2 years postpartum, proceed with question #3:**

**3. Around 1 year postpartum, did you do any moderate activities for more than 10 minutes?**

____ Yes or ____ No

**If No, skip to question #4**
**If Yes, proceed to question #3A:**

**3A. How many days a week did you usually do these moderate activities?**

_____ Days per week

**3B. How much time did you usually spend doing these activities in one day?**

_____ Hours and _____ Minutes

**4. Vigorous activities are ones that cause an increase in your breathing or heart rate. Some examples of vigorous activities are running, jogging, and aerobics. Around 6 months postpartum, did you do any vigorous activities for more than 10 minutes?**

_____ Yes or _____ No

**If No AND 1 year postpartum, skip to Section 4**
**If No AND 2 years postpartum, skip to question #5**
**If Yes, proceed to question #4A:**

**4A. How many days a week did you usually do these vigorous activities?**

_____ Days per week

**4B. How much time did you usually spend doing these activities in one day?**

_____ Hours and _____ Minutes

**If at 1 year postpartum, skip to Section 4**

**If at 2 years postpartum, proceed with question #5:**

**5. Around 1 year postpartum, did you do any vigorous activities for more than 10 minutes?**

_____ Yes or _____ No

**If No, skip to Section 4**
**If Yes, proceed to question #5A:**

**5A. How many days a week did you usually do these vigorous activities?**

_____ Days per week

**5B. How much time did you usually spend doing these activities in one day?**

_____ Hours and _____ Minutes

# APPENDIX D:
# TABLE FOR INTERACTION MODELS (CHAPTER 3)

## APPENDIX D

**Interaction models# examining the relationships among pre-pregnancy BMI, moderate LTPA, and vigorous LTPA on the outcome of Excess GWG.**

| | **Excess Enrollment GWG OR (95% C.I.)** | **Excess Birth Certificate GWG OR (95% C.I.)** |
|---|---|---|
| **Enrollment BMI*Moderate LTPA** *(ref: Normal weight, Not Active)* | | |
| Overweight*Active | 18.59 (2.63, 131.13)* | 9.13 (1.45, 57.44)* |
| Obese*Active | 4.62 (0.82, 25.98) | 8.69 (1.50, 50.55)* |
| **Birth certificate BMI*Moderate LTPA** *(ref: Normal weight, Not Active)* | | |
| Overweight*Active | 39.90 (4.61, 345.45)* | 17.35 (2.36, 127.31)* |
| Obese*Active | 3.61 (0.62, 21.12) | 4.66 (0.82, 26.52) |
| **Enrollment BMI*Vigorous LTPA** *(ref: Normal weight, Not Active)* | | |
| Overweight*Active | 2.42 (0.17, 33.89) | 2.36 (0.17, 32.79) |
| Obese*Active | 0.85 (0.79, 8.97) | 0.70 (0.07, 7.41) |
| **Birth certificate BMI*Vigorous LTPA** *(ref: Normal weight, Not Active)* | | |
| Overweight*Active | 2.73 (0.19, 39.24) | 3.07 (0.22, 43.70) |
| Obese*Active | 0.38 (0.03, 4.86) | 0.53 (0.04, 6.68) |

* $p \leq 0.05$
# Interaction models are adjusted for main effects, in order to examine the interaction term's relationship with GWG categorization, net of the main effects of BMI and LTPA.

# REFERENCES

## References


1. Rodrigues PL, de Oliveira LC, Brito Ados S, Kac G. Determinant factors of insufficient and excessive gestational weight gain and maternal-child adverse outcomes. *Nutrition.* Jun 2010;26(6):617-623.

2. Savitz DA, Stein CR, Siega-Riz AM, Herring AH. Gestational weight gain and birth outcome in relation to prepregnancy body mass index and ethnicity. *Ann Epidemiol.* Feb 2011;21(2):78-85.

3. Deierlein AL, Siega-Riz AM, Adair LS, Herring AH. Effects of pre-pregnancy body mass index and gestational weight gain on infant anthropometric outcomes. *J Pediatr.* Feb 2011;158(2):221-226.

4. Crane JM, White J, Murphy P, Burrage L, Hutchens D. The effect of gestational weight gain by body mass index on maternal and neonatal outcomes. *J Obstet Gynaecol Can.* Jan 2009;31(1):28-35.

5. Schieve LA, Cogswell ME, Scanlon KS. An empiric evaluation of the Institute of Medicine's pregnancy weight gain guidelines by race. *Obstet Gynecol.* Jun 1998;91(6):878-884.

6. Mamun AA, Kinarivala M, O'Callaghan MJ, Williams GM, Najman JM, Callaway LK. Associations of excess weight gain during pregnancy with long-term maternal overweight and obesity: evidence from 21 y postpartum follow-up. *Am J Clin Nutr.* May 2010;91(5):1336-1341.

7. Olson CM, Strawderman MS. Modifiable behavioral factors in a biopsychosocial model predict inadequate and excessive gestational weight gain. *J Am Diet Assoc.* Jan 2003;103(1):48-54.

8. Oken E, Taveras EM, Kleinman KP, Rich-Edwards JW, Gillman MW. Gestational weight gain and child adiposity at age 3 years. *Am J Obstet Gynecol.* Apr 2007;196(4):322 e321-328.

9. Streuling I, Beyerlein A, Rosenfeld E, Hofmann H, Schulz T, von Kries R. Physical activity and gestational weight gain: a meta-analysis of intervention trials. *BJOG.* Feb 2011;118(3):278-284.

10. Gardner B, Wardle J, Poston L, Croker H. Changing diet and physical activity to reduce gestational weight gain: a meta-analysis. *Obes Rev.* Jul 2011;12(7):e602-620.

11. Althuizen E, van Poppel MN, Seidell JC, van Mechelen W. Correlates of absolute and excessive weight gain during pregnancy. *J Womens Health (Larchmt).* Oct 2009;18(10):1559-1566.

12. Weight gain during pregnancy: reexamining the guidelines. Washington DC: Institute of Medicine; 2009.

**13.** Linne Y, Barkeling B, Rossner S. Long-term weight development after pregnancy. *Obes Rev.* May 2002;3(2):75-83.

**14.** Linne Y, Dye L, Barkeling B, Rossner S. Weight development over time in parous women--the SPAWN study--15 years follow-up. *Int J Obes Relat Metab Disord.* Dec 2003;27(12):1516-1522.

**15.** Rooney BL, Schauberger CW. Excess pregnancy weight gain and long-term obesity: one decade later. *Obstet Gynecol.* Aug 2002;100(2):245-252.

**16.** Rooney BL, Schauberger CW, Mathiason MA. Impact of perinatal weight change on long-term obesity and obesity-related illnesses. *Obstet Gynecol.* Dec 2005;106(6):1349-1356.

**17.** Chu SY, Callaghan WM, Bish CL, D'Angelo D. Gestational weight gain by body mass index among US women delivering live births, 2004-2005: fueling future obesity. *Am J Obstet Gynecol.* Mar 2009;200(3):271 e271-277.

**18.** Gunderson EP, Abrams B, Selvin S. Does the pattern of postpartum weight change differ according to pregravid body size? *Int J Obes Relat Metab Disord.* Jun 2001;25(6):853-862.

**19.** Nohr EA, Vaeth M, Baker JL, Sorensen TI, Olsen J, Rasmussen KM. Pregnancy outcomes related to gestational weight gain in women defined by their body mass index, parity, height, and smoking status. *Am J Clin Nutr.* Nov 2009;90(5):1288-1294.

**20.** Ostbye T, Peterson BL, Krause KM, Swamy GK, Lovelady CA. Predictors of Postpartum Weight Change Among Overweight and Obese Women: Results from the Active Mothers Postpartum Study. *J Womens Health (Larchmt).* Nov 17 2011.

**21.** Linne Y, Dye L, Barkeling B, Rossner S. Long-term weight development in women: a 15-year follow-up of the effects of pregnancy. *Obes Res.* Jul 2004;12(7):1166-1178.

**22.** Pereira MA, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Peterson KE, Gillman MW. Predictors of change in physical activity during and after pregnancy: Project Viva. *Am J Prev Med.* Apr 2007;32(4):312-319.

**23.** Olson CM, Strawderman MS, Hinton PS, Pearson TA. Gestational weight gain and postpartum behaviors associated with weight change from early pregnancy to 1 y postpartum. *Int J Obes Relat Metab Disord.* Jan 2003;27(1):117-127.

**24.** Althuizen E, van Poppel MN, de Vries JH, Seidell JC, van Mechelen W. Postpartum behaviour as predictor of weight change from before pregnancy to one year postpartum. *BMC Public Health.* 2011;11:165.

**25.** Oken E, Taveras EM, Popoola FA, Rich-Edwards JW, Gillman MW. Television, walking, and diet: associations with postpartum weight retention. *Am J Prev Med.* Apr 2007;32(4):305-311.

**26.** Nehring I, Schmoll S, Beyerlein A, Hauner H, von Kries R. Gestational weight gain and long-term postpartum weight retention: a meta-analysis. *Am J Clin Nutr.* Nov 2011;94(5):1225-1231.

**27.** Melzer K, Schutz Y. Pre-pregnancy and pregnancy predictors of obesity. *Int J Obes (Lond).* Dec 2010;34 Suppl 2:S44-52.

**28.** Siega-Riz AM, Evenson KR, Dole N. Pregnancy-related weight gain--a link to obesity? *Nutr Rev.* Jul 2004;62(7 Pt 2):S105-111.