University of Alberta

# Gestational Weight Gain and Body Composition Changes during Pregnancy and Early Postpartum

by

Fatheema Begum Subhan

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Nutrition and Metabolism

Department of Agriculture Food and Nutritional Sciences


Spring 2013
Edmonton, Alberta

## Abstract

Gestational weight gain (GWG) is associated with short-and long-term maternal and infant health outcomes. The purpose of this research was to describe longitudinal changes in weight and body composition during pregnancy and early postpartum according to pre-pregnancy body mass index (BMI) categories. The contributions of sociodemographic and lifestyle factors and resting energy expenditure (REE) on these changes were examined, and the effects of gaining within and outside the recommended GWG on maternal and infant anthropometrics were studied. Overall, 56% of women exceeded total GWG recommendations; higher rates of weight gain above recommendations were observed among overweight and obese women. GWG was significantly associated with higher postpartum weight retention irrespective of pre-pregnancy BMI; however, overweight and obese women retained a larger quantity of fat mass, particularly in the truncal and abdominal regions, at postpartum. Excessive GWG was positively associated with higher weight at birth and 3 months, and rapid postnatal growth in infants. Other covariates associated with changes in weight and adiposity, were as follows: being nulliparous and having a smoking history were associated with excessive GWG and with a faster rate of fat accumulation in late pregnancy; ethnicity contributed to significant differences in GWG and adiposity; and belonging to a low-income family was associated with higher postpartum weight and fat retention and low birth weight. The sports activity score was a significant predictor of lower fat mass and higher fat-free mass accretion during pregnancy, while REE was positively associated with fat

mass, fat free mass and excessive GWG during pregnancy. Longer duration of breast feeding was associated with greater loss of fat mass at postpartum. There was no significant difference in macronutrient intake irrespective of BMI; however, overweight and obese women's energy intake at trimesters 2 and 3 were significantly less than their estimated energy intake requirements. In sum, this research has shown that excessive GWG plays a significant role in postpartum weight retention and could be a risk factor for incremental weight gain in mother-infants. Effective intervention programs promoting optimal GWG should account for variation in an individual woman's energy expenditure, dietary intake and the presence of risk factors.

**Acknowledgements**

I would first like to thank my supervisor, Dr. Rhonda Bell, for the opportunity to study and train with her. I extend my sincere thanks to her for being an excellent mentor; I have learned a lot under her guidance, and I have truly appreciated this experience.

I would also like to thank my committee members, Dr. Linda McCargar and Dr. Ian Colman, for their invaluable guidance and support throughout my study. I extend my appreciation to Dr. Linda for her advice during my entire program, and especially for sharing her expertise on the aspects of the project related to energy metabolism. I express my sincere gratitude to Dr. Ian for his encouragement and for his advice on statistical aspects throughout this project. Thank you as well to Drs. Heidi Kalkwarf and Dean Eurich and Diana Mager for participating in my defense.

The Alberta Pregnancy Outcomes and Nutrition (APrON) study staff, Sarah Loehr, Jacqueline Jumpsen, Lubna Anis, Anne Gilbert and Dyna-Lynn Dynianiw, helped in recruiting study participants and data collection; I thank them very much for doing this. Thank you to Roycent Tumbare and volunteers for facilitating data entry.

Many people provided technical assistance and support on various occasions during my research, and I sincerely acknowledge their assistance. I would like to thank Marg Fedyna for her technical assistance in helping to create a program to calculate body composition and physical activity scores. I sincerely appreciate Gian Jhangiri's advice on the longitudinal data analysis. Thank you to

Rob Desjardins for helping me to proofread this thesis. I would also like to thank Jody Forslund and Tracy Vetsch for their excellent administrative support throughout my study.

I would like to thank my fellow graduate students, both past and present, for their friendship and help: Tomoe Watanabe, Gayathiri Devi Durai Raj, Dr. Laura Forbes, Stephanie Thomas, Jocelyn Graham, Doaa Dahlawi and Aleida Song.

I would like to thank the women and their babies who volunteered for the APrON study for their time and enthusiasm. I also wish to thank all volunteers who helped us practice/develop the anthropometric reliability protocol.

This study would not have been possible without funding; I thank Alberta Innovates Health Solutions for funding the APrON study.

Finally I would like to thank my family, my husband Abdul Subhan, my daughters Safiya and Sadiya, my parents and my siblings, for their continued support and encouragement.

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| | |
|---|---|
| ACOG | American College of Obstetrics and Gynecologists |
| AGA | Appropriate-for-Gestational Age |
| AMDR | Adequate Macronutrient Distribution Range |
| ANOVA | Analysis of Variance |
| AOR | Adjusted Odds Ratio |
| APrON | Alberta Pregnancy Outcomes and Nutrition |
| BIA | Bioelectric Impedance Analysis |
| BMI | Body Mass Index |
| BMR | Basal Metabolic Rate |
| CI | Confidence Interval |
| CV | Coefficient of Variation |
| CT | Computerized Tomography |
| DEXA | Dual Energy X-ray Absorptiometry |
| ECF | Extracellular Fluid |
| EER | Estimated Energy Requirement |
| FFM | Fat-Free Mass |
| FM | Fat Mass |
| GDM | Gestational Diabetes Mellitus |
| GWG | Gestational Weight Gain |
| IOM | Institute of Medicine |
| K | Potassium |
| LGA | Large-for-Gestational Age |

| | |
|---|---|
| MJ | Megajoules |
| MRI | Magnetic Resonance Imaging |
| OR | Odds Ratio |
| PA | Physical Activity |
| RDA | Recommended Dietary Allowance |
| REE | Resting Energy Expenditure |
| SGA | Small-for-Gestational Age |
| SD | Standard Deviation |
| TBW | Total Body Water |
| TBK | Total Body Potassium |
| WHO | World Health Organisation |

# CHAPTER 1: Introduction and Literature Review

## 1.1 Purpose

The purpose of this chapter is to provide an overview of changes in body weight and body composition during pregnancy and elucidate factors influencing these changes, and to describe the outcomes of gaining gestational weight within and outside the recommended clinical ranges.

## 1.2 Introduction

In Canada, the number of overweight and obese women of childbearing age has progressively increased in the past 3 decades (1). In 2007-2009, approximately 50% of women of childbearing age were categorized with a BMI in either the overweight or obese categories (2). A recent rise in high maternal pre-pregnancy body mass index (BMI) has brought attention to the possible health risks associated with being overweight or obese prior to pregnancy. Recent studies have identified high maternal pre-pregnancy BMI and excessive gestational weight gain (GWG) as two potential risk factors that could jeopardize favorable pregnancy outcomes (3-5).

## 1.3 Body Mass Index

BMI is defined as weight-for-height of an individual and is calculated as weight in kilograms divided by the square of height in meters ($kg/m^2$). According to the BMI classification by Health Canada (6) and the WHO (7), women can be categorized in one of the following BMI categories based on their BMI ($kg/m^2$):

underweight (<18.5), normal (18.5 - 24.9), overweight (>25.0 - 29) or obese ( ≥ 30). These BMI classifications provide an approximate estimation of an individual’s adiposity and have been widely accepted and used in clinical settings; further the GWG recommendations by the Institute of Medicine IOM (2009) (8) and Health Canada (2010) (9) are based on these classifications of BMI.

### 1.3.1 Pre-pregnancy BMI and Pregnancy Outcomes

Maternal pre-pregnancy BMI is an indicator of a mother’s health status prior to pregnancy and is an important predictor of pregnancy and delivery outcomes. Infants born to underweight women are more likely to be exposed to intra-uterine growth restriction, and are born small-for-gestational age, pre-term and they are at an increased risk for neonatal mortality and morbidity (8). In the past few decades the number of women in the underweight pre-pregnancy BMI category has decreased, while the prevalence of overweight and obese pregnant women has significantly increased (10). Women with higher pre-pregnancy BMI are at an increased risk for pregnancy and delivery complications such as gestational diabetes, preeclampsia, caesarean sections and assisted births; their infants are at high risk for neonatal complications such as macrosomia, congenital birth defects and still birth (5). Higher pre-pregnancy BMI also increases the risk of chronic health conditions in later life for both the mother and her infant. Irrespective of pre-pregnancy BMI categories, all pregnant women are expected to gain weight and adiposity, which is a normal physiological adaptation caused by increasing fluid levels, the growing fetus and the addition of maternal tissue and fat mass to support maternal and fetal energy demands (11). However, gaining very small or large amounts of weight can be detrimental to maternal and fetal health. Thus, based on evidence from several studies, the IOM (8) and Health Canada (9) have recognized modulating GWG as a potential primary method to overcome complications during pregnancy and to reduce the risk of chronic health risks in mother and infant.

### 1.4 Total Gestational Weight Gain

Total GWG refers to the total amount of weight gained by the pregnant woman from conception to delivery. The changes in weight in normal full term pregnancies may vary considerably, from loss to a gain of 23 kg or more (12). The 2009 IOM committee that revised the GWG recommendations reviewed studies conducted in the United States from 1985 to the present; they indicated that the mean total GWG in singleton pregnancies among normal-weight women ranged from 10.0-16.7 kg. In general, adolescent women tend to gain more total gestational weight than adult women (8). Several studies conducted on pregnant women including women of high pre-pregnancy BMI have shown that GWG is inversely associated with pre-pregnancy BMI; however GWG can vary within women from a particular BMI category (8). Detailed discussions of these and other factors will be presented in the following sections of this chapter. Total weight gain in twin pregnancies is higher than in singleton pregnancies, averaging from 15 to 22 kg. Similar to singleton pregnancies there is an inverse association between total GWG and pre-pregnancy BMI in women with twins (8).

### 1.4.1 Pattern of Gestational Weight Gain

The pattern of weight gain in pregnancy is generally described as sigmoidal, which reflects minimal weight gain during the first trimester; followed by a steady increase in weight up to about 16-18 weeks at a rate of 0.36 kg/wk; after which weight is gained at an accelerated rate (0.45 kg/wk) until 26-28 weeks, followed by a slower rate (0.36-0.41 kg/wk) of weight gain until delivery (12). However linear, concave and convex patterns of weight gain have also been observed (13). The IOM 1990 report "Nutrition During Pregnancy" (14) described that the average rate of weight gain among well-nourished women in the second and third trimesters was 0.45 kg/wk and 0.40 kg/wk respectively. However, recent studies examining American women with normal BMI observed a higher rate of weight gain in the second and third trimesters than that which is reported in IOM 1990 report. Carmichael et al.(15) examined a large cohort of pregnant women enrolled in a study conducted at the University of California between 1980-1990, and they indicated that the average weight gain in the first, second and third trimesters was 0.169 kg/wk, 0.563 kg/wk and 0.518 kg, respectively, in women from all pre-pregnancy BMI groups except obese women. The average rate of weight gain among underweight and normal-weight women in the second and third trimester was higher than that in overweight and obese women. In another study conducted during 1983-1987 on predominantly Hispanic nulliparous women, the rate of weight gain in the second trimester (0.52 kg/wk) was similar to the rate of weight gain in the third trimester (0.53/kg) (16). In another study adolescent women ( mean age =16.6 ± 1.4 yrs ) had a pattern of weight gain similar to that of adult women; however median weight gain and rate of weight gain was higher among adolescents compared with adult women throughout gestation (17). It appears that weight gain in pregnancy is temporal; variations in the pattern of weight gain seem to be influenced by several maternal factors such as age, parity and ethnicity in addition to pre-pregnancy BMI. In present-day society which includes a multiethnic, rapidly aging population with higher body weights; examining the important maternal characteristics that are associated with weight prior to and during pregnancy may be necessary in promoting and adhering to GWG recommendations.

### 1.4.2 Gestational Weight Gain Recommendations

In 1990, the IOM subcommittee for GWG recognized that women gaining lower amounts of gestational weight were at a greater risk for fetal intrauterine growth retardation, low birth weight and maternal complications. Thus, the subcommittee suggested that women in the underweight BMI category gain more gestational weight than women from higher pre-pregnancy BMI categories. This would reduce the incidence of low birth weight and small-for- gestational-age babies (Table1.1) (14). Keeping in view the recent evidence of growing obesity among women of child bearing age and the trends of exceeding GWG recommendations, the Institute of Medicine (IOM) in 2009 (8) and Health Canada in 2010 (9) put forth revised GWG recommendations to optimize pregnancy outcomes.

Recommendations for total GWG and weekly weight gain between the second and third trimesters are available for women with different pre-pregnancy BMIs (Table 1.2).

### 1.4.3 Trends in Gestational Weight Gain

Viswanathan et al.(5) conducted a meta-analysis of studies published between 1990 and 2007, they indicated an increase in the prevalence of women exceeding recommended gestational weight ranges (44% women), while the percent of women gaining less than the recommended amounts was relatively stable over time (~23%). Recent reports from the Canadian Maternity Experience Survey (18) (Figure 1.1) and the Southampton Women's Survey (19) indicated that approximately 49% of women gained more than the recommended amount of weight.

## 1.5 Body Composition

Measuring changes in GWG is a primary method for assessing the normal healthy progression of a pregnancy. Conventionally the belief has been that, people with a high BMI have high body fat content. However only recently it is recognized that individuals with same BMI may have different amounts of lean and fat stores (20). During pregnancy women gain a considerable amount of weight; based on the normal physiological adaptations women are expected to gain ~ 4 kg fat mass, ~ 1kg protein or lean mass and 7-8 litres of fluid (12). However GWG and its composition are considerably variable and are influenced by interaction of several biological, environmental and behavioural factors. Further changing lifestyle in the contemporary world, which include intake of high energy/low nutrient dense food coupled with limited physical activity have caused the development of sarcopenic obesity i.e. increased adiposity accompanied with muscle wasting among non-pregnant adults (21). Thus in this context, studying changes in body composition in addition to weight during pregnancy will describe the contribution of fat /fat-free mass accumulation to total GWG which will provide valuable clinical information. Body composition assessment describes the contribution of water retention, fat mass (FM) and fat-free mass (FFM) to weight gain.

### 1.5.1 Techniques to Assess Body Composition in Pregnancy

Several techniques are available to measure body composition, including dual energy x-ray absorptiometry (DEXA), bioelectric impedance analysis (BIA), computerized tomography (CT), magnetic resonance imaging (MRI), ultrasound, air-displacement plethysmography, underwater weighing or hydrodensitometry, total body potassium (TBK), total body water (TBW) assessment using isotope dilution methodology and anthropometric techniques such as skinfold thicknesses measured using calipers and body circumference measurements assessed using non-elastic tape.

Some of these techniques, such as DEXA and CT, are not suitable during pregnancy as they involve X-ray transmission. Other techniques mentioned above, except anthropometric measurements, require expensive equipment and involve complex procedures, which make them difficult to apply in measurements involving large-scale pregnant populations. Anthropometric assessments are inexpensive and easy to perform, and can be used in longitudinal body composition assessments of large populations (20). Anthropometric assessments have previously been used in the assessment of body composition changes during pregnancy (11, 22, 23). In addition longitudinal measurements of subcutaneous fat mass at specific skinfold sites and measurements of body circumferences also help in understanding patterns of fat mass distribution.

Total body weight can be divided into four compartments: FM or adipose, FFM or protein, bone or mineral, and water in FFM. Three models have been used in the literature to study body composition based on compartmentalizing body weight: the two-compartment model (classifies body weight as fat and fat-free mass), the three-compartment model (classifies body weight as fat, protein and water) and the four-compartment model (classifies body weight as fat, protein, mineral and water) (20). The four-compartment model involves measuring each body compartment; hence, it is considered more accurate than the other two models. However, during pregnancy, bone mineral content cannot be estimated as this requires using X-rays; instead two or three compartment models are often used to measure body composition.

It should be noted that during pregnancy significant increases in body water levels occur in response to hormonal changes and this varies as pregnancy progresses. On average, women with healthy pregnancies accumulate 7-8 litres of fluid. Hytten et al (12) measured longitudinal changes in TBW in 93 healthy pregnant women; they suggested that for a reference woman with a 12.5 kg weight gain, the total water gain at term is distributed in the fetus (2,414 g), placenta (540 g), amniotic fluid (792 g) blood-free uterus (800 g), mammary gland (304 g), blood (1267 g) and extravascular-extracellular cellular fluid (ECF) with no edema or leg edema (1496 g), and ECF with generalized edema (4697 g). Hence as discussed above there is a considerable variation in the hydration of fat-free mass as pregnancy progresses. The two component methods based on TBW, TBK and body density may lead to the erroneous estimation of fat mass and fat-free mass if general constants for hydration, K and density are used. To provide accurate estimation of fat mass and fat free mass the two- component model has to be corrected for pregnancy-specific hydration, K and density constants (24, 25) which account for changes in density of FFM caused by variations in water levels in the fat free mass. Further variations in density of FFM due to oedema can also be accounted for by choosing pregnancy specific equations in the presence of oedema (24). These estimated measurements would be similar to estimates obtained from three and four component models where hydration or density of fat free mass are measured (8).

### 1.5.2 Components of Gestational Weight Gain

The total GWG can be divided in two components: maternal weight and the product of conception (placenta, fetus and amniotic fluid).

#### 1.5.2 .1 Composition of Maternal Weight Gain

**Total Body Water**

TBW is often estimated using isotope dilution technique which employs expensive equipment and cumbersome procedures. The strength of isotope dilution technique is it enables assessment of changes in body composition in free living conditions and requires minimum participant compliance. Most of the studies measuring changes in TBW using this procedure were conducted in the 1960 and /or were cross-sectional involving a small sample (n = 4-26) of pregnant women (26-28). Alternatively a few other studies have utilized the BIA technique to measure changes in body water in pregnant women and have produced reliable results compared to TBW and hydrodensitometry (29, 30); also monthly BIA measurement of 170 normal healthy pregnant women confirmed the progressive expansion of TBW, ECF and intracellular water during pregnancy (31). The equipment used in BIA is simple, portable and inexpensive; however its usability is questionable since it requires passing a low voltage electric current through the pregnant woman's body. Further, distribution of fat mass cannot be ascertained using either isotope dilution or BIA techniques.

**Protein Accretion**

Protein accretion occurs predominantly in the fetus (45%), but also in the uterus (17%), blood (14%), placenta (10%), and breasts (8%) (12) (8). Protein accretion during pregnancy is estimated by measuring increments in TBK by whole body K counting technique. Several studies have suggested that pregnant women may gain less protein than the estimates of ~1 kg suggested by Hytten and Chamberlain. In a cross-sectional study of 10 adolescent pregnant women (15-19 years), King et al. (32) measured increase in K levels during the third trimester using TBK, and they observed an increase in K by 3.4 milliequivalents (meq) per day. In another study of 22 healthy pregnant women Forsum et al (33) observed a significant decrease in TBK levels from prior to conception (2397 ± 327 mmol) to 16-18 weeks (2224 ± 298 mmol) and at 30 weeks gestation (2290 ± 330 mmol), but TBK levels increased at 36 weeks (2507±307 mmol). Similar results were observed in a study of 63 pregnant women; Butte et al (34) observed a decline in TBK in the first trimester (−44 mg/d), followed by a moderate rise in the second trimester (22 mg/d), and a maximum increase in the third trimester (83 mg/d) compared to the pre-pregnancy TBK levels. Forsum et al in their article suggest that the decline in TBK levels may be due to lower levels of intracellular K levels during pregnancy than in the non-pregnant state and due to changes in water and electrolyte balance during pregnancy. During pregnancy an increase in protein accretion is expected, however the decrease in TBK during pregnancy is these studies reflects muscle mass loss. In present-day society an increased prevalence in overweight accompanied with insulin resistance could interfere with normal physiological adaptations to pregnancy. Furthermore a decrease in physical activity and poor diet quality during pregnancy may also contribute to low protein mass accretion during gestation.

**Fat Mass Accretion**

The majority of maternal fat deposition during pregnancy is subcutaneous (13); subcutaneous adipose tissue accumulation occurs between 6 and 35 weeks preferentially over hips, back and upper thighs (11). A review of literature suggests that GWG and fat mass accretion are inversely associated with pre-pregnancy obesity. Lederman et al. (35) measured the body composition of 197 pregnant women twice during gestation (14 and 37 weeks), using a four compartment body composition model. Measurements of total body water (deuterium dilution), body density (hydrodensitometry) and bone mineral mass (DEXA, measured at 2-4 weeks postpartum) were used to determine body composition at these stages of gestation. They found that compared to underweight and normal-weight women, obese women gained less fat mass. There was no difference in TBW among these women. Fat mass positively correlated with GWG (r = 0.81) and inversely correlated with pre-pregnancy weight (r = -0.25). In this study a high percent of women from the all pre-pregnancy BMI categories (67 % underweight, 61% normal-weight, 69% overweight and 78% obese women) gained above the IOM 1990 gestational weight gain recommendations. Among women who gained above the recommended amount, fat mass accretion was highest in the underweight women, followed by normal-weight, overweight and obese women. Similarly among women who met IOM recommendations, fat mass accretion was highest in the underweight women, followed by normal-weight and overweight women, while obese women lost fat mass. Among women who gained less than the recommended amount, fat mass accretion was highest among the normal-weight women, followed by underweight and overweight women. Obese women who gained below the recommended amount lost a significant amount of fat mass (-5.2 ± 1.5kg).

In another study measuring longitudinal changes in body composition during pregnancy, Butte el al. (34) found that GWG was positively correlated with TBW (r = 0.39), TBK (r = 0.49), FFM (r = 0.50) and FM (r = 0.76). In this study, women from all pre-pregnancy BMI groups gained a similar amount of fat-free mass; however, women from the high BMI group (BMI ≥ 26 $kg/m^2$) gained a higher amount of weight and fat mass. In these women postpartum weight and fat retention were positively correlated with GWG and FM gain but not with TBW, TBK or FFM gain. These findings suggest that the variability in maternal GWG is primarily influenced by fat mass accretion which also influences postpartum weight retention and adiposity.

The inverse association between fat mass accretion and pre-pregnancy BMI as suggested in the former study may be influenced by the maternal pre-pregnancy metabolic condition. In a study of 16 healthy lean women who were measured before conception, in early (12-14 weeks) and late (34-36 weeks) pregnancy, results indicate that women from both abnormal glucose tolerance and normal glucose tolerance groups gained significant fat mass over time ($p<0.01$). However there were significant differences in fat mass accretion in early gestation, whereby women with abnormal glucose tolerance gained less fat mass (1.3 kg, p = 0.04) than women with normal glucose tolerance (2.0 kg) during early pregnancy; but women from both groups gained similar amounts of fat mass between early to late pregnancy. Results from this study also indicated that changes in insulin sensitivity from before conception to early pregnancy were inversely associated with changes in resting energy expenditure and FM accretion, however there was no correlation between changes in REE and fat mass and insulin sensitivity between early to late pregnancy (36). Despite a small sample of normal healthy women, authors from this study showed that a decrease in insulin sensitivity in early pregnancy may play a significant role on fat mass accretion.

In the present- day scenario of increasing pre-pregnancy BMI, studies examining metabolic adaptations among a larger sample of pregnant women especially those with higher BMI would help us to understand the influence of metabolic adaptations on fat mass accretion.

### 1.5.2 .2 Components of Conception

The components of conception comprise approximately 35% of the total GWG.

**Fetal weight**

***Growth***

Fetal growth curves are based on cross-sectional evidence (i.e. each fetus having been measured only once) (12). According to these curves the pattern of fetal growth is sigmoid; however individual fetal growth in utero may not occur at the same average rate. For example a baby born with less than average body weight could have grown at a slower rate throughout gestation, or could have grown normally until a stage and then slowed growth, or could have lost some weight in utero (12). Comparing infant birth weight to a healthy reference is used to help in interpreting the variation in fetal growth; infants are generally categorized as small for gestational age (SGA) [birth weight less than 10% for gestational age]; appropriate for gestational age (AGA) [birth weight between 10-90% for gestational age]; or large for gestational age (LGA) [birth weight greater than 90% for gestational age] (8).

Besides gestational age, a number of factors influence fetal growth and birth weight: the infant's gender, and the mother's age, height, weight, gestational weight gain, parity and, medical conditions such as gestational diabetes, hypertension, pre-eclampsia, auto-immune diseases and, maternal lifestyle factors such as dietary intake, physical activity and smoking (8). Detailed discussion of these factors will be presented in later sections of this chapter.

***Fetal Body Composition***

The body composition of the fetus at birth is approximately 12-16 % body fat. The remaining tissue is FFM. The FFM contains 15% protein (12.8% of birth weight), approximately 40g glycogen and 80% water (8). An examination of 169 fetal cadavers indicated variations in fat content with gestational age but little differences in FFM (37). Further variations in fetal weight may be associated with fat mass; in a study of body composition measurement of 214 singleton infants at birth using DEXA, Koo et al. (38) found that neonates whose birth weight was < 2500g had 6-14 % body fat, while infants with birth weight >2500 had 8-20% body fat and a 3500 g infant had 16.2% body fat. Similar to birth weight, fetal body composition is also influenced by multiple factors which will be elaborated later in this chapter.

## Placenta

### *Growth*

The growth of the placenta progresses with gestation but slows down towards the end of gestation. At 40 weeks the average placental weight is about 650 g (12). Thomson et al. (39) studied the birth weight and placental weight of 52,004 infants born between 1948-1964, and results from their study indicated that, the variations observed in birth weight cannot be explained by variations in placental weight; i.e., at a given placental weight, birth weight of infants born at similar gestational age may be different. In another study of 1621 placentas obtained from mothers of Ukranian infants born during1993-1994 showed that weight of placenta was positively correlated with birth weight ($r = 0.60$, $p<0.01$), while placenta-to-birth weight ratio was inversely associated with infant birth weight ($r = - 0.15$, $p<0.01$) and positively associated with maternal pre-pregnancy BMI ($p = 0.036$) (40).

The presence of maternal medical conditions such as hypertension and preeclampsia may play a role in the size and functionality of the placenta, thereby decreasing fetal weight. Obese women tend to have larger placentas and heavier babies in comparison to normal-weight women. Recent evidence suggests that the placentas of obese women have 2-3 times more macrophages, and more pro-inflammatory cytokines than normal-weight women. The authors suggest that the resulting inflammatory milieu may play a role in increasing maternal insulin resistance and decreasing her fat mass accretion while promoting increased placental and fetal growth (41).

***Composition***

The composition of the placenta varies with gestational age and maternal metabolic status. An analysis of the composition of the placenta between 17 and 40 weeks of gestation indicated that it consisted of 88% water, 11% protein and 1% fat (42). An analysis of the placentas of women with Type 1 diabetes showed an increase in the amount of glycogen and lipids compared to women with normal glucose tolerance; more specifically a true increase in glycogen and lipids such as of triglycerides and phospholipids per placental cell was observed (43).

**Amniotic Fluid**

The amniotic fluid volume increases in the first two trimesters and peaks at 33 weeks gestation, after which it remains stable until birth. The amniotic fluid volume is determined by the inflow from fetal urine and lung liquid secretions, and outflow from fetal swallowing and intra-membranous absorption. There is a wide variation in the volume of this fluid in a normal pregnancy; on an average it can contribute ~1kg to the maternal gestational weight (13).

## 1.6 Outcomes of Gaining Within or Outside Recommendations

The recommendations for GWG were put forward to make sure women gain adequate weight to minimize maternal health risk during pregnancy, to support optimal fetal growth and to reduce delivery complications and long-term health risks in the mother and infant.

### 1.6.1 Maternal Complications during Pregnancy and Delivery

Maternal pre-pregnancy BMI is a well known predictor of pregnancy-induced disorders such as gestational diabetes mellitus, gestational hypertension and preeclampsia (10); however, gaining excess gestational weight has also been associated with abnormal glucose tolerance (44) and a two-fold risk of developing preeclampsia during pregnancy (45). Women who gained inadequate gestational weight are also likely to have abnormal glucose tolerance (46). Women who exceed GWG recommendations are also more likely to have a prolonged labour, caesarean delivery or assisted birth (5).

### 1.6.2 Infant Outcomes

Strong evidence (46-49) suggests that infant birth weight is associated with GWG (5). Infants born to women who exceeded the GWG recommendations are at an increased risk of having high birth weight or being large-for-gestational age (LGA) (4, 5). They are also more likely to have a high body weight at 6 months (50) and a high BMI in childhood (51, 52) and adolescence (53). Women who gain less than the recommended amount of gestational weight are more likely to have a preterm birth, or give birth to low birth weight (LBW) or small-for-gestational-age babies (SGA) (5).

Besides birth weight, neonatal body composition is also associated with maternal body composition, pre-pregnancy BMI and GWG. In a study of body composition of 63 mother-infant pairs; birth weight significantly correlated with maternal pre-pregnancy weight ($r = 0.34$) and pre-pregnancy FM ($r = 0.32$); GWG ($r = 0.35$) and gestational gains in FFM ($r = 0.39$), TBW ( $r = 0.37$) and TBK (r =

0.35) but not with FM. Infant FFM and FM measured at 2 weeks using DEXA were not associated with maternal body composition before or during pregnancy (34). However in a study of 19 infants, maternal total body fat prior to pregnancy and at 32 weeks gestation was positively associated with birth weight (54). Similarly, in another study of 72 infants (<35 days old) whose body composition was measured using air displacement plethysmography, it was found that infants born to overweight or obese women had higher fat mass and lower FFM than infants born to normal-weight women (55). Also, in another study of exclusively breastfed infants, infants born to overweight women had a higher fat mass at 2 weeks than infants of normal-weight women. This association was not significant at 3 months (56). A recent study that measured adiposity using DEXA suggested a positive association between excess GWG and offspring adiposity at birth and at 4 and 6 years (19).

In sum it appears that high pre-pregnancy BMI and excessive GWG, particularly gain in fat mass may play a significant role in infant birth weight and adiposity thus predisposing the risks of overweight and obesity in offspring's later life.

Several other factors influence fetal/infant weight and composition in addition to maternal weight and composition. Among these factors are infant gender: male fetuses grow at a faster rate in mid-pregnancy than female fetuses (57) and also tend to have greater lean mass than females, while female fetuses have a higher percentage of body fat (58). Maternal age and parity were associated with fetal growth (59). Parity was also positively associated with infant adiposity (60). Environmental conditions such as high altitude and exposure to smoking decreased fetal weight; maternal smoking primarily caused a decrease in the infant's lean mass by ~150g (61). Maternal medical conditions such as gestational diabetes were associated with higher birth weight and adiposity at birth (62) and in childhood (63), while maternal hypertension and autoimmune diseases are associated with decreased fetal growth. In a study comparing women with high pre-pregnancy BMI and women with rates of high GWG, the former were more likely to give birth to LGA babies (OR = 3.23) than the latter (OR =1.61). When women with chronic conditions such as gestational diabetes and hypertension were excluded from the above analysis, the association between high pre-pregnancy BMI and LGA weakened (OR = 2.57) but the association between rates of high GWG strengthened (OR = 2.08) (64). These results suggest that the presence of high pre-pregnancy BMI with medical conditions such as GDM and hypertension exacerbate negative fetal outcomes.

### 1.6.3 Postpartum Weight Retention

Previous follow-up studies of pregnant women have indicated that women who exceeded the GWG recommendations retained more weight at 6 weeks (65), 5 to 9 months (66), and 10 to 18 months postpartum (67, 68). High GWG is associated with inter-pregnancy weight retention (69, 70) and may also lead to incremental weight gain in the later years. Long-term follow-up studies conducted at 15 years (71) and 21 years (72) postpartum indicated that women who gained excessive weight were more likely to show an increase in their BMI. Women who exceeded the weight-gain recommendations also retained higher fat mass than women who met the recommendations at 2-6 weeks (34, 35) and 27 weeks postpartum (34).

### 1.6.4 Breastfeeding

Some studies have shown that high pre-pregnancy BMI is associated with failure to initiate and sustain breastfeeding. However, the association between GWG and breastfeeding is inconclusive (10). Exceeding the IOM 1990 GWG recommendations was associated with failure to initiate breastfeeding, especially among normal-weight and obese women (73); in this same study, underweight, overweight and obese women who exceeded the recommendations, as well as obese women who gained within the recommendations, breastfed for a shorter period of time than normal-weight women. A meta-analysis of studies examining the influence of GWG on breastfeeding initiation and duration indicated that low GWG was moderately associated with difficulty to initiate breastfeeding but there was a weak association between GWG and duration of breast feeding (5). A recent study showed that introducing non-breast milk foods and fluids during the first month postpartum was more common among overweight (OR = 2.29, 95% C.I = 1.16-4.51) and obese women (OR =3.33, 95% C.I = 1.49-7.47) who gained above GWG recommendations compared to normal-weight women or women who experienced adequate GWG (74).

### 1.7 Factors Influencing Gestational Weight Gain

A number of factors are considered to be associated with GWG. These include physical, social, behavioural, physiological, genetic and psychological factors.

#### 1.7.1 Physical Factors

**Pre-pregnancy BMI**

Maternal pre-pregnancy BMI is a significant predictor of GWG. Chu et al. (71) examined the GWG of 52,988 women enrolled in the Pregnancy Risk Assessment Monitoring System study during 2004-2005. The authors found that obese women gained less total GWG than normal or overweight women; however one-fifth of these women gained above clinically acceptable GWG ranges. In addition, women of short stature are also likely to gain less GWG than tall thin women (2).

#### 1.7.2 Maternal Sociodemographic Factors

**Maternal Age**

The IOM 1990 guidelines recommended that adolescents gain in the upper limits of recommended weight specific to their pre-pregnancy BMI. This was because pregnant adolescents were at an increased risk for preterm birth, low birth weight and neonatal mortality (14). Recent studies indicate that adolescents are more likely than adults to gain excessive gestational weight (75, 76). Also, adolescents who gain at the upper end of recommended weight ranges or above the recommendations are more likely to be overweight or obese 6-9 years postpartum (77, 78). Nevertheless, it should be kept in mind that adolescents who conceive soon after menarche are still growing; in a study of adolescent pregnancies, Scholl et al. (79) observed that infants born to adolescents who were still growing were lighter than infants born to adolescents who were finished growing. Additionally, in a study of 815 adolescents recruited during1990-2000, Nielsen et al. (80) showed that birth outcomes among all pre-pregnancy BMI groups improved when GWG increased from below the recommended range to within the lower half of the IOM 1990 recommended weight gain range. Nielsen also showed that further weight gain was not beneficial, especially for infants of adolescents with a high pre-pregnancy BMI. It should be noted that this study was conducted in the year 2006, which is prior to the revision of GWG guidelines in 2009. Furthermore, gaining at the upper end of BMI was also associated with increased risk of higher postpartum weight retention (81) and an increase in maternal BMI 6 to 9 years postpartum across women in all BMI categories (78). The effect of GWG on pregnancy outcomes among adolescents is similar to the effect on adult women; however, there are more studies on adult than adolescent pregnancies especially younger adolescent pregnancies. In summary, the information available in the literature supports adherence to GWG recommendations in adolescent pregnancies to optimize infant and maternal health outcomes. Thus, the new recommendations suggest that adolescents less than two years post-menarche should be advised to gain within recommended weight ranges specific to their BMI without restricting weight or encouraging weight gain at the upper end of the range (8).

Several studies have reported that women of older age (≥35 years old) are associated with high pre-pregnancy BMI and low GWG; however limited evidence is available about how GWG contributes to maternal and infant outcomes in this population (8).

**Race or Ethnicity**

Limited data are available on the contribution of ethnicity to differences in GWG. Findings from a review article indicate that compared to white women, Hispanic and black women were more likely to gain less than the IOM's 1990 weight recommendations; however, black women retained more weight at postpartum compared to white and Hispanic women (82). A review of birth records from New York City indicated that Asian and black women gained less weight than Caucasian women. Further research on minority populations from their country of origin may help clarify the reasons for differences in weight gain.

**Socioeconomic Status**

A few studies have examined the associations between factors relating to women's socioeconomic status and GWG. Data of 52,988 pregnant women were obtained from the Pregnancy Risk Assessment Monitoring System (PRAMS), an ongoing surveillance project of the Centers for Disease Control and Prevention (CDC) in the US between 2004-2005; results from this study indicated that women with fewer than 12 years of education were more likely than women with more than 12 years of education to gain <15 lbs and less likely to gain >34 lbs above the weight gain recommendations (76). In another recent retrospective study of 3554 singleton pregnancies in Korea, low education level in the pregnant women and her spouse was associated with lower GWG (83).

Food insecurity is associated with an increased risk of being overweight or obese. Olson and Strawderman followed 622 healthy women from rural area in upstate New York from early pregnancy to 2 years postpartum and found that women who were obese and also experienced food insecurity during early pregnancy were at a greater risk for higher GWG and postpartum weight retention (84).

Socioeconomic factors associated with dietary intake have been explored in a few recent studies. Ugwuja et al.(85) studied 349 pregnant women, aged 15-40 years during their second trimester and indicated that economically disadvantaged women had lower plasma iron and zinc levels. In another study Uusitalo et al. (86) studied the association between sociodemographic variables and intake of antioxidant nutrients and their dietary sources in a group of 3730 pregnant women from Finland, they found that women from low income families, smokers and women with low education consumed lower antioxidants and were more likely to consume foods low in nutrients. These studies highlight that women from the low income/low education families may have poor dietary quality, which in turn could play a significant role in GWG. Future studies are required to understand the association between lifestyle patterns and GWG among women from high risk groups.

**Marital Status**

Women who were married were more likely to gain within the recommended weight ranges than single/separated /divorced women; 42-48% of unmarried women gained above recommendations compared to 38% of married women. Unmarried mothers were also more likely than married mothers to gain below weight gain recommendations (8).

**Family Violence**

A systemic review of studies conducted to examine the association of emotional and physical abuse on pregnancy outcomes (87) indicated that women who were abused gained less weight during pregnancy than non-abused women and were also more likely to be associated with adverse pregnancy outcomes, including low birth weight, maternal mortality and infant mortality.

**Social Support**

The association between GWG and social support is not clear; in a prospective study of low-income non-obese women, the level of social support was not associated with low GWG (88). In another study, adolescents who received psychological support had a higher weight gain than those who did not receive support (89). Another study indicated that the effect of social support on GWG varied between pre-pregnancy BMI groups; underweight and normal-weight women gained more weight than women from their respective BMI groups who did not receive support; however, obese women who had less social support gained less weight than women with average or high social support (90).

### 1.7.3 Behavioural Factors

**Energy Intake**

During pregnancy the demand for energy intake is increased to provide energy to support the growth and development of the fetus and meet maternal energy requirements. Several observational studies have demonstrated the association between energy intake and GWG. In a study to examine the association between dietary intake and GWG Bergmann et al. analyzed weighed 7 day food records that were collected longitudinally in each trimester during pregnancy from 156 pregnant women from Germany, they reported that women with high pre-pregnancy BMI were significantly less often in the high energy intake category than women with medium or low pre-pregnancy BMI (15% vs. 36% and 48% respectively); further total GWG was inversely associated with pre-pregnancy BMI and positively associated with daily energy intake during pregnancy (91). Energy intake is frequently under-reported by women with a high pre-pregnancy BMI (92-94), hence this could be a plausible reason why women with high pre-pregnancy BMI in the above study less often reported high energy intake. In another study, 622 healthy pregnant women were questioned about changes in their food intake during pregnancy compared to their food intake prior to pregnancy; eating “much more” or “much less” food during pregnancy was associated with higher (3.67 lbs , $p<0.001$) and lower (-3.16 lbs, $p<0.05$) GWG respectively, compared to maintaining the same food intake (68). Lagiou et al. (95) reported that a higher energy intake as well as a higher proportion of protein and lipids from animal origin were associated with increased GWG at the end of the second trimester. Further, adequate energy intake, in accordance with the recommendation of the Food and Agriculture Organization, resulted in lower GWG (96).

Besides energy intake, other aspects of dietary intake such as type of food consumption, the macronutrient and micronutrient composition of the diet and energy density of the diet consumed also play an important role in weight gain. Energy density is defined as the number of calories per gram of food; foods high in energy density tend to be lower in nutrients density. Dieierlein et al. (97) examined the dietary habits of 231 women with singleton pregnancies who participated in the Pregnancy Infection and Nutrition (PIN) cohort study. Dietary information was collected at 26-29 wk of gestation using a food-frequency questionnaire; Dieierlein et al found women in the lower, medium and highest quartile for energy density consumed a mean dietary energy of 0.71 kcal/g, 0.98 kcal/g and 1.21 kcal/g respectively. Compared to women in the lowest quartile for energy density, women in the medium quartile and highest quartile gained ~1.1 kg more total GWG during pregnancy. Olafsdottir concluded that among overweight women, the percentage of energy intake from different macronutrients was an important predictor of GWG; overweight women who gained excessive weight had a higher percentage of energy intake from fat and lower energy intake from carbohydrates than did women who gained inadequate gestational weight (98). The consumption of processed meats  and foods high in sugar, such as soft drinks, candies and chocolate , were associated with excessive GWG (99); similarly, another study showed that the intake of dairy products and sweets was associated with excessive GWG during late pregnancy (98). On the other hand, the consumption of higher amounts of fruits and vegetables (3-5 servings per day) was associated with lower weight gain than consuming fewer servings of fruits and vegetables during pregnancy (90). In a systematic review of trials on energy/protein supplementation or restriction, modest improvements in maternal weight gain and birth weight were observed with balanced energy/protein supplementation. High protein supplementation was associated with a non-significant increase in maternal weight gain but with an increased risk in SGA birth. Among women with high pre-pregnancy BMI or excessive weight gain, energy/protein restriction was associated with a significantly slow weekly weight gain and mean birth weight (100).

Martins et al. highlight the importance of dietary intake on postpartum weight retention in a group of 82 pregnant women at 15 days postpartum; dietary intake of pregnant women at all three trimesters was determined using a 24 hour dietary recall. They found that the intake of saturated fat and processed foods during pregnancy were significantly associated with postpartum weight retention independent of family income, maternal height, age, education, and smoking status (101).

**Physical Activity Energy Expenditure**

The American College of Obstetrics and Gynecologists (ACOG) recommends, in the absence of either medical or obstetric complications, 30 minutes or more of moderate exercise a day on most, if not all days for pregnant women (102). Review articles on physical activity during pregnancy have associated exercise with favourable maternal outcomes. Moderate physical activity during low-risk pregnancies has also been found to be safe for both mother and fetus (13). The Physical Activity Guidelines Advisory Committee (2009) (103) concluded that moderate physical activity is not associated with an increased risk of low birth weight, preterm delivery or early pregnancy loss; however, participation in vigorous activities was associated with a small reduction in birth weight compared to birth weight of infants born to less active women. A Cochrane review (104) indicated that evidence is insufficient to evaluate the effects of maternal physical activity on risks or benefits associated with infant outcomes. Further results from a meta-analysis of physical activity studies published in 2005 (105) and several other reviews (8) also failed to reveal an association between physical activity and GWG. However, the studies included in these analyses did not consider the level of physical activity-related energy expenditure on GWG.

On the contrary, a recent study showed an inverse association between vigorous physical activity and excess GWG (106). Other observational studies also support reduced weight gain and adiposity in the third trimester among women who continued to exercise compared to those who stopped exercising during pregnancy; additionally, maternal pre-pregnancy physical activity was also associated with a reduced rate of weight gain in the third trimester among a group of healthy Swedish women (13). A study of obese women with gestational diabetes who were either on a diet or diet and exercise indicated that, the rate of weekly weight gain in the third trimester was slower among women in the diet and exercise group. Based on limited evidence, the Physical Activity Guidelines Advisory Committee (2009) concluded that, "unless there are medical reasons to the contrary, pregnant women can begin or continue a regular physical activity program throughout gestation, adjusting the frequency, intensity and time as her condition warrants" (103).

**Substance Abuse**

**Cigarette Smoking**

Contradictory evidence exists on the effect of cigarette smoking on maternal GWG. One early study found a strong association between the amount of smoking and decreased GWG (107); other studies did not observe an effect of smoking on maternal weight gain, but concluded that infants born to women with a smoking history were more likely to be small for gestational age or have a low birth weight (108, 109). Recent observational studies indicate that women who either had a smoking history prior to pregnancy or who quit smoking gained more weight than non-smokers (110) or those who continued to smoke during pregnancy (111); further, in a more recent prospective study, women with a pre-pregnancy smoking history were five times more likely to exceed the IOM 2009 recommended gestational weight ranges than women who did not smoke (112).

### Alcohol Use

Alcohol consumption is a potent teratogen independent of GWG. No studies have found a significant association between the amount of alcohol consumed and GWG; however, a study showed a positive association between the frequency of alcohol consumption and rapid GWG (8).

### Drug Use

Chronic use of drugs such as methamphetamine or cocaine is associated with adverse maternal and fetal consequences (8). Smith et al. found that women who were exposed to methamphetamine in the first two trimesters of their pregnancy but stopped using it by the third trimester gained significantly more GWG compared to women who used the drug throughout pregnancy or women who never used it (113). Also results from this study indicate that exposure to methamphetamine during pregnancy was strongly associated with the risk of SGA babies. In another study chronic cocaine use was associated with obstetric complication, infant mortality, pre-term birth and low birth weight (114).

### 1.7.4 Physiological Factors

Changes in the basal metabolic rate and hormonal levels are a normal physiological response to pregnancy. These factors can influence GWG and composition.

**Resting Energy Expenditure and Basal Metabolic Rate**

Resting energy expenditure (REE) is defined as the amount of energy required to support vital physiological functions of the body such as respiration, circulation and hormone synthesis, while the body is at rest. Energy expended towards these processes amounts to about 60-70% of the total daily energy expenditure. Basal metabolic rate (BMR) is defined as "the rate of energy expenditure in the post-absorptive state after a 12-hour overnight fast"(115). During pregnancy, the energy requirements increase because the body needs to support fetal growth, provide energy to synthesize new maternal tissue, and add adipose stores in the mother and meet her basal energy requirements. As a result, the energy demands increase. Longitudinal studies of well-nourished pregnant women indicate that the REE increases during pregnancy, but a wide variability in these changes has been reported. In a longitudinal study of well-nourished women from pre-conception to 36 weeks gestation, Prentice et al. (116) documented an incremental gain in lean mass and a mean total GWG of 14.4 ± 4.1kg. The measured BMR in these women varied between 8.6 to 35.4 % above pre-pregnancy BMR; however two women from this study showed a significant decline in the BMR until the middle of the second trimester. Women in this study showed a significant decline in their physical activity from their pre-pregnancy levels, which was approximately 10% of total energy expenditure. The authors concluded that since BMR is highly variable and reduced physical activity only contributed to a small amount of energy saving, offering "prescriptive" energy intake recommendations to all women may not be practical as it is difficult to interpret how an individual woman's metabolism may respond.

Similarly, in a study of 12 well-nourished women (117), the total energy-cost of pregnancy calculated from measured BMR, total energy expenditure and fat mass accretion was 99837 ± 83118 kcal. The self-reported energy intake over the course of pregnancy of these women was 49680 ± 64966 MJ, which represented a cost that was significantly lower than the calculated estimated cost of pregnancy. This study also supports the theory that there is a wide variability in individual biological responses to pregnancy; hence, rigid recommendations for energy intake during pregnancy may not be applicable.

An incremental increase in BMR was also observed in a study from Sweden (118); whereas in a study conducted in Scottish and Dutch women, Durnin et al. (119) observed no increase in BMR until 16 weeks gestation followed by a mean increase in BMR of 400 kcal/day over pre-pregnancy BMR. After adjusting for dietary energy intake, Durnin et al concluded that reduced physical activity or increased efficiency of work accounted for energy saving in this population. A study conducted in Gambia (120) showed that food intake was associated with BMR and weight gain. REE increased when women were supplemented with additional energy intake above their basal diet, which resulted in a mean GWG of 8 kg and an increase in adiposity by 2 kg. However, Gambian women who were limited to only their basal diet showed no increases in REE above pre-pregnancy levels and their GWG was 4 kg with no increase in fat mass during pregnancy.

Another longitudinal study of pregnant women from different BMI groups (121) indicated that women with a high pre-pregnancy BMI gained more fat mass than women from a low BMI group. BMR accounted for 33% of variability in total energy expenditure in these women, which was mediated through changes in body fat, weight gain, fat-free mass and pre-pregnancy BMI. Physical activity accounted for only a small net increase in total energy expenditure and decreased in all BMI groups with advancing gestation.

**Hormones and Cytokines**

Insulin plays a very important role in human pregnancy. Maternal insulin sensitivity may decrease by 40-60% of pre-pregnancy levels with advancing gestation. The purpose of this adaptation is primarily to conserve energy for feto-placental growth and for fat storage, which could be used as source of energy during late pregnancy and lactation (122). However, women who enter pregnancy with a high pre-pregnancy BMI and presence of other chronic conditions may also have an existing insulin and leptin resistance and high levels of adiposity; progression of gestation exacerbates insulin resistance and predisposes these women to pregnancy-induced conditions such as gestational diabetes, preeclampsia and hypertension (123). Further adipocytokines such as leptin and adiponectin are associated with insulin sensitivity both in pregnant and non-pregnant states. Leptin levels increase beginning in the second trimester of pregnancy and are positively correlated with maternal BMR and fat mass. Leptin is negatively associated with insulin sensitivity and may play a role in lipid oxidation in late pregnancy. Adiponectin is positively associated with insulin sensitivity and negatively correlated with adiposity (8). In a non-pregnant state, weight loss is positively associated with insulin and leptin concentrations. A randomized control trial (123) of non-diabetic obese pregnant women was conducted to observe how following a healthy diet based on individual estimated energy requirements affected GWG and insulin and leptin concentrations. Results from this study indicated that women who followed a healthy diet gained less gestational weight, and had lower serum insulin and leptin levels than women who did not follow the healthy diet. Similar results were observed from a few other studies conducted on pregnant women; in one study insulin sensitivity was inversely related to BMR and fat accretion (36). In another study serum-leptin mediated increase in insulin resistance was associated with an increase in fat mass accretion in group of pregnant women (124). Results from the latter study also indicated that insulin resistance was inversely associated with serum adiponectin concentration.

### 1.7.5 Genetic Factors

The role of genetic factors on GWG and familial heritability of GWG has received very little attention to date. Some evidence, however, is available on the contribution of single nucleotide polymorphisms in specific genes associated with weight gain. Several studies have looked at the effect of a Trp64Arg allelic substitution in the beta 3 adrenergic receptor gene (ADRβ3) on GWG (8). The beta-3 adrenergic receptor is located mainly in adipose tissue and is involved in the regulation of lipolysis and thermogenesis. Higher weight gain from pre-pregnancy to 20-31 weeks gestation was observed among women with homozygotes for the 64Arg allele (125). In another study conducted on pregnant women with type 2 diabetes, 12.2 percent of women who had homozygotes for a Trp allele and 19.2 percent of women who had heterozygotes for the same allele gained more than 5 BMI units during pregnancy; 28.6 percent of women who had homozygotes for an Arg allele gained more than 5 BMI units during pregnancy (126). Three other studies found no differences among the ADRβ3 genotypes for weight gain (g/day) during pregnancy (127-129).

The Pro12Ala polymorphisms in the peroxisome proliferator-activated receptor gamma 2 (PPARδ2) have also been associated with GWG; diabetic women with an Ala allele gained more gestational weight, although non-diabetic women with the same allele did not (130).

### 1.7.6 Psychological Factors

#### Depression

Depression during pregnancy is associated with adverse maternal and infant outcomes. In a study of well-educated Caucasian women, Bodnar et al. (2009) showed that major depression during pregnancy was associated with low GWG regardless of a woman's pre-pregnancy BMI. Another study showed that gaining gestational weight above the 1990 IOM recommended ranges was also associated with depressive symptoms (131). Further, the Bodnar et al. study also indicated that overweight women who gained below and above gestational recommendations also had major depressive disorders during pregnancy (132).

Racial differences associated with depression were noted in the following studies: white women with high depressive scores were more likely than white women with low scores to gain less than the recommended gestational weight; this association was not true with black women (88). However in a study of Hispanic women, there was a correlation between a high depressive score and low GWG (133).

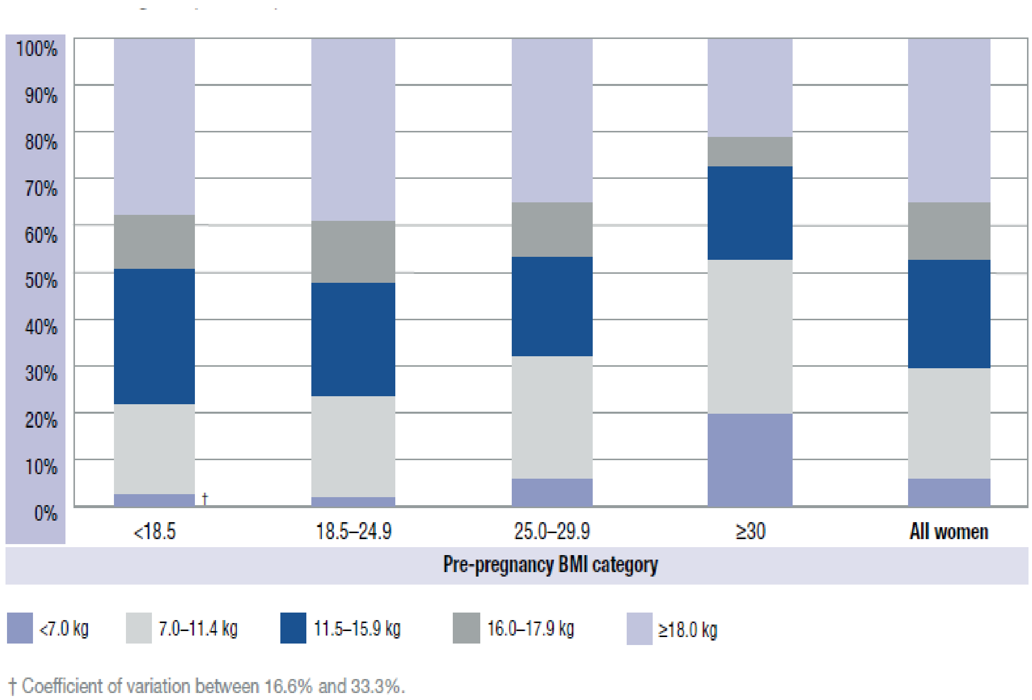
**Stress**

Women who experienced psychological stress during pregnancy were likely to gain low gestational weight; however there was no significant association between stress and excess GWG (5). Picone et al.(134) examined the association of GWG and stress during pregnancy in a prospective study of 60 healthy pregnant women who were recruited prior to 13 weeks gestation and followed throughout pregnancy. Dietary intake of the participants was obtained using the 24 hour dietary recall method and 2 - 6 (average 5) recalls were obtained for each participant. Picone et al.(134) found that stress did not affect the average food intake of women but it was significantly associated with low GWG independent of nutritional intake. The authors suggested that utilization of calories and nutrients from food consumed may be impacted in women under stress. Further the authors explained that several hormones such as corticoids, catecholamines, growth hormone and prolactin are increased under stress; these hormones may impair insulin release which may interfere with normal carbohydrate and lipid metabolism. Further research is required to fully understand this hypothesis and the underlying mechanisms involved.

## 1.8 Summary

There is a growing incidence of high BMI among women of child-bearing age and a significant increase in excessive GWG. This review summarises that GWG and the composition of the weight gain are important predictors of maternal and childhood health outcomes. As recommended by the 2009 IOM (8) and 2010 Heath Canada revised GWG recommendations (9), pregnant women should gain weight within the BMI-specific recommended weight ranges to optimize pregnancy outcomes. However, weight gain during pregnancy is complex and is influenced by numerous components such as diet and exercise, physiological and hormonal adaptations of pregnancy; and genetic, socio-environmental and psychological factors. The influence of several of these components is not understood well: in particular, the roles of diet and exercise, metabolic adaptations and genetic influences have to be fully explored. Future studies are required to further understand the causes for variations in weight gain and adiposity during pregnancy and to develop successful intervention programs that will help pregnant women and health care professionals to implement and adhere to recommended weight gain guidelines. An interdisciplinary approach is required to address this situation to prevent further increases in excessive GWG and adiposity during pregnancy, thereby improving short- and long-term maternal and child health.

**Figure 1.1 Distribution of weight gain categories (kg) during pregnancy, by pre-pregnancy BMI categories (kg/m$^2$) in Canada during 2006-2007**




Adapted from Canadian maternity experience survey (18)

**Table 1.1: Summary of IOM Recommended Total Weight Gain Ranges for Pregnant Women [a] by Pre-pregnancy Body Mass Index (BMI) [b]**

| Weight-for-Height Category | Recommended Total Gain | |
|---|---|---|
| | **kg** | **Lb** |
| Low (BMI <19.8) | 12.5–18 | 28–40 |
| Normal (BMI of 19.8 to 26. 0) | 11.5–16 | 25–35 |
| High [c] (BMI >26.0 to 29.0) | 7–11.5 | 15–25 |

[a] Young adolescents and black women should strive for gains at the upper end of the recommended range. Short women (<157 cm, or 62 in) should strive for gains at the lower end of the range.

[b] BMI is calculated using metric units.

[c] The recommended target weight gain for obese women (BMI >29.0) is at least 6.8 kg (15 lbs).

Adapted from: Institute of Medicine (1990) (14)

**Table 1.2: New recommendations for total and rate of weight gain during pregnancy by pre-pregnancy BMI**

| Prepregnancy BMI | Total Weight Gain | | Rates of Weight Gain* 2nd and 3rd Trimester | |
|---|---|---|---|---|
| | Range in kg | Range in lbs | Mean (range) in kg/week | Mean (range) in lbs/week |
| Underweight ($< 18.5$ kg/m$^2$) | 12.5–18 | 28–40 | 0.51 (0.44–0.58) | 1 (1–1.3) |
| Normal weight (18.5–24.9 kg/m$^2$) | 11.5–16 | 25–35 | 0.42 (0.35–0.50) | 1 (0.8–1) |
| Overweight (25.0–29.9 kg/m$^2$) | 7–11.5 | 15–25 | 0.28 (0.23–0.33) | 0.6 (0.5–0.7) |
| Obese ($\geq 30.0$ kg/m$^2$) | 5–9 | 11–20 | 0.22 (0.17–0.27) | 0.5 (0.4–0.6) |

* Calculations assume 0.5-2 kg (1.1-4.4 lbs) weight gain in the first trimester

Adapted from IOMs Revised Guidelines (2009) for Weight Gain During Pregnancy (8)

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# CHAPTER 2: Research Plan

## 2.1 Rationale

Over 50% of Canadian women of child bearing age are categorized as either overweight or obese (1); the implications of which, in terms of maternal and infant health risks, are cause for concern (2). Recent studies indicate that a majority of pregnant women gain gestational weight above clinical recommendations (3, 4). High pre-pregnancy body mass index (BMI) and excessive GWG are associated with increased risk for short-term complications during the antenatal and perinatal periods and may also influence long-term risk for chronic diseases in the mother and her infant (5, 6). Recent revisions to the recommendations for GWG (2,7) have highlighted the importance of appropriate weight gain for optimal pregnancy outcomes.

Although measurement of GWG is an easy and primary method of assessing health during pregnancy, the data examining the composition of GWG are limited, and the factors contributing to the differences in weight gain remain unclear. Weight gain and subcutaneous fat deposition are normal physiological adaptations to pregnancy (8); however, women with different pre-pregnancy BMIs may enter pregnancy with different amounts of fat stores. It is therefore unclear whether differences in gestational weight reflect differences in fat mass, fat free mass, water retention or a combination of these, and whether differences in pre-pregnancy BMI influence the composition of the weight gained. Furthermore, pregnancy is a period associated with an increased demand for energy that is required to lay down maternal tissues, to support fetal growth and development, and to meet maternal basal energy demands (9). Energy requirements during pregnancy may be influenced by maternal nutritional status prior to pregnancy (e.g., fat stores) (9, 10); lifestyle factors such as the quality and quantity of diet and physical activity; the presence of chronic diseases; and individual metabolic adaptations during pregnancy. Evidence from studies that are primarily cross-sectional and limited to small groups of healthy population suggests that women can utilize different strategies to meet the increased demands, such as increasing energy intake and/or decreasing physical activity and changing basal energy demands (11). The contribution of these processes to variability in weight gain and adiposity remains unclear.

## 2.2 Objectives and Anticipated Results

### Investigated in Chapter 3: Gestational Weight Gain and Early Postpartum Weight Retention in a Prospective Cohort of Albertan Women

The primary objective of this study was to determine total GWG and rate of weight gain between the second and third trimester among women with different pre-pregnancy BMIs. The secondary objective was to describe the effects of adherence to GWG guidelines on postpartum weight retention.

**<u>Study questions</u>**

1. Among women with different pre-pregnancy BMI what is the
    a) total weight gain in pregnancy;

b) weekly weight gain between second and third trimester during pregnancy and

c) postpartum weight retention?

2. Do women in all the pre-pregnancy BMI categories adhere to the 2010 total and weekly weight gain recommendations from Health Canada?
3. Is there an association between adherence to the total GWG recommendations and postpartum weight retention?

**Anticipated Results**

1. Compared to women with normal pre-pregnancy BMI, women who were overweight or obese before pregnancy
   a) will gain less total gestational weight.
   b) will have a slower rate of weight gain between the second and third trimester of pregnancy.
   c) will retain more weight than normal weight women at postpartum.
2. Compared to women with normal pre-pregnancy BMI, women who were overweight or obese before pregnancy will exceed GWG recommendations.
3. Compared to women who meet the GWG recommendations, women who exceeded GWG recommendations will retain more weight at postpartum; while women who gained less than recommended will have less weight at postpartum.

**Investigated in Chapter 4: Fat Mass Accretion and Distribution during Pregnancy and Early Postpartum**

The objectives of this study were to describe fat mass accumulation and distribution during pregnancy and fat mass loss, retention and distribution in the early postpartum period among women with different pre-pregnancy BMIs.

**Study questions**

4. Among women with different pre-pregnancy BMI what is the
    a. pattern of fat mass accretion during pregnancy;
    b. amount of fat loss between third trimester in pregnancy to postpartum;
    c. amount of fat retained at postpartum; and
    d. pattern of fat distribution in pregnancy and at postpartum?
5. Among women with different pre-pregnancy BMI, what is the pattern of fat-free mass accretion during pregnancy and postpartum?

**Anticipated Results**

4. Compared to women with normal pre-pregnancy BMI, women who are overweight or obese prior to pregnancy will
    a. gain higher amount of fat mass during pregnancy.
    b. lose less fat mass between the third trimester and postpartum.
    c. retain more fat at postpartum.
    d. will gain and retain higher percent body fat at all skinfold sites and will have higher waist to hip ratio at postpartum.
5. Compared to women with normal pre-pregnancy BMI, women who are overweight or obese prior to pregnancy will gain significantly higher amounts of fat-free mass during pregnancy and postpartum.

**Investigated in Chapter 5: Association between Energy and Macronutrient Intake, Physical Activity and Resting Energy Expenditure with Body Composition Changes during Pregnancy**

The objective of this study was to describe differences in energy and macronutrient intake, physical activity and resting energy expenditure among women with different pre-pregnancy BMIs, and to examine the associations between changes in energy and macronutrient intake, physical activity and resting energy expenditure relative to- fat mass and adherence to weight gain recommendations during pregnancy.

**<u>Study questions</u>**

6. Among women with different pre-pregnancy BMI what is the pattern of
    a. energy and macronutrient intake during pregnancy;
    b. physical activity during pregnancy; and
    c. resting energy expenditure during pregnancy ?
7. What is the association between energy and macronutrient intake, physical activity and resting energy expenditure during pregnancy with
    a. changes in fat mass during pregnancy;
    b. fat-free mass accretion during pregnancy;
    c. adherence to weight gain recommendations during pregnancy?

**<u>Anticipated Results</u>**

6a.There will be no significant difference in energy and macronutrient intake irrespective of pre-pregnancy BMI during pregnancy or postpartum.

6b. Compared to normal-weight women, overweight and obese women will have lower physical activity scores during pregnancy and postpartum

6c. Compared to normal-weight women, overweight and obese women will have higher resting energy expenditure during pregnancy and postpartum

7 a. Energy intake and macronutrient and resting energy expenditure will be positively associated with fat mass and fat-free mass accretion, while physical activity will be inversely associated with fat mass and fat-free mass accretion during pregnancy

7b. Women who exceed GWG recommendation will have higher energy and macronutrient intake and higher resting energy expenditure and less physical activity than women who meet the GWG recommendations.

**Investigated in Chapter 6: Higher Pre-Pregnancy BMI and Excessive Gestational Weight Gain are Risk Factors for Rapid Growth in Infants**

The objective of this study was to describe the effects of maternal pre-pregnancy BMI and GWG on infant anthropometrics at birth and 3 months, and on infant growth rates between birth and 3 months.

**Study questions**

8. Among women with different pre-pregnancy BMI what is the
    a) infant birth weight;
    b) weight, length and BMI at 3 months;
    c) infant growth rate between birth to 3 months?

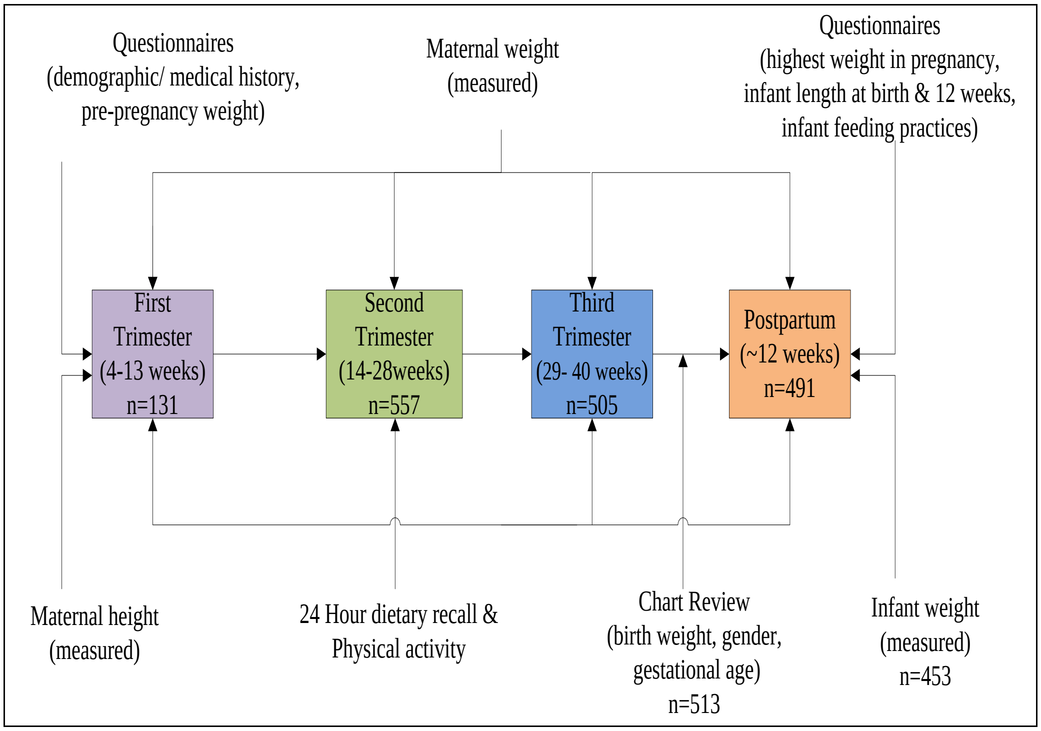
9. Is there an association between maternal adherence to GWG recommendations and:
    a. infant birth weight;
    b. weight, length and BMI at 3 months; and
    c. infant growth between birth to 3 months?

**Anticipated Results**

8. Compared to infants born to women with normal pre-pregnancy BMI, infants born to women from the overweight or obese pre-pregnancy categories will
    a. have higher birth weight
    b. have higher weight, BMI and will be longer at 3 months
    c. experience rapid growth between birth to 3 months
9. Compared to infants born to women who meet the GWG recommendations,
    a. infants born to women who exceeded GWG recommendations will have higher birth weight, higher weight, BMI and will be longer at 3 months and experience rapid growth between birth to 3 months
    b. infant born to women who gained below recommendations will have lower birth weight and lower weight, BMI and height at 3 months and will experience slow growth between birth to 3 months

The research presented in this thesis is part of a longitudinal birth cohort study entitled "Alberta Pregnancy Outcomes and Nutrition" (APrON). Women eligible for this study were ≥ 16 years of age, able to read and write in English and ≤ 27 weeks in gestation. Women were recruited between June 2009 and March 2010 from the cities of Edmonton and Calgary in Alberta, Canada; advertisements were placed in the local media and in physicians' offices. Data were collected at three visits during pregnancy; these corresponded to trimester 1, trimester 2 and trimester 3 at gestational ages (Mean ± S.D) 10.7 ± 2.3 weeks, 19.2 ± 3.7 weeks, 32.4 ± 1.4 weeks respectively, and at 11.6 ± 1.8 weeks at postpartum. The study design for this project is summarized in Figure 2.1. All women provided their written and informed consent for their own and their infant's participation in the study prior to enrolment. Ethics approval for this study was obtained from the Health Research Ethics Boards at the University of Alberta (Pro 00002954) and the University of Calgary (E22101).

**Figure 2.1: Study Design**



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# CHAPTER 3: Gestational Weight Gain and Early Postpartum Weight Retention in a Prospective Cohort of Alberta Women[1]

## 3.1. Introduction

A significant proportion of Canadian women of childbearing age are either overweight or obese. Reports from Statistics Canada indicate that between 2007 and 2009, 23% of women aged 18-39 years were overweight and an additional 20% were obese (1). Being overweight or obese before pregnancy is associated with complications during the antenatal and perinatal periods such as gestational diabetes, hypertension, preeclampsia, prolonged labour, assisted birth, caesarean section and an increased risk for neonatal morbidities such as still birth and macrosomia (2, 3). Another important predictor of pregnancy outcomes is weight gain during pregnancy. Gaining too little weight is associated with low birth weight and preterm birth, while gaining too much weight is associated with complications such as gestational diabetes, hypertension, caesarean sections and macrosomia in infants (4). In addition, excess GWG is associated with higher maternal weight retention postpartum (5) which increases the likelihood of high body weight in women in subsequent pregnancies (6) and this significantly increases her risk of chronic conditions in later life.

[1] A version of this chapter has been published as: "Begum F, Colman I, McCargar LJ, Bell RC., Gestational weight gain and early postpartum weight retention in a prospective cohort of Alberta women. J Obstet Gynaecol Can. 2012 Jul; 34(7):637-47".

The GWG guidelines have been recently revised by Health Canada (7) and The Institute of Medicine (8) and now have specific target ranges for total weight gain and rates of weekly weight gain during the 2nd and 3rd trimesters (kg/week), according to pre-pregnancy BMI. To date, the only Canadian study to our knowledge that has examined adherence of Canadian women to weight gain guidelines (9) demonstrates that they tend to gain more weight than recommended (10). However, this study relied solely on self-reported data, was retrospective in nature and only considered total weight gain since weekly weight gain recommendations were introduced very recently (7).

The objectives of this study were to describe total weight gain in pregnancy, the rate of weekly weight gain in pregnancy, and weight retention in the early postpartum period, among women participating in a prospective cohort study in Alberta, Canada. Total weight gain and rate of weight gain were examined relative to women's pre-pregnancy BMI and compared with the 2010 Health Canada Gestational Weight Gain Guidelines.

## 3.2. Methods

### 3.2.1 Cohort Description

The Alberta Pregnancy Outcomes and Nutrition (APrON) study is a prospective cohort of pregnant women and their infants. Women eligible for this study were ≥ 16 years old, able to read and write in English, and ≤26 weeks gestation. Women were recruited between June 2009 and June 2010 from Edmonton and Calgary through advertisements in the media and physicians' offices. Ethics approval for this study was obtained from the Health Research Ethics Boards at the University of Alberta (Pro 00002954) and the University of Calgary (E22101). Written consent was obtained from all women prior to enrolment in the study.

### 3.2.2 Study Protocol

Based on the power calculations necessary for the analysis of different APrON sub-studies, and in order to standardize sample sizes, the first 600 women recruited were included in the initial analyses. Women recruited in their 1$^{st}$ trimester (1-13 weeks) were assessed on three occasions (once during each trimester), while those recruited during their 2$^{nd}$ trimester (14-26 weeks) were assessed twice (in 2$^{nd}$ and 3$^{rd}$ trimesters). All women were requested to return for a subsequent assessment at approximately 10-12 weeks postpartum.

At the first visit, women completed questionnaires detailing their demographic information, medical and smoking history. Pre-pregnancy weight was self-reported. Height was measured at their first visit and body weight was measured at every visit. Highest weight in pregnancy and breastfeeding duration were self-reported at the 3-month postpartum visit.

### 3.2.3 Study Variables

Weight was measured with light clothing to the nearest 0.01 kg (Healthometer Professional 752KL, Pelstar LLC, IL, USA) and height was measured to the nearest 0.1 cm using a digital stadiometer (235A Heightronic Digital Stadiometer, Quick Medical, USA) by trained research staff. Pre-pregnancy BMI was calculated as pre-pregnancy weight (kg) divided by height ($m^2$) and women were classified as underweight (<18.5), normal weight (18.5-24.9) overweight (<25.0-29) or obese (≥30) (11) according to their BMI.

Total weight gain was calculated as the difference between pre-pregnancy body weight and the highest weight reported in pregnancy. Weekly weight gain was defined as the difference between weights measured in the 2nd and 3rd trimesters of pregnancy divided by the number of intervening weeks. Postpartum weight retention was defined as the difference between postpartum body weight measured at the time of their clinic visit and pre-pregnancy body weight.

In order to assess adherence to weight gain guidelines, women were categorized into 1 of 3 groups: “Below” if they gained less than the recommended total weight; “Met” if they gained within the recommended weight range; or, “Above” if they exceeded the recommended amount of weight gain. Similarly women were classified according to their adherence to the weekly weight gain guidelines as “Below, Met or Above” based on the weekly weight gain recommendations (7).

Maternal and socio-demographic characteristics considered as covariates for weight gain in pregnancy included pre-pregnancy BMI, maternal age (16-30 years or over 30 years), parity (nulliparous (no children), primiparous (1child) or multiparous (≥2 children)), marital status (married (married/common law) or unmarried (single/divorced)), smoking status (never smoked (no smoking history) or ever smoked (women who smoked but quit prior to or during pregnancy or those who still smoked)), ethnicity (Caucasian or other (African American, Latin American, Native or Asian)), family income (low (<20k-69k/year), medium (70k-

99k/year), or high(above 100k/year)), maternal education (high school/ diploma/certificate (<high school, high school, diploma or certificate), or university degree(s)) and gestational age at term. Additional covariates considered for postpartum weight retention included breastfeeding duration (<12 weeks or >12 weeks) and exact number of postpartum weeks at the time of the postpartum visit.

### 3.2.4 Validity/Reliability

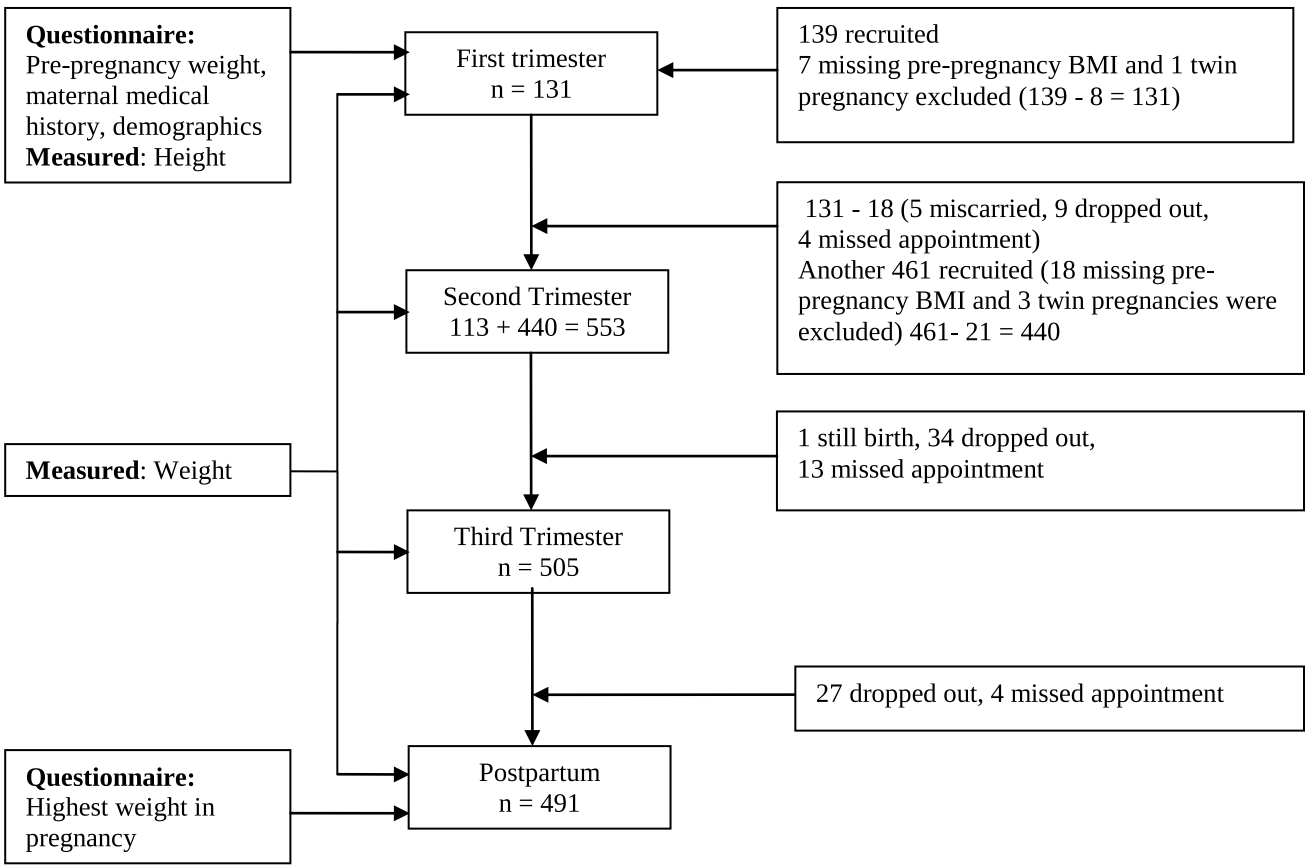
To determine the reliability of measured height and weight the % coefficient of variance (CV) was calculated. The CV for inter-rater measurement error was 0.1 cm for height and 0.1 kg for weight. To determine the validity of BMI calculated from self-reported pre-pregnancy weight, BMI was calculated using measured height and weight for the 131 participants recruited in their first trimester. A weight gain of 0.5 to 2 kg is suggested during this time (7). BMI calculated from measured data grouped women into the same categories as the BMI calculated from self- reported data for all participants in the underweight and obese categories. Of the women whose self-reported BMI was categorized as normal, 87% remained in this group and 13% were classified as overweight according to their measured BMI. Of the women who’s self-reported BMI was categorized as overweight, 85% remained in this group and 15% were classified as obese according to their measured BMI.

### 3.2.5 Statistical Analysis

Differences in total weight gain, rate of weekly weight gain and postpartum weight retention between BMI groups according to maternal /socio-demographic characteristics were tested using a one-way ANOVA with a Bonferroni correction or a Kruskal Wallis non-parametric test and Wilcoxon rank-sum test as appropriate. Multilinear regression was used to determine associations between pre-pregnancy BMI and total weight gain, between pre-pregnancy BMI and rates of weekly weight gain, and relationship between GWG and postpartum weight retention. Regression models were adjusted for covariates where noted. Adherence to total GWG and weekly weight gain recommendations by women with different pre-pregnancy BMIs was determined using multinomial logistic regression and was adjusted for covariates. In these analyses, women who had a normal pre-pregnancy BMI and who met the weight gain recommendations were used as the reference group; results are presented as adjusted odd ratios (AOR). The change in BMI between the pre-pregnancy and the postpartum period was assessed using a paired t-test. Multinomial regression analysis, adjusted for covariates, was used to assess the odds of incurring a change in BMI category in the postpartum period among women who met the guidelines or gained more total weight than is recommended in the Guidelines. Data were analysed using STATA (Version 11, StataCorp LP, TX, USA). A p value of $<0.05$ was considered statistically significant in all cases.

## 3.3 Results

**Figure 3.1: Participant Recruitment and Follow-up**



Out of the 600 women recruited in this study (139 women were recruited in their 1st trimester and another 461 women were recruited in their 2nd trimester) only 565 women were eligible for study analyses (6 women miscarried and 4 women with twin pregnancies and 25 women with missing pre-pregnancy BMI were excluded). Of these 565 women, 70 women dropped out of the study and an additional 4 women missed the postpartum visit (565-74 = 491) (Figure 3.1). Study participants were predominantly Caucasian (84%), married/ common law (93%), held university degrees (67%), and had high family incomes (53% >100K) (Table 3.1).

### 3.3.1 Total Weight Gain

Data for total weight gain in pregnancy were available for 472 women (highest body weight in pregnancy was missing for 19 women (491-19 = 472). Total weight gain was similar among women classified as underweight, normal weight, or overweight according to their pre-pregnancy BMI. Obese women gained less total weight than normal-weight women ($p < 0.01$) (Table 3.2). In multivariate models, additional characteristics that were associated with higher total weight gain were: being nulliparous vs. multiparous (adj $p < 0.05$) or having a smoking history vs. never smoked ($p < 0.05$). Being 16-30 years old was associated with higher weight gains in unadjusted analyses but did not remain significant after adjustment. Marital status, education and income were not associated with total weight gain.

Weight gain among women in the different pre-pregnancy BMI categories and all women is shown in Figure 3.2. Few women gained less weight than is recommended. Weight gain guidelines were met by 64.3%, 38%, 16.1% and 14.2 % of women in the underweight, normal, overweight and obese BMI categories respectively. Approximately 30%, 46%, 80% and 80% of women in the underweight, normal, overweight and obese BMI categories respectively gained more total weight than currently recommended. The mean weight gain by these women was 23.9 ± 3.7 kg, 20.6 ± 4.1kg, 17.7 ± 4.4 kg, and 15.4 ± 5.9 kg respectively.

After adjusting for maternal covariates, women in the obese (AOR = 6.5, $p < 0.001$, 95 % CI = 2.5-16.5) and overweight BMI categories (AOR = 5.5, $p < 0.001$, 95 % CI = 2.7-10.9) were more likely to gain in excess of the total weight gain recommendations compared to women in the normal BMI group. The following maternal characteristics were associated with gaining weight in excess of recommendations during pregnancy: having a smoking history vs. never smoked (AOR = 1.96, p = 0.01, 95 % CI = 1.18-3.26), or nulliparous vs. multiparous (AOR = 2.23, p = 0.054, 95 % CI = 0.99-5.05).

### 3.3.2 Weekly Weight Gain between 2nd and 3rd Trimester

Data for weekly weight gain in pregnancy were available for 500 women (5 missing 2$^{nd}$ trimester weight). Weekly weight gain was similar among women classified as underweight, normal weight, or overweight according to their pre-pregnancy BMI. Obese women gained less weight per week than normal weight women ($p < 0.01$) (Table 3.3). In multivariate analyses, being nulliparous vs.

multiparous (adj p <0.01) or primiparous (adj p <0.05) was associated with a higher rate of weight gain/week. Age (16-30 years old) and ethnicity (Caucasian) was associated with higher weight gain in unadjusted analyses but these were not significant after adjustment. Marital status, smoking status, education and income were not associated with weekly weight gain.

Overall, 71% of women gained above the recommended rate (0.65 ± 0.17 kg/week), 18% gained weight at the recommended rate (0.40 ± 0.08 kg/week), while 11% gained weight less quickly than recommended (0.21 ± 0.18 kg/week). Most women gained weight more quickly than is recommended: 38% in the underweight, 66% in the normal weight, 87% in the overweight, and 76% in the obese categories. The mean weight gain by these women was 0.72 ± 0.09, 0.68 ± 0.16, 0.62 ± 0.16, and 0.57 ± 0.19 kg/week respectively. In multinomial analyses, maternal and socio-demographic characteristics that were associated with gaining above the recommended rate of weekly weight guidelines were: being overweight vs. normal (AOR = 2.97, p <0.01, 95 % CI = 1.38-6.38) or being nulliparous vs. primiparous (AOR = 2.23, p <0.01, 95 % CI = 1.26-3.93).

### 3.3.3 Postpartum Weight Retention

Data for postpartum weight retention were available for 489 women (postpartum body weight was missing for 2 women). Women who retained more weight postpartum were more likely to be classified as low income ((6.3 ± 6.0 kg vs. medium income = 4.6 ± 4.9 kg (p <0.05) vs. high income = 3.9 ± 4.3 kg (p <0.01)), unmarried (8.1 ± 7.7 kg vs. married 4.3 ± 4.6 kg), or younger (16-30 years = 5.1 ± 5.3 kg vs. 31- 45 years = 4.0 ± 4.3 kg). Only income remained significant after adjusting for other covariates. There were no significant differences in weight retention among women based on pre-pregnancy BMI, parity, ethnicity, maternal education, smoking status or breastfeeding duration. Compared to women who met the total weight gain recommendations (n = 149), those who gained above the recommendations (n = 268) retained significantly more weight postpartum [(3.3 ± 3.3 kg vs. 5.9 ± 5.1 kg) (ß = 3.57, p <0.001, 95 % CI = 2.58- 4.56)], while women who gained below the recommendations (n = 57) retained less weight postpartum [(0.66 ± 2.6 kg, ß = -3.03, p <0.001, 95 % CI = -4.44- -1.62)]. When stratified by pre-pregnancy BMI and total weight gain adherence, women with pre-pregnancy BMI in the normal or overweight ranges who gained more total weight than is recommended retained more weight in the postpartum period than women who met the total weight gain recommendations (Table 3.4).

Similar results were observed when adherence to weekly weight gain recommendations was considered. Women who gained weight at rates above recommendations (n = 331) retained more body weight in the postpartum period compared to women who met (n = 87) the weekly weight guidelines [(5.4 ± 4.8 kg vs. 2.2 ± 3.8 kg) (ß = 3.32, p <0.01, 95% CI = 2.07 - 4.56)]. When stratified by pre-pregnancy BMI and weekly weight gain adherence, women whose rate of weight gain exceeded the recommendations retained more weight in the postpartum period than women who met the weekly weight gain recommendations in their respective pre-pregnancy BMI categories: normal weight women [(5.7 ± 4.3 kg vs. 2.9 ± 3.3 kg ) (ß = 2.46, $p < 0.01$, 95 % CI = 1.17- 3.75)] and obese women [(4.6 ± 6.9 kg vs. -1.4 ± 4.3) (ß = 8.6, $p < 0.01$, 95 % CI = 3.11-14.14)].

### 3.3.4 Changes in BMI from Pre-pregnancy to Postpartum

BMI increased by approximately 1.5 BMI units from pre-pregnancy to postpartum across all pre-pregnancy BMI categories ($p < 0.05$ for each) (Table 3.5). Among the women in the normal pre-pregnancy BMI group, those who gained above the total weight gain recommendations (n = 141) were more likely to move to a BMI classified as overweight in the postpartum period than women who met recommendations (n = 117; AOR = 4.1, 95% CI = 1.96-8.64); 36 % (n = 50) of women whose weight gain exceeded recommendations were categorized as overweight at the postpartum visit (Figure 3.3).

## 3.4 Discussion

The pregnancy – postpartum cycle is a critical period in the life-course of women since it has the potential to significantly affect long term weight management and predispose to chronic disease risk later in life. Our study indicates that excessive total weight gain and an accelerated rate of weight gain are common during pregnancy. To our knowledge, this is the first study to report in Canadian women that the rate of weight gain, in addition to total weight accumulated in pregnancy, exceeds recommendations, with 71% of women exceeding recommendations for the rates of weight gain during the 2$^{nd}$ and 3$^{rd}$

trimesters. Other large studies of weight gain in pregnancy have not examined this outcome (6, 12-14) as these recommendations are recent.

Although previous studies have shown that excessive weight gain is common during pregnancy (6, 12, 13), the proportion of women with excessive weight gain in the present study was higher than has been previously reported. A meta-analysis of articles published between 1990 and 2007 indicated that 42-44% of women gained weight above recommendations (6). More recent reports from the Canadian Maternity Experience Survey (12) and the Southampton Women's Survey (13) suggest that ~ 49 % of women gained above recommendations. The higher proportion of women exceeding recommendations in our study suggests the number of women meeting weight gain recommendations for pregnancy has not improved.

Our results confirm that higher pre-pregnancy BMI is a significant predictor of excessive weight gain in pregnancy. When examined by pre-pregnancy BMI categories, 80% of women with a BMI in the overweight or obese groups gained more total weight than is recommended. In fact, these women were 5.5 to 6.5 times more likely to gain weight in excess of the recommendations compared to women in the normal pre-pregnancy BMI category. Women with a pre-pregnancy BMI in the overweight or obese category are particularly vulnerable to gaining in excess of recommendations (14) and are at increased risk for antenatal and perinatal complications (2, 3). Although it is recommended that all women gain weight in pregnancy, the recommendation is that women starting at a higher BMI gain less weight. From a practical perspective, gaining only a small amount of weight in pregnancy is likely challenging. Clearly, the development of tools and intervention programs to promote healthy weight gain for all pregnant women is warranted but efforts focused specifically on those with a high pre-pregnancy BMI are most needed.

The relationship between specific maternal socio-demographic characteristics and GWG requires further investigation. Our study results indicate that nulliparous women and women with a smoking history gained more total weight in pregnancy than those who were multiparous and those who had never smoked respectively. Results from Canadian Maternity Experience Survey indicated that nulliparous women were 1.5 times more likely than multiparous women in exceeding recommended GWG (14). Previous studies have shown similar results with regards to women who had a smoking history prior to pregnancy or those who quit smoking during pregnancy, such that women with a pre-pregnancy smoking history were 5 times more likely to exceed the recommended weight gain compared to non-smokers, and women who quit smoking also gained higher weight during pregnancy than women who smoked during pregnancy (15-18).

Our findings suggest that meeting the weight gain guidelines during pregnancy may limit postpartum weight retention. In contrast, women who gained excess weight during pregnancy retained more weight at the postpartum visit than women who met the guidelines. Gaining above the recommendations has been previously associated with higher postpartum weight retention at 6 weeks (19), 5 to 9 months (14), and 10 to 18 months postpartum (20). Results from our study add an intermediate time point to the data previously reported and help better define the pattern of weight retention. Of note, among women with a normal pre-pregnancy BMI, 17% of those who met the weight gain guidelines moved up one BMI unit while 36% of those whose weight gain exceeded recommendations moved up one BMI unit at the postpartum period**.** Modification of lifestyle factors, including changes in diet, physical activity and other physiological patterns due to a changing life situation might contribute to weight retention at this time (21). Further qualitative studies examining the behavioural and lifestyle characteristics associated with weight management could be carried out, perhaps exploring behaviours of women who adhere to weight gain recommendations during pregnancy and return to pre-pregnancy weight postpartum. Importantly, the current analysis focuses on weight retention in the early postpartum period. Typically weight loss in the first 2-3 weeks postpartum is steep and is attributed to fluid loss (22), and further decline in body weight is observed until 12 months postpartum (23), following which there is an increase in body weight (5). Follow-up of pregnant women in the postpartum period is required to understand body composition changes during this time and will be possible with the data available from the ongoing prospective longitudinal cohort enrolled in APrON.

Consistent with previous findings (22), low family income was significantly associated with postpartum weight retention. Future studies focusing on women in the low income groups should explore the specific barriers that predispose them to continuing weight retention.

## Strengths and Limitations

This is one of the first prospective studies examining changes in maternal body weight during pregnancy and the early postpartum period, thus providing the most recent data in a North American context. Unlike previous studies that have relied only on body weight before pregnancy and at delivery (4, 10), we have measured body weight 2-3 times during pregnancy and once in the early postpartum. This allowed us to examine adherence to the most recent recommendations on weekly weight gain during the $2^{nd}$ and $3^{rd}$ trimesters in addition to total weight gain. Measured postpartum body weight provides an unbiased measurement of body weight and although further follow up is warranted, the information provided through this study contributes to a more thorough description of fluctuations in body weight at this time in the life course.

Self-reported pre-pregnancy body weight was used to calculate pre-pregnancy BMI. Errors in self-reported pre-pregnancy weight could overestimate total GWG and hence also overestimate the percentage of women exceeding GWG recommendations. Further although the rate of weekly weight gain between the second and third trimester is based on measured body weight, errors in self-reported pre-pregnancy weight could potentially cause errors in misclassifying women's pre-pregnancy BMI. This would result in women being categorized in a lower BMI category and hence these women will be allowed to gain a higher rate of weekly weight.  To determine the validity of self-reported pre-pregnancy weight data we calculated BMI using measured height and weight for the participants recruited in the first trimester. BMI calculated from measured data agreed with that calculated using self-reported weights and measured heights for approximately 90% of these participants.

In this study we compared changes in individual women's BMI from pre-pregnancy to postpartum using a paired t-test. By comparing the same participants BMI before and after pregnancy, we were effectively using each participant as their own control; however this method does not control the effect of regression towards the mean. Using statistical tests such as analysis of covariance (ANCOVA) would minimize this issue as it would adjust each participant's follow-up measurement according to their baseline measurement.

Another limitation of this study was missing data. Of the 565 women who were eligible for the study analysis, data on total weight gain was available for 84% of the study participants (n = 472) and data on postpartum weight retention was available for 87% (n = 489) of the study participants. Missing data can affect the quality of results observed and the interpretations and conclusions drawn from the results due to the possibility that participants with missing data might have different socio-demographics characteristics in comparison to those with complete data. A comparison of the sociodemographic characteristics of women who reported their highest weight (n = 472) with that of those women with missing highest weight and those who dropped out of the study (n = 93) was done. Results from this analyses indicated that the socio-demographic characteristics of women who reported their highest weight was similar in comparison to that of women who missed/dropped out of study except for the postpartum age (p = 0.013). Postpartum age of women who reported their highest weight in pregnancy was

11.6 ± 1.7 weeks, while that of women with missing data/dropouts was 12.6 ± 2.2 weeks.

APrON participants included in these analyses comprise a relatively homogenous group with respect to socio-demographic variables. This limited our ability to identify significant associations between total weight gain and ethnicity, maternal age, education, marital status or family income. Future investigations addressing populations at risk are warranted.

### 3.5 Conclusion

Accelerated rates of weekly weight gain and excessive total weight gain during pregnancy are common in all BMI categories which is a cause for concern. Pre-pregnancy BMI is a significant predictor of weight gain in pregnancy. Women with a pre-pregnancy BMI in the overweight or obese ranges are more likely than those with BMI in the underweight or normal ranges to gain above the recommended amounts of weight. Higher GWG predisposes women to higher postpartum weight retention across all pre-pregnancy BMI categories. Hence pregnant women, physicians and obstetricians need to implement the current weight gain guidelines and future studies may be needed to design tools and intervention programs for supporting appropriate weight gain during pregnancy. Such support may reduce the risk of incremental weight gain as a result of pregnancy and improve women's risk of weight–related disorders in later life.

**Table 3.1: Anthropometric and sociodemographic characteristics, gestational age at delivery, and breast feeding duration of women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study by pre-pregnancy BMI**

| Characteristic | n * | Underweight | Normal | Overweight | Obese |
|---|---|---|---|---|---|
| Pre-pregnancy BMI ($kg/m^2$)† | 571 | 17.7 ± 0.7 | 21.7 ± 1.6 | 26.8 ± 1.3 | 33.8 ± 3.8 |
| Height (cm)† | 571 | 168.1 ± 5.8 | 165.7 ± 6.7 | 166.5 ± 5.3 | 166.1 ± 6.6 |
| Pre-pregnancy weight (kg)† | 571 | 50.0 ± 4.6 | 59.6 ± 6.6 | 74.3 ± 6.2 | 93.3 ± 11.5 |
| Age (yrs)† | | | | | |
| 17 to 30 | 265 | 27.3 ± 3.0 | 27.9 ± 2.3 | 27.9 ± 2.7 | 27.8 ± 2.1 |
| 31 to 45 | 306 | 33.6 ± 2.7 | 34.8 ± 2.7 | 34.9 ± 3.0 | 34.4 ± 2.4 |
| Parity | | | | | |
| 0 | 305 | 3.0% | 67.8% | 16.7% | 12.5% |
| 1 | 184 | 3.3% | 60.9% | 24.5% | 11.4% |
| 2 + | 56 | 1.8% | 60.7% | 17.9% | 19.6% |

| | | | | | |
|---|---|---|---|---|---|
| Marital Status | | | | | |
| Married | 531 | 2.8% | 65.6% | 19.4% | 12.2% |
| Other | 20 | 5.3% | 52.6% | 15.8% | 26.3% |
| Smoking Status | | | | | |
| Never smoked | 372 | 3.0% | 63.1% | 19.6% | 14.2% |
| Ever smoked | 174 | 1.7% | 69.5% | 19.0% | 9.8% |
| Ethnicity | | | | | |
| Caucasian | 480 | 2.5% | 63.9% | 20.4% | 13.2% |
| Other | 70 | 5.7% | 72.6% | 11.4% | 10% |
| Family Income | | | | | |
| Low (≤ $69 000) | 106 | 6.7% | 61.9% | 200% | 11.4% |
| Medium ($70 000 - $99 000) | 135 | 2.9% | 59.3% | 18.5% | 19.3% |
| High (≥ $100 000) | 302 | 1.7% | 68.4% | 19.6% | 10.3% |
| Maternal Education | | | | | |
| High school/ diploma/certificate | 168 | 3.6% | 54.5% | 20.4% | 21.5% |
| University degree/ postgraduate degree | 382 | 2.6% | 69.8% | 18.9% | 8.7% |

| | | | | | |
|---|---|---|---|---|---|
| Gestational Age (wks)† | 508 | 38.6 ± 1.4 | 40.0 ± 1.7 | 38.8 ± 1.7 | 39.2 ± 1.4 |
| Breastfeeding | | | | | |
| > 12 weeks | 403 | 3.0% | 66.7% | 19.4% | 10.9% |
| ≤ 12 weeks | 41 | 4.9% | 51.2% | 24.4% | 19.5% |

*N = 571 (underweight = 16, normal = 373, overweight = 108, obese = 74); sample sizes within a particular characteristic may not total 571 due to missing responses.

†Values reported are mean ± S.D.

**Table 3.2: Total weight gain during pregnancy by maternal sociodemographic characteristics among women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study**

| Characteristic | n (%) (N = 472) | Total Weight Gain in Kg (mean ± SD) | ß-Coefficient‡ | 95% CI |
|---|---|---|---|---|
| Pre-pregnancy BMI category[1] | | | | |
| Underweight | 14 (2.9) | 16.8 ± 5.2 | 0.73 | −2.5-3.69 |
| Normal | 308 (65.3) | 16.3 ± 5.3 | Referent | - |
| Overweight | 94 (19.9) | 16.1 ± 5.3 | −0.13 | −1.50-1.22 |
| Obese | 56 (11.9) | 13.6 ± 6.5‖ | −2.30** | −4.04- −0.55 |
| Age (yrs)[2] | | | | |
| 17 to 30 | 220 (46.6) | 16.6 ± 5.7 | Referent | - |
| 31 to 45 | 252 (53.4) | 15.5 ± 5.3¶ | −0.13 | −1.29-1.03 |
| Parity[2] | | | | |
| 0 | 260 (55.1) | 16.4 ± 5.4 | Referent | - |
| 1 | 157 (33.3) | 15.6 ± 5.1 | −0.60 | −1.83-0.63 |
| ≥ 2 | 46 (9.7) | 13.9 ± 5.9§ | −1.91* | −3.84-0.02 |

| | | | | |
|---|---|---|---|---|
| Marital Status[1] | | | | |
| Married | 456 (96.6) | 15.9 ± 5.3 | Referent | - |
| Other | 14 (3.0) | 16.1 ± 9.9 | −1.26 | −4.68-2.16 |
| Smoking Status[2] | | | | |
| Never smoked | 307 (65.0) | 15.5 ± 5.3 | Referent | - |
| Ever smoked | 145 (30.7) | 17.0 ± 5.8¥ | 1.22* | 0.07-2.37 |
| Ethnicity[1] | | | | |
| Caucasian | 406 (86.0) | 16.2 ± 5.3 | Referent | - |
| Other | 63 (13.3) | 14.7 ± 6.5 | −1.44 | −3.07-0.18 |
| Family Income[1] | | | | |
| Low (≤ $69 000) | 86 (18.2) | 16.7 ± 7.5 | Referent | |
| Medium ($70 000-$99 000) | 117 (24.8) | 16.5 ± 5.1 | −0.05 | −1.82-1.7 |
| High (≥ $100 000) | 258 (54.7) | 15.4 ± 4.8 | −1.16 | −2.78-0.47 |
| Maternal Education[1] | | | | |
| High school/ diploma/certificate | 143 (30.3) | 16.3 ± 6.8 | 0.15 | −1.07-1.37 |
| University degree/ post graduate degree | 326 (69.1) | 15.8 ± 4.8 | Referent | - |

[1]Kruskal Wallis test and post-hoc estimation using Wilcoxon two-sample test

[2]One-way ANOVA with Bonferroni corrections

‡Multilinear regression model was adjusted for pre-pregnancy BMI, maternal age, parity, marital status, smoking status, ethnicity, family income, maternal education, and gestational age at term

‖ different from all other pre-pregnancy BMI categories, $p < 0.01$

¶ different from women aged 17-30 years, $p < 0.05$

§ different from nulliparous and primiparous women, $p < 0.05$

¥ different from women who never smoked, $p < 0.05$

[*] β-coefficient different from referent group, $p < 0.05$.

[**]β-coefficient different from referent group, $p < 0.01$.

**Table 3.3: Weekly weight gain during second and third trimester in women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study classified according to their pre-pregnancy BMI**

| Pre-pregnancy BMI | Recommended weekly weight gain (kg/wk) | n (%) (N =500) | Weekly weight gain (kg/wk; mean ± SD)[1] | ß Coefficient[2] | 95% C.I |
|---|---|---|---|---|---|
| Underweight | 0.44-0.58 | 16 (3.2) | 0.51 ± 0.19 | −0.09 | −0.20-0.02 |
| Normal | 0.35-0.50 | 326 (65.2) | 0.58 ± 0.21 | Referent | |
| Overweight | 0.23-0.33 | 100 (20) | 0.56 ± 0.22 | −0.01 | −0.06-0.03 |
| Obese | 0.17-0.27 | 58 (11.6) | 0.46 ± 0.27‖ | −0.14** | −0.20- −0.08 |

[1] One-way ANOVA was done to determine differences in weekly weight gain by maternal pre-pregnancy BMI

[2]Multilinear regression model was adjusted for pre-pregnancy BMI, maternal age, parity, marital status, smoking status, ethnicity, family income, maternal education, and gestational age at term

‖ different from women in all other pre-pregnancy BMI categories, $p < 0.01$

**β-coefficient significantly different from referent group, $p < 0.01$

**Table 3.4: Postpartum weight retention by pre-pregnancy BMI and adherence to total weight gain guidelines in women enrolled in Alberta Pregnancy Outcomes and Nutrition Study (n = 472)**

| Weight Gain Categories | Pre-pregnancy BMI | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Underweight | | Normal | | Overweight | | Obese | |
| | n | Mean ± S.D[1] | n | Mean ± S.D[1] | n | Mean ± S.D[1] | n | Mean ± S.D[†] |
| Below | 1 | 3.0 ± 0 | 50 | 0.7 ± 2.4‡ | 3 | 1.4 ± 5.1 | 3 | −1.6 ± 3.5 |
| Met | 9 | 4.7 ± 3.7 | 117 | 3.5 ± 3.0 | 15 | 1.5 ± 3.9 | 8 | 1.5 ± 3.9 |
| Above | 4 | 5.7 ± 9.0 | 141 | 7.0 ± 4.4‖ | 76 | 5.1 ± 4.8¶ | 45 | 4.3 ± 7.4 |
| Total | 14 | 4.9 ± 5.2 | 308 | 4.6 ± 4.3 | 94 | 4.6 ± 5.0 | 56 | 3.5 ± 6.5 |

[1] One-way ANOVA was done to determine significant differences in postpartum weight retention among women within each maternal pre-pregnancy BMI category

‡ significantly different from women in “Met” and “Above” categories within the same pre-pregnancy BMI group, $p < 0.001$

‖ significantly different from women in “Met” and “Below” categories within the same pre-pregnancy BMI group, $p < 0.001$

¶ significantly different from women in “Below” and “Met” categories within the same pre-pregnancy BMI group, $p < 0.05$

**Table 3.5 Changes in BMI pre-pregnancy to postpartum in women enrolled in Alberta Pregnancy Outcomes and Nutrition Study**

| | n (%) (N = 489) | Pre-pregnancy | Postpartum | p value† |
|---|---|---|---|---|
| | | Mean ± S.D | Mean ± S.D | |
| Underweight | 14 (2.9) | 17.6 ± 0.8 | 19.5 ± 1.8 | <0.001 |
| Normal | 322 (65.8) | 21.7 ± 1.6 | 23.4 ± 2.2 | <0.001 |
| Overweight | 94 (19.2) | 26.8 ± 1.3 | 28.4 ± 2.2 | <0.001 |
| Obese | 59 (12.1) | 33.7 ± 3.6 | 35.0 ± 4.2 | <0.001 |
| Total | 489 (100) | 24.0 ± 4.6 | 25.7 ± 4.8 | <0.001 |

† paired t-test

**Figure 3.2: Percentage of women in different pre-pregnancy BMI categories enrolled in the Alberta Pregnancy Outcomes and Nutrition Study who gained Below ▬ , Met ☐ , or gained Above ⬓ Health Canada 2010 recommendations for total weight gain (n = 472).**

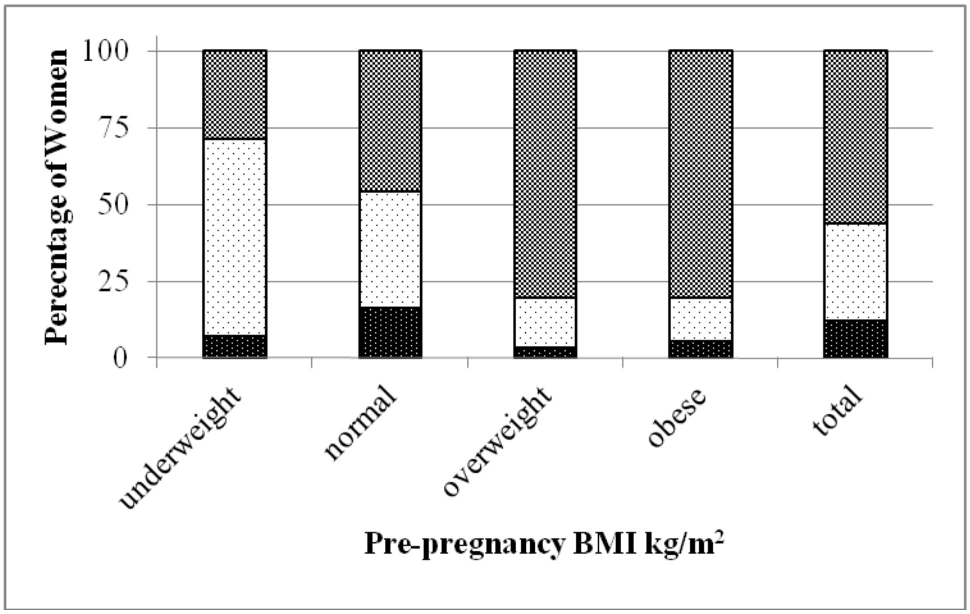
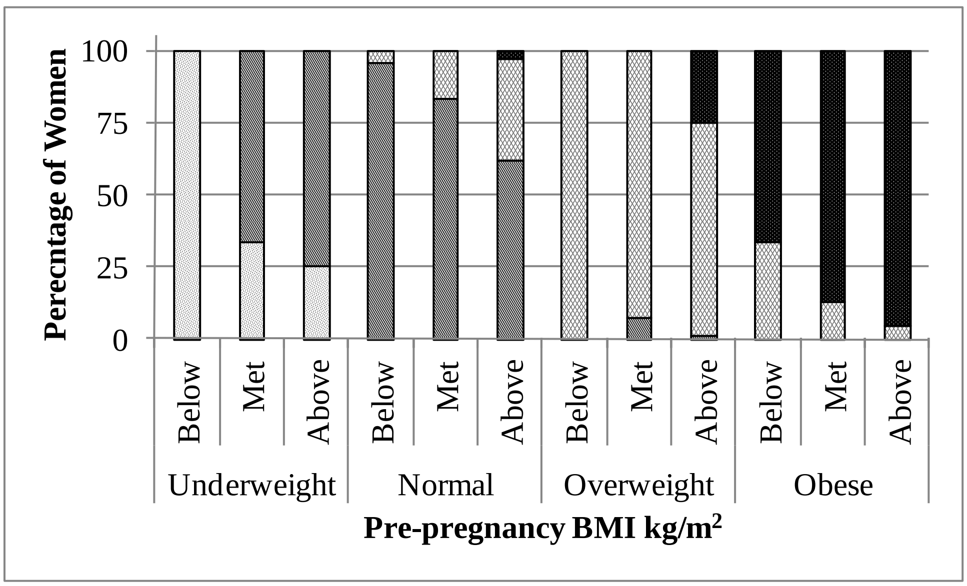


**Figure 3.3: Percentage of women in the Alberta Pregnancy Outcomes and Nutrition Study who were classified as having a BMI in the Underweight ▭, Normal ▭, Overweight ▭, or Obese ■ categories at approximately three months postpartum according to their pre-pregnancy BMI and their adherence to Health Canada 2012 recommendations for total weight gain in pregnancy (n = 472).**



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# CHAPTER 4: Fat Mass Accretion and Distribution during Pregnancy and Early Postpartum

## 4.1 Introduction

In the past three decades there has been a significant increase in the proportion of women of child bearing age being categorized as overweight or obese (1). Recent studies indicate that a high percentage of women in all pre-pregnancy BMI categories gain weight in excess of the recommended weight ranges during pregnancy (2-4). High pre-pregnancy BMI and excessive GWG are associated with greater risks of short-term complications during pregnancy and delivery, higher birth weight, adiposity in offspring's later life and risks for chronic diseases in both maternal and offspring's later life (5). Recent revisions to the recommendations for GWG have highlighted its importance for optimal pregnancy outcomes (6); however, the composition of GWG and its implications on maternal-infant health are not yet well understood. Monitoring maternal body weight is an easy and important indicator of healthy pregnancy; however, changes in weight or BMI are not solely representative of changes in fat mass. Women with different pre-pregnancy BMIs enter pregnancy with different levels of fat stores. It is therefore unclear whether changes in gestational weight are primarily caused by changes in fat mass, fat free mass, water retention or a combination of these, and whether differences in pre-pregnancy BMI influence composition of the weight gain (7, 8).

Body composition changes are a normal physiological adaptation to pregnancy, and it is expected that subcutaneous fat accumulation occurs during the first and second trimester in pregnancy in order to support maternal and fetal energy demands (9). Fat stores decrease during late pregnancy to meet increased maternal energy demands, and in the postpartum period to support lactation (10). Studies examining changes in body composition by maternal pre-pregnancy BMI are limited; they have tended to include small sample sizes or have been conducted cross-sectionally later in pregnancy or at postpartum. The probable reasons for limited research in studying body composition during pregnancy are the cost of the equipment and the invasiveness of the procedures, which may be unethical for a pregnant population; e.g. DEXA is a gold standard to measure body composition but due to the use of ionising radiation in this technique it is unsafe to be used in pregnancy (11). The use of BIA has been demonstrated as safe and easy technique to measure changes in TBW and hence to determine changes in FFM and FM during pregnancy (11), however its safety is questionable as it involves passing a low voltage electric current through the pregnant woman's body. A newer technique, the "Bod-pod" which utilizes the air-displacement plethysmography procedure to measure body composition in adult non-pregnant population is speculated to be a non-invasive and safe technique to measure body composition during pregnancy (11). But to our knowledge to date there have been no published studies reporting its use among pregnant women. Further relatively few studies have used anthropometric assessment procedures involving skin fold thickness and body circumference measurements to study body composition during pregnancy (8, 9, 12). These assessments are inexpensive, easy to perform, and provide reliable results and can be used in studying larger populations longitudinally (11, 13). Skinfold thickness is a measure of a double fold of the skin and the underlying subcutaneous adipose tissue, hence these measurements also allow to describe subcutaneous fat mass distribution (13). Waist circumference is a reliable tool for estimating intra-abdominal body fat in non-pregnant women (14) and higher intra-abdominal fat is indicative of an increased risk of chronic diseases such as cardiovascular disease and Type 2 diabetes in both men and women (15). A decrease in waist circumference has been associated with a reduction in cardiovascular risk factors (16). Waist circumference measured in women up to 16 weeks gestation is predictive of pregnancy complications such as hypertension and preeclampsia (17). Hence studying longitudinal changes in body composition, in addition to studying body weight during pregnancy will provide information on influences of maternal adiposity on maternal-infant short and long-term health outcomes.

The objectives of this study were to describe fat mass accumulation and retention during pregnancy and at early postpartum among women with different pre-pregnancy BMIs, and to describe fat mass distribution during each of these time periods. The changes in fat-free mass during pregnancy and early postpartum among these women were also described.

## 4.2 Methods

### 4.2.1 Study Design

Study participants were the first 600 pregnant women enrolled in a prospective longitudinal cohort, the Alberta Pregnancy Outcomes and Nutrition (APrON) study. Women were ≥16 years of age, able to read and write in English; and ≤ 27 weeks in gestation. Participants included in these analyses entered the study between June 2009 and March 2010 and were recruited from the cities of Edmonton and Calgary in Alberta, Canada through advertising in local media and physicians' offices. Data were collected at three visits during pregnancy corresponding to trimester 1, trimester 2 and trimester 3 in pregnancy at gestational ages (Mean ± S.D) 10.7 ± 2.3 weeks, 19.2 ± 3.7 weeks, 32.4 ± 1.4 weeks respectively and at 11.6 ± 1.8 weeks at postpartum. Ethical approval for this study was obtained from the Health Research Ethics Boards at the University of Alberta (Pro 00002954) and the University of Calgary (E22101). Women provided written and informed consent to participate in the study prior to their enrolment.

### 4.2.2 Study Variables

#### 4.2.2.1 Demographics

Women completed questionnaires detailing their demographic information, medical and smoking history prior to and during pregnancy, and breastfeeding duration. Maternal and socio-demographic characteristics considered as covariates for changes in fat mass during pregnancy and postpartum included maternal age (16 - 30 years or over 30 years), parity (nulliparous (no children), primiparous (1child) or multiparous ( ≥ 2 children)), marital status (married (married/common law) or unmarried (single/divorced)), smoking status (never smoked (no smoking history) or ever smoked (women who smoked but quit prior to or during pregnancy or those who still smoked)), ethnicity (Caucasian or other (African American, Latin American, Native or Asian)), family income (low (< 20k – 69k/year), medium (70k - 99 k/year), or high (above 100k/year)), maternal education (high school/ diploma/certificate (< high school, high school, diploma or certificate), or university degree(s)) and gestational age at term. Additional covariates at postpartum were breastfeeding duration (> 12 weeks or ≤ 12 weeks) and exact number of postpartum weeks at the time of the postpartum visit.

#### 4.2.2.2 Anthropometric Measurement

Detailed methods for the assessment of maternal height and weight have been described in Chapter 3. At each study visit weight was measured with light clothing to the nearest 0.01 kg (Healthometer Professional 752KL, Pelstar LLC, IL, USA) and height was measured to the nearest 0.1 cm using a digital stadiometer (Charder HM200P Portstad Portable Stadiometer, USA) by trained research staff. Pre-pregnancy weight was self-reported. Pre-pregnancy BMI was calculated as pre-pregnancy weight/height$^2$ (kg/m$^2$) and women were classified as underweight (< 18.5), normal (18.5 - 24.9) overweight (< 25.0 – 29) or obese (≥ 30) (18) according to their pre-pregnancy BMI.

At each study visit, skinfold thickness was measured at five sites (biceps, triceps, subscapular, suprailiac and mid- thigh) using Lange skinfold calipers (Beta Technologies, Inc., Cambridge, MD) following the procedures of Lohman et al. (1988) (13). Skinfold thickness was assessed in triplicate on the right side of each participant's body. Measurements were performed by trained research assistants, and for 75% of participants the same research assistant completed the measurements at all study time points. Body density was calculated from the sum of four skinfold thicknesses (biceps, triceps, subscapular, suprailiac ) using the Durnin and Womersley equation (19). During pregnancy, fat mass was computed from body weight and body density using a pregnancy-specific equation (Van Raaij 1988) (20). At postpartum, fat mass was calculated from body weight and body density using a non-pregnant equation (Siri, 1961) (21). The only difference between the pregnancy specific and the non-pregnant equations was, the pregnancy specific equation accounted for the variability in the density of fat-free mass that is expected during pregnancy. Fat-free mass was calculated as the difference between body weight and fat mass at each study visit.

*Total fat mass* gained was calculated as the difference between fat mass measured at trimester 1 and trimester 3 in pregnancy. *Fat mass loss* was defined as the difference between fat mass measured at trimester 3 and at the postpartum visit. *Fat retention* was defined as the difference in fat mass measured at the postpartum visit and fat mass measured at trimester 1. The *rate of fat mass gained in early pregnancy* was defined as the difference between fat mass at trimester 1 and 2 of pregnancy divided by the number of intervening weeks; similarly, the *rate of fat mass gained in late pregnancy* was defined as the difference between fat mass at trimester 2 and 3 divided by the number of intervening weeks.

Fat mass distribution during pregnancy and at postpartum were studied by examining changes in skinfold thickness (triceps, subscapula, suprailiac and thigh), waist circumference and waist:hip ratio. Waist and hip circumferences were measured in participants whose first study visit occurred at ≤ 16 weeks gestation, and the second measurement was measured in all participants at the postpartum visit using a non-elastic tape and following the procedures of Lohman et al. (1988) (13). Waist circumference was measured at the narrowest part of the torso, i.e. the smallest horizontal circumference in the area below the lower costal ribs ($10^{th}$ rib) and above the iliac crest (hip bone). Hip circumference was measured by placing the non-elastic tape around the level of maximum extension of the buttocks in a horizontal plane and taking a measurement.Waist and hip circumferences were measured to the nearest 0.1 cm (13) and waist:hip ratio was calculated as waist(cm)/hip (cm).

### 4.2.3 Reliability

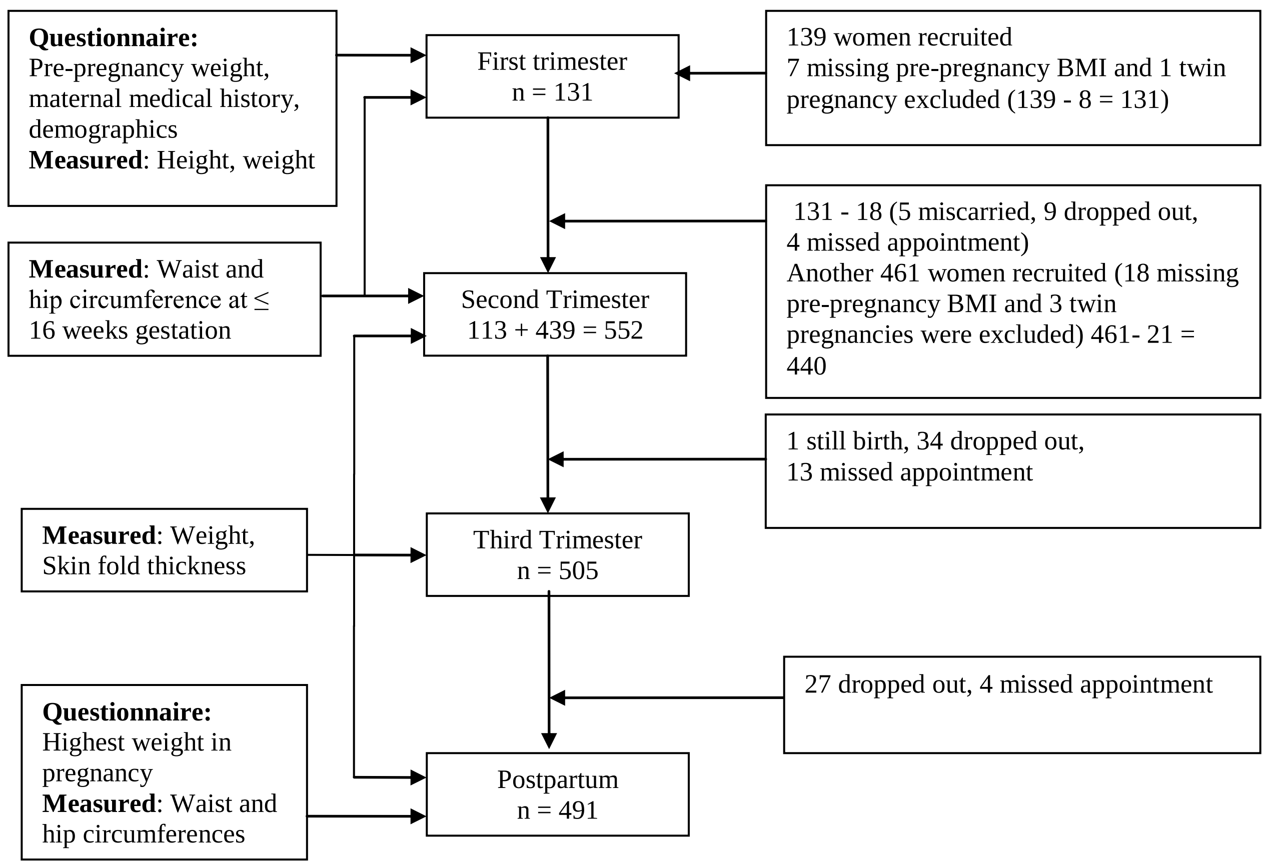
To determine the reliability of skinfold thickness measurements, the coefficient of variance (CV %) was calculated. An acceptable CV for intra-rater error and inter-rater error of 12% and 15% respectively have been reported by other investigators (22-24). Prior to beginning data collection for this study, intra-rater and inter-rater reliability for measurement of skin fold thickness by the trained research assistants on non-pregnant volunteers was assessed. The CVs for intra-rater measurement error of biceps, triceps, subscapula, suprailiac and thigh skin fold thickness (%) were 3.7, 3.3, 2.5, 3.6, and 2.8 respectively. The CVs for inter-rater measurements of biceps, triceps, subscapula, suprailiac and thigh skin fold thickness (%) were 8.2, 6.3, 6.8, 8.3 and 6.5 respectively. In order to ensure the accuracy of data being collected from the pregnant women, intra-rater reliability of skinfold thickness measurement was assessed on every 50th study participant. The CVs for intra-rater measurement error of biceps, triceps, subscapula, suprailiac and thigh skin fold thickness (%) were 6.1, 5.4, 5.2, 3.8 and 3.0 respectively. The CVs for intra-rater measurement error of skin fold thickness measurements according to each trimester in pregnancy are not reported in this study.

### 4.2.4 Statistical Analysis

Differences in total fat mass gained in pregnancy, the rate of fat mass accretion during early and late pregnancy, fat mass loss from trimester 3 to postpartum, and fat retention according to pre-pregnancy BMI categories and maternal sociodemographic variables were tested using a one-way ANOVA with a Bonferroni correction or a Kruskal-Wallis non-parametric test and Wilcoxon rank-sum test as appropriate. Longitudinal changes in observed fat mass according to maternal characteristics were tested using a univariate linear mixed model adjusted for the time of study visits (trimester1, 2, 3 and postpartum visits). The longitudinal effects of maternal pre-pregnancy BMI on fat mass were analyzed using a multivariate mixed model adjusted for the time of study visit, maternal age, parity, ethnicity, marital status, education, prenatal smoking status, family income and gestational age, breast feeding duration and postpartum period. Predictors of changes in fat mass were determined through backward elimination of variables from the above model that were not significantly associated with fat mass. Interaction between pre-pregnancy BMI and study visits with respect to changes in fat mass were tested in crude and adjusted models. Changes in skinfold thickness at different sites according to maternal pre-pregnancy BMI were tested using a linear mixed model adjusted for time of study visit. Differences in skinfold thickness according to pre-pregnancy BMI categories were tested using a one-way ANOVA with a Bonferroni correction or a Kruskal Wallis non-parametric test and Wilcoxon rank-sum test as appropriate. Data were analysed using STATA (Version 11, StataCorp LP, TX, USA). A p value of $<0.05$ was considered statistically significant in all cases

## 4.3 Results

**Figure 4.1: Participant Recruitment and Follow-up**



Study participants were predominantly Caucasian (84%), married/common-law (93%), university graduates (67%), and had high family incomes (53% >$100 000/year) (Table 4.1). Complete data were available from 131 women in their first trimester, 552 women in their second trimester, 504 women in their third trimester and 489 women at the postpartum visit. Women in the underweight pre-pregnancy BMI category were not included in the final analyses due to the small sample size (n=16).

### 4.3.1 Fat mass during pregnancy and postpartum according to pre-pregnancy BMI categories and socio-demographic variables

Women from the overweight and obese pre-pregnancy BMI groups had higher fat mass than normal-weight women ($p<0.001$) at all study visits (Figure 4.2). Women with a normal pre-pregnancy BMI showed an increase in fat mass at each study visit over the preceding visit during pregnancy ($p<0.01$). Fat mass at postpartum in these women was significantly lower than fat mass in trimester 3 during pregnancy ($p<0.01$). However, a significant amount of fat mass was retained at postpartum compared to trimester 1 in pregnancy ($p<0.01$). Among the overweight women there was no significant change in fat mass accretion in the first two trimesters in pregnancy. However, there was a significant increase in fat mass accretion in trimester 3 compared to trimester 1 or 2 during pregnancy ($p<0.05$). In these women, a decline in body fat from trimester 3 in pregnancy to postpartum was observed ($p<0.05$). Fat retained at postpartum was higher than the fat mass at trimester 1 or 2 in pregnancy ($p<0.05$). Women with an obese pre-pregnancy BMI showed no significant change in fat mass accretion in the first two trimesters in pregnancy, but their fat mass accretion in trimester 3 (Mean ± SD = 39.0 ± 5.8 kg) was marginally higher than that in trimester1 ($\beta$ = 1.33, p = 0.071, 95 % C.I = - 0.11-2.8). In addition, obese women had no significant fat loss between trimester 3 in pregnancy to postpartum; and, the observed fat mass at postpartum was similar to the fat mass at trimester 1 in pregnancy (Figure 4.2).

Table 4.2 shows the changes in fat mass by maternal sociodemographic characteristics. Women categorized under different sociodemographic characteristics showed a similar trend in fat mass change with an increase in fat mass at trimester 2 and 3 compared to trimester 1, followed by fat mass loss at postpartum. Maternal sociodemographic characteristics that were significantly associated with higher fat mass at all study visits during pregnancy and postpartum were being Caucasian vs. belonging to other ethnicity ($p<0.01$), having a medium family income vs. having low family income ($p<0.01$), having a high school/diploma education vs. a university degree ($p<0.001$) and breast feeding ≤ 12 weeks vs. >12 weeks ($p<0.001$). There was no significant difference in fat mass by maternal age, parity, smoking status or marital status ($p>0.05$) (Table 4.3).

Results from the multivariate linear mixed model indicated that after adjusting for maternal pre-pregnancy BMI and sociodemographic variables, all women showed an incremental gain in fat mass at each subsequent trimester visit compared to their fat mass in trimester 1, (trimester 2: $\beta$ =1.2, 95% C.I.= 0.6-1.7, $p<0.001$; trimester 3:$\beta$ = 3.0, 95% C.I.= 2.4-3.6, $p<0.001$) which was followed by a decline in fat mass at postpartum (β =1.3, 95% C.I.= 0.7-1.9, p<0.001). The association between higher pre-pregnancy BMI and fat mass remained significant in this model; women from the overweight (β = 7.7, 95% C.I. = 6.7 - 8.7, p<0.001) and obese (β = 16.3, 95% C.I. = 15.0 - 17.6, p<0.001) pre-pregnancy BMI groups had higher fat mass than did normal-weight women at all study visits during pregnancy and at postpartum. Maternal sociodemographic characteristics that were significantly associated with higher fat mass at all study visits during pregnancy and postpartum were being Caucasian vs. belonging to other ethnicity (β = 1.4, 95% C.I.= -2.7 - -0.2, p = 0.02) and breast feeding ≤ 12 weeks vs. >12 weeks (β = 2.4, 95% C.I. = 1.0 - 3.9, p<0.001). Having a high school/diploma education vs. a university degree was marginally associated with higher fat mass at all study visits during pregnancy and postpartum (β = 0.9, 95% C.I. = -0.01 - 1.8, p = 0.051). The association between fat mass and income was not statistically significant. Elimination of non-significant variables from the multivariate model did not change the abovementioned associations; compared to trimester 1 during pregnancy, fat mass increased in trimester 2 (β = 1.1, 95% C.I. = 0.6 - 1.7, p<0.001) and again in trimester 3 (β = 3.0, 95% C.I. = 2.5 - 3.6, p<0.001), followed by a decrease at postpartum (β = 1.4, 95 % C.I. = 0.8 - 0.1, p<0.001). Compared to normal-weight women, overweight (β = 7.5, 95 % C.I. = 6.6 - 8.5, p<0.001) and obese (β = 16.1, 95 % C.I. = 14.9 - 17.3, p<0.001) women had higher fat mass at all visits, and women from other racial ethnicities had less fat mass (β -1.4, 9 % C.I. = -2.4 - -0.2, p = 0.02) than Caucasian women. Women who breastfed for ≤ 12 weeks had more fat mass than women who breastfed for more than 12 weeks postpartum ($\beta = 2.7$, 95% C.I = 1.3 - 4.0, $p<0.001$) at all study visits. The association between high school/diploma/certificate-level education and higher body fat ($\beta = 0.9$, 95 % C.I = 0.1=1.8, $p = 0.03$) became significant after the elimination of non-significant variables.

Interactions between body fat according to BMI categories and study visits were tested in the crude and the adjusted models. Significant interactions appeared between being obese and trimester 3 study visit. Compared to normal-weight women, in the crude analysis obese women gained less fat mass at trimester 3 ($\beta = -2.3$, 95 % C.I. = -3.8- -1.02, $p = 0.001$). Adjusting for maternal socio-demographic variables did not change this association ($\beta = -2.1$, 95 % C.I. = -3.7- -0.52, $p = 0.009$).

### 4.3.2 Total Fat Mass Accretion, Fat Mass Loss and Postpartum Fat Retention

Total fat mass gain during pregnancy was similar between women with a pre-pregnancy BMI in the overweight category and normal-weight women; but obese women gained less fat mass than normal-weight or overweight women (1.5 ± 3.4 kg, n = 19) ($p<0.01$) (Table 4.3). Fat mass loss between trimester 3 in pregnancy and postpartum was similar among women in the overweight category and normal-weight women; however, obese women lost less fat mass than normal-weight women ($p<0.01$). Fat mass retention at postpartum was similar among women from all pre-pregnancy BMI categories (Table 4.3).

There was no significant difference in total fat mass accretion by any of the socio-demographic variables except maternal smoking status [compared to women who never smoked, women who ever smoked gained higher total fat mass during pregnancy ($p < 0.05$)]. Similarly significant differences in fat loss were only observed by maternal smoking status [compared to women who never smoked, women who ever smoked had higher fat loss between trimester 3 and postpartum ($p<0.05$], family income [compared to women with a higher family income, women with low family income lost less fat between trimester 3 and postpartum ($p<0.05$)], and breast feeding duration [women who breastfed >12 weeks lost more fat between trimester 3 and postpartum than did women who breastfed ≤ 12 weeks ($p<0.05$)]. Maternal age [compared to older women, younger women retained more fat mass at postpartum ($p<0.05$)], and family income [compared to women with a higher family income, women with low family income retained higher fat mass at postpartum ($p<0.05$)] were the two variables which showed significant differences in fat mass retention at postpartum (Table 4.3).

### 4.3.3 Rate of Fat Mass Accretion

The rate of fat mass accretion during early pregnancy was similar among women from the overweight (0.07 ± 0.36 kg/wk, n = 25) and obese (0.07 ± 0.36 kg/wk, n = 19) pre-pregnancy BMI groups when compared to that of normal-weight women (0.17 ± 0.21 kg/wk, n = 67).The rate of fat mass accretion during late pregnancy was also similar between women with a pre-pregnancy BMI in the overweight category (0.17 ± 0.25 kg/wk, n = 100) and normal-weight women (0.16 ± 0.29 kg/wk, n = 331); however, obese women gained fat more slowly

(0.15 ± 0.77 kg/wk, n = 58) than normal-weight or overweight women during this time ($p < 0.01$)**.**

There was no significant difference in the rate of fat mass accretion in early pregnancy irrespective of socio-demographic variables. However faster rate of fat mass accretion at late pregnancy was observed among women with the following socio-demographic characteristics: maternal age (17-30 years: 0.20 ± 0.48 kg/wk, n = 232 vs. 31-45 years: 0.13 ± 0.23 kg/wk, n = 273, $p<0.05$), parity (nulliparous: 0.17 ± 0.45 kg/wk, n = 278 vs. multiparous: 0.10 ± 0.16 kg/wk, n = 50, $p<0.05$), maternal smoking status (never smoked: 0.14 ± 0.25 kg/wk, n = 330 vs. ever smoked: 0.21 ± 0.54 kg/wk, n = 153, $p<0.05$).

### 4.3.4 Fat Mass Distribution

#### 4.3.4.1 Skinfold thickness

Table 4.4 shows the changes in skinfold thickness (triceps, subscapula, suprailiac and thigh) by pre-pregnancy BMI categories. All women from different pre-pregnancy BMI categories showed a significant increase in subscapula skinfold thickness at trimester 3 compared to their skinfold thickness at trimester1 during pregnancy ($p < 0.05$). Normal and overweight women also had significant increases in triceps, suprailiac and thigh skinfold thickness at trimester 3 compared to their skinfold thickness at trimester1 during pregnancy ($p<0.05$). Obese women did not show any significant increase in skinfold thickness at the abovementioned sites in trimester 3 compared to their trimester 1 skinfold thickness. Between trimester 3 and postpartum, normal and overweight women lost a significant amount of skinfold thickness in the triceps and thigh regions ($p \leq 0.01$); obese women showed no significant changes in these regions at this time. In addition, between trimester 3 and postpartum, normal-weight women lost significant skinfold thickness at the subscapula skin fold site. In contrast, overweight and obese women increased skinfold thickness at this site ($p \leq 0.01$). During the same time period, all women decreased skinfold thickness ($p \leq 0.01$) at the suprailiac region with greatest loss observed in the normal-weight women, followed by the overweight and obese women respectively.

The skinfold thicknesses at all sites (triceps, subscapula, suprailiac and thigh) were significantly higher among the overweight and obese women compared to normal-weight women at all study visits during pregnancy ($p<0.01$) (Table 4.5). The rate of change in all skinfold thicknesses during early pregnancy was similar among women in different pre-pregnancy BMI categories. In comparison to that of normal-weight women, the rate of change in triceps and suprailiac skinfold thickness during late pregnancy was slower among obese women ($p<0.01$), but it was similar among overweight women. There was no significant difference in the rate of change in subscapula skinfold thickness at late pregnancy among women with different pre-pregnancy BMIs. Total change in triceps and subscapula skinfold thickness during pregnancy (trimester 1-3) was similar among overweight, obese and normal-weight women; however, the total change in suprailiac skinfold thickness was significantly less in overweight and obese women than in normal-weight women ($p<0.01$). Compared to women with a normal pre-pregnancy BMI, overweight and obese women retained a significantly higher subscapula skinfold thickness at postpartum compared to trimester 3 in pregnancy ($p<0.01$). There was a similar decrease in suprailiac skinfold thickness between trimester 3 in pregnancy and postpartum among women with normal and overweight pre-pregnancy BMIs, but obese women had a smaller decrease in skinfold thickness at this site. There was no significant difference in triceps skinfold thickness between trimester 3 in pregnancy and postpartum among women with different pre-pregnancy BMIs.

#### 4.3.4.2 Waist circumference

Women with an overweight and obese pre-pregnancy BMI had significantly larger waist circumference than normal-weight women at ≤ 16 wks gestation (normal = 76.1 ± 6.3 cm, n = 168; overweight = 86.8± 5.5 cm, n = 46, $p<0.001$, obese = 98.6 ± 9.2 cm, n = 35, $p< 0.001$) and at postpartum (normal = 78.6 ± 6.4 cm, n = 322; overweight = 89.1± 10.2 cm, n = 95, $p<0.001$, obese = 101.8 ± 10.5 cm, n = 59, $p< 0.001$). The change in waist circumference from ≤ 16 wks gestation to postpartum was similar among all women (normal = 3.2 ± 5.0 cm, n = 134; overweight = 3.4 ± 5.7 cm, n = 39; obese = 4.6 ± 7.6 cm, n = 26). When stratified by pre-pregnancy BMI categories, women's waist circumferences at postpartum were significantly larger than their waist circumferences at ≤ 16 wks. This was true of normal-weight women (3.2 ± 5.0 cm, $p < 0.001$, n = 134), overweight women (3.4 ± 5.7 cm, $p <0.001$, n = 39), and obese women (4.6 ± 7.6 cm, $p <0.01$, n = 26).

#### 4.3.4.3 Waist:Hip Ratio

Compared to normal-weight women, women with an overweight pre-pregnancy BMI had similar waist:hip circumference at ≤ 16 wks gestation (normal = 0.78 ± 0.04cm, n =168; overweight = 0.79 ± 0.05, n = 46), but women with an obese pre-pregnancy BMI had a significantly larger waist:hip circumference (0.81 ± 0.06 cm, p = 0.001, n = 35). At postpartum, overweight (0.81 ± 0.09 cm, p < 0.001, n = 95) and obese (0.83 ± 0.07 cm, p < 0.001, n = 59) women had a larger waist:hip circumference than normal weight women (0.79 ± 0.05cm, n = 322). The change in waist: hip circumference from ≤ 16 wks gestation to postpartum was similar among all women (normal = 0.01 ± 0.04 cm, n= 134; overweight = 0.02 ± 0.05 cm, n = 39; obese = 0.03 ± 0.06 cm, n = 26). When stratified by pre-pregnancy BMI categories, women's waist:hip circumferences at postpartum were significantly larger than their waist:hip circumferences at ≤ 16 wks. This was true of normal-weight women (0.01 ± 0.04 cm, p = 0.01, n = 134), overweight women (0.02 ± 0.05cm, p = 0.03, n = 39) and obese women (0.03 ± 0.06 cm, p = 0.03, n = 26).

### 4.3.5 Fat-free mass during pregnancy and postpartum according to pre-pregnancy BMI categories

Women with an overweight or obese pre-pregnancy BMI had significantly higher fat-free mass than did normal-weight women at all study visits during pregnancy and at postpartum (overweight: β = 6.9, 95% C.I = 5.8 -8.0, p<0.0001) (obese: β = 15.1, 95% C.I =13.9 - 16.4, p<0.0001) (Figure 4.2). Women from all pre-pregnancy BMI groups (normal, overweight and obese) showed an increase in fat-free mass at each study visit over the preceding visit during pregnancy ($p<0.01$) which was followed by a decline in fat-free mass at postpartum ($p<0.01$). Compared to their fat-free mass at trimester 1, normal and overweight women retained significantly higher amount of fat-free mass at postpartum ($p<0.01$); while obese women showed no significant difference (Figure 4.2). Results from the multivariate linear mixed model indicated that after adjusting for maternal pre-pregnancy BMI and sociodemographic variables, all women showed an incremental gain in fat-free mass at each subsequent trimester visit compared to their fat-free mass in trimester 1, (trimester 2: $\beta$ =1.8, 95% C.I.= 1.3-2.4, $p<0.001$; trimester 3: $\beta$ = 7.3, 95% C.I.= 6.7- 7.8, $p<0.001$) which was followed by a decline in fat mass at postpartum ($\beta$ =1.5, 95% C.I.= 1.0-2.0, $p<0.001$). The association between higher pre-pregnancy BMI and fat-free mass remained significant in this model; women from the overweight ($\beta$ = 6.5, 95% C.I. = 5.4 - 7.7, $p<0.001$) and obese ($\beta$ = 14.2, 95% C.I. = 12.8 - 15.7 $p<0.001$) pre-pregnancy BMI groups had higher fat -free mass than did normal-weight women at all study visits during pregnancy and at postpartum. However the ratio of fat mass to fat-free mass (kg) was also significantly higher in the overweight and obese women at all study points during pregnancy (overweight: $\beta$ = 0.09, 95% C.I = 0.07- 0.10, $p<0.0001$) (obese: $\beta$ = 0.17, 95% C.I = 0.15 - 0.19, $p<0.0001$) as compared to that of normal-weight women.

### 4.4 Discussion

Changes in body weight along with the amount and distribution of adipose tissue are all important indicators of a healthy pregnancy. While body weight has been studied extensively, less is known about adiposity and distribution of adipose tissue in contemporary women. Studying maternal body composition during pregnancy provides insight into the implications of these changes on maternal adiposity at postpartum and the subsequent health risks associated with it.

Results from this research indicate that differences in fat mass accretion, retention and distribution were apparent according to pre-pregnancy BMI categories. Women with a normal pre-pregnancy BMI showed incremental gain in fat mass throughout their pregnancy, while overweight and obese women in the present investigation only gained fat mass significantly during the third trimester of their pregnancy. Increased adiposity during pregnancy was more likely to be associated with higher postpartum fat retention. Normal and overweight women retained significantly higher fat mass at postpartum than at trimester 1 in pregnancy. Although obese women showed no significant difference in fat retention at postpartum, they lost less fat at postpartum than did women from the other BMI categories. Moreover, overweight and obese women had less fat mobilization from the truncal and abdominal regions (9); these women retained higher fat in the subscapular, suprailiac (25) and waist regions. Thus the combined effects of lower fat loss and decreased mobilization of abdominal body fat stores could exaggerate the central adiposity which was present prior to pregnancy.

High body weight, especially higher central adiposity has been associated with increased risk for developing chronic conditions such as hypertension, type 2 diabetes, breast cancer etc. in women. A few studies have shown that maternal biological factors such as age, parity contribute to higher GWG (26, 27); however less is known about the influence of socio-economic and ethnic variability on composition of GWG. In a growing multi-cultural population with diverse lifestyle behaviours and increasing prevalence of chronic diseases studying the influences of socio-demographic factors on variations in weight gain and composition of weight gain is important. The present investigation indicated that, having a high school education, being Caucasian and having a shorter duration of breast feeding, in addition to having a higher pre-pregnancy BMI, were significantly associated with higher fat mass at all study visits during pregnancy and postpartum. A higher proportion (52%) of women in the obese pre-pregnancy BMI category had a high school/ diploma/certificate education than in the normal-weight (25%) and overweight (32%) pre-pregnancy BMI categories, but no interaction effects were observed between education and pre-pregnancy BMI on fat mass accretion. Results also indicated that a higher duration of breastfeeding was significantly associated with more fat loss at postpartum, thus indicating that breastfeeding helps in the mobilization of stored fat in the postpartum period (28).

In a comparative study of adolescent women (17.7 ± 1.3 years), Thame and colleagues found that adolescent women gained greater fat mass in pregnancy compared to older women (28.2 ± 5.2 years) (12). Although women in our study belonged to a relatively older age group than the previous study we found differences in pattern of fat mass accretion by maternal age; young adult women (27.8 ± 2.4 years) had a faster rate of fat mass accretion during late pregnancy and retained more fat mass at postpartum than did older adult women (34.7 ± 2.7 years). Study results also showed that nulliparous women had greater rate of fat mass accretion in late pregnancy, but that there was no significant difference in total fat gained in pregnancy or fat retention as observed in a previous study (29). Several studies have associated decreased lean mass and increased adiposity in infants born to women with a smoking history (30, 31). However, there is no study to our knowledge that has examined the effects of smoking on maternal body composition changes during pregnancy. Cross sectional studies of adult men and women have shown that smokers have higher waist circumference, lower BMI (32, 33) and decreased overall body fat (34) and smoking cessation is associated with higher weight gain (35, 36). Similarly, there is evidence suggesting that excessive weight gain in pregnancy is associated with smoking history prior to or during pregnancy (2, 37, 38) but it is not known if the weight gain is through increases in fat mass, lean mass or both. A recent study of postmenopausal women indicated that smoking cessation was associated with higher weight gain, fat mass, muscle mass and functional muscle mass (39). In the present study, women with a smoking history had a faster rate of fat mass accretion during late pregnancy, and a greater total fat mass, than did women who had never smoked. However, these women also lost more fat mass at postpartum. In contrast to data from studies conducted in developing countries (40) (41), our research indicated that women from low-income families lost less fat mass at postpartum and retained more fat mass than did women from high-income families.

In this study we also observed that all women irrespective of pre-pregnancy BMI categories showed an increase in FFM. Changes in FFM represent changes in maternal fluid levels, protein accretion in the mother and fetus. Although previous studies have shown that FFM is positively associated with REE (42), the contribution of changes in fluid volume and protein mass accretion is not explicit. Further changes in insulin sensitivity on FFM accretion and its implications on REE require further investigation.

**Strengths and Limitations**

In this study anthropometric assessments including skinfold thickness and body circumference measurements were used to measure changes in fat mass accretion and distribution. This technique is safe, inexpensive and easy to apply in longitudinal studies; however it may be subject to measurement errors. Hence to minimize the error associated with measurements, data were collected by trained research staff and for 75% of women the same research staff completed the measurements on all study time points. Further intra-observer error estimated for measurement of every $50^{th}$ study participant throughout the study was within the acceptable error limits.

Another limitation of this study is data on body composition in the first trimester of pregnancy were available only from a small group of women; hence examination of body composition changes in early pregnancy was limited only to these women. Further as mentioned in the results section of this chapter not all women in our study had body composition assessment at all four study visits. Body composition assessment of 131 women in their first trimester, 552 women in their second trimester, 504 women in their third trimester and 489 women at the postpartum visit was done. This was due to women missing appointments and due to dropouts. Hence to study longitudinal changes in adiposity we used the statistical technique of linear mixed methods which enabled us to utilize measured data available from all participants without excluding participants with missing data. In addition we analysed the changes in fat mass by pre-pregnancy BMI categories among a subgroup of women with data at all 4 study visits (n=111) (data not shown) using repeated measures ANOVA, and the results obtained from this approach were similar to the results discussed in this manuscript using linear mixed method analysis.

## 4.5 Conclusions

Pre-pregnancy BMI predisposes women to selective fat mass accretion and retention during pregnancy and postpartum. Total fat mass accretion and rate of fat mass gain in early and late pregnancy were similar among overweight and normal-weight women. However, obese women gained less fat mass during pregnancy and lost smaller amounts at postpartum than did normal or overweight women. Differences in subcutaneous fat mass distribution were also apparent according to pre-pregnancy BMI categories. Overweight and obese women were more likely to retain higher amounts of fat in the subscapula, suprailiac and waist regions, thus making them more susceptible to increased central adiposity. Further examination of data to investigate the influence of changes in lifestyle pattern including diet and exercise and physiological influences exerted by changing basal energy expenditure during pregnancy in addition to sociodemographic factors would help in identifying plausible causes for variations in fat mass accretion and retention according to BMI.

**Table 4.1: Anthropometric and socio-demographic characteristics, gestational age at delivery, and breast feeding duration of study participants**

| Characteristic | n [1] | Normal [2] | Overweight | Obese | P |
|---|---|---|---|---|---|
| Pre-pregnancy BMI ($kg/m^2$)[3] | 571 | 21.7 ± 1.6[b] | 26.8 ± 1.3[c] | 33.8 ± 3.8[d] | <0.001 |
| Height (cm)[3] | 571 | 165.7 ± 6.7 | 166.5 ± 5.3 | 166.1 ± 6.6 | 0.48 |
| Pre-pregnancy weight (kg)[3] | 571 | 59.6 ± 6.6[b] | 74.3 ± 6.2[c] | 93.3 ± 11.5[d] | <0.001 |
| Body weight (kg)[3] | | | | | |
| Trimester 1[4] | 131 | 60.2 ± 7.2[b] | 77.5 ± 7.3[c] | 94.7 ± 11.9[d] | <0.001 |
| Trimester 2[4] | 552 | 64.6 ± 7.9[b] | 79.1 ± 7.2[c] | 96.5 ± 10.8[d] | <0.001 |
| Trimester 3[4] | 505 | 72.2 ± 8.1[b] | 86.6 ± 7.5[c] | 103.0 ± 1.7[d] | <0.001 |
| Postpartum[4] | 489 | 64.3 ± 7.8[b] | 78.9 ± 8.3[c] | 96.3 ± 12.5[d] | <0.001 |
| Age (yrs)[3] | | | | | |
| 17 to 30 | 265 | 27.9 ± 2.3 | 27.9 ± 2.7 | 27.8 ± 2.1 | 0.88 |
| 31 to 45 | 306 | 34.8 ± 2.7 | 34.9 ± 3.0 | 34.4 ± 2.4 | 0.43 |
| Parity | | | | | |
| 0 | 305 | 31.8% | 42.5% | 29.6% | 0.31 |

| | | | | | |
|---|---|---|---|---|---|
| 1 | 184 | 58.5% | 48.1% | 54.9% | |
| 2 + | 56 | 9.7% | 9.4% | 15.5% | |
| Marital Status | | | | | |
| Married | 531 | 97.2% | 97.2% | 91.5% | 0.12 |
| Other | 20 | 2.8% | 2.8% | 8.4% | |
| Smoking Status | | | | | |
| Never smoked | 372 | 66.0% | 68.9% | 75.7% | 0.35 |
| Ever smoked | 174 | 33.4% | 31.1% | 24.3% | |
| Ethnicity | | | | | |
| Caucasian | 480 | 85.5% | 92.5% | 90.1% | 0.10 |
| Other | 70 | 14.5% | 7.5% | 9.9% | |
| Family Income [5] | | | | | |
| Low (≤ $69 000) | 106 | 18.5%[b] | 20.0%[b] | 17.4%[b] | 0.027 |
| Medium ($70 000 - $99 000) | 135 | 22.7%[a] | 23.8%[a] | 37.7%[b] | |
| High (≥ $100 000) | 302 | 58.8%[a] | 56.2%[a] | 44.9%[a] | |
| Maternal Education | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| High school/ diploma/certificate | 168 | 25.4%[a] | 32.0%[a] | 52.2%[b] | <0.001 |
| University degree/ postgraduate degree | 382 | 74.6%[a] | 68.0%[a] | 47.8%[b] | |
| Gestational Age (wks) [3] | 508 | 40.0 ± 1.7 | 38.8 ± 1.7 | 39.2 ± 1.4 | 0.38 |
| Postpartum age(wks) [3] | 489 | 11.7 ± 1.8 | 11.6 ± 1.6 | 11.5 ± 2.0 | 0.78 |
| Breast feeding duration | | | | | |
| > 12 weeks | 403 | 92.8% | 88.6% | 84.6% | 0.20 |
| ≤ 12 weeks | 41 | 7.2% | 11.4% | 15.4% | |

[1] n = 571 (underweight = 16, normal = 373, overweight = 108, obese = 74); sample sizes within a particular characteristic may not total 571 due to missing responses.

[2]Based on their pre-pregnancy BMI ($kg/m^2$) women were classified as normal (18.5 - 24.9 $kg/m^2$) overweight (< 25.0 – 29 $kg/m^2$) or obese (≥ 30 $kg/m^2$) (Health Canada, 2003).

[3] Values reported are mean ± S.D.

[4] Trimester 1 = 10.7 ± 2.3 weeks gestation, Trimester 2 = 19.2 ± 3.7 weeks gestation, Trimester 3 = 32.4 ± 1.4 weeks gestation, Postpartum = 11.6 ± 1.8 weeks postpartum

[5] Statistics Canada (2011), Median total income by family type, by census metropolitan area, CANSIM, table 111-0009. http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil107a-eng.htm

[a, b, c, d] Values with different superscripts are different from each other within a row.

**Table 4.2: Fat mass at trimester 1, 2 and 3 during pregnancy and at postpartum among women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study (APrON) study according to pre-pregnancy BMI and maternal sociodemographic characteristic**

| Characteristic | Fat Mass (kg)[1,2] | | | | β (95% C.I)[4] | p value |
|---|---|---|---|---|---|---|
| | Trimester 1[3] | Trimester 2 | Trimester 3 | Postpartum | | |
| Age (yrs) | | | | | | |
| 17 to 30 | 23.5±9.5 (66) | 24.1±7.8[a] (252) | 26.3±7.5[a,b] (233) | 24.7±8.2[a,b,c] (226) | Reference | |
| 31 to 45 | 24.7±8.1 (65) | 24.2±7.2[a] (300) | 25.8±7.0[a,b] (271) | 24.0±7.4[a,c] (263) | -0.26 (-1.51-0.99) | 0.68 |
| Parity | | | | | | |
| 0 | 22.5±8.2 (57) | 24.2±7.6[a] (298) | 26.2±7.5[a,b] (278) | 24.3±7.9[a,c] (271) | Reference | |
| 1 | 25.5±9.5 (60) | 23.9±6.8[a] (176) | 25.7±6.6[a,b] (165) | 24.0±7.2[a,c] (159) | 0.006 (-1.38-1.39) | 0.99 |
| ≥ 2[5] | 27.7±6.5 (8) | 25.1±8.8 (55) | 26.5±8.5[a,b] (50) | 25.5±9.2[c] (49) | 0.97 (-1.20-3.13) | 0.38 |
| Marital Status | | | | | | |
| Married | 24.1±8.8 (123) | 24.0±7.3[a] (515) | 25.9±7.1[a,b] (484) | 24.2±7.7[c] (472) | Reference | |
| Other | 31.2±11.8 (2) | 26.8±10.4 (20) | 29.9±10.9[a,b] (16) | 27.1±9.6[c] (15) | 2.88 (-0.49-6.25) | 0.094 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Smoking Status | | | | | | |
| Never smoked | 24.7±9.4 (79) | 24.6±7.8[a] (361) | 26.2±7.3[a,b] (329) | 24.6±7.9[a,c] (319) | Reference | |
| Ever smoked | 23.1±8.0 (45) | 23.4±7.0[a] (168) | 25.7±7.3[a,b] (153) | 23.6±7.6[a,c] (150) | -1.08 (-2.45-0.30) | 0.13 |
| Ethnicity | | | | | | |
| Caucasian | 24.6±8.9 (113) | 24.4±7.5[a] (465) | 26.4±7.3[a,b] (432) | 24.6±7.8[a,c] (421) | Reference | |
| Other | 20.5±8.5 (12) | 22.1±7.1 (70) | 23.5±6.8[a,b] (68) | 22.4±7.4[c] (66) | -2.78 (-4.64- -0.91) | 0.004 |
| Family Income | | | | | | |
| Low (≤ $69 000) | 20.7± 5.5 (20) | 23.3±7.6[a] (103) | 25.1±7.0[a,b] (93) | 24.3±7.9[a,b,c] (90) | Reference | |
| Medium ($70 000-$99 000) | 28.4±10.2 (34) | 25.4±7.8 (130) | 27.5±7.5[a,b] (118) | 26.0±8.4[c] (121) | 2.79 (0.89-4.69) | 0.004 |
| High (≥ $100 000) | 23.2±8.4 (69) | 23.8±7.1[a] (294) | 25.7±7.1[a,b] (280) | 23.6±7.4[a,c] (268) | 0.69 (-0.96-2.33) | 0.41 |
| Maternal Education | | | | | | |
| University degree/ post graduate degree | 22.7±7.9 (89) | 23.3±6.9[a] (373) | 25.3±6.8[a,b] (356) | 23.6±7.3[a,c] (341) | Reference | |
| High school/ diploma/certificate[6] | 27.3±9.8 (35) | 25.9±8.4 (162) | 27.8±8.2[a,b] (144) | 26.0±8.6[a,c] (146) | 3.14 (1.81-4.48) | <0.001 |
| Breastfeeding Duration | | | | | | |
| >12weeks | 23.2±7.9 (90) | 23.7±6.9[a] (399) | 25.6±6.9[a,b] (393) | 23.8±7.3[a,c] (399) | Reference | |
| ≤12 weeks | 31.1±9.9 (8) | 28.0±9.2 (41) | 29.5±8.1[a, b] (40) | 28.6±9.7 (41) | 4.14 (1.89-6.41) | <0.001 |

[1] Univariate linear mixed model analysis; data was stratified by each maternal characteristic and adjusted for study visit (Trimester 1, 2 and 3 and postpartum visit)

[2] Fat mass reported as Mean ± S.D

[3] Trimester1 = 10.7 ± 2.3 weeks gestation, Trimester 2 = 19.2 ± 3.7 weeks gestation, Trimester 3 = 32.4 ± 1.4 weeks gestation, Postpartum = 11.6 ± 1.8 weeks postpartum

[4]Univariate linear mixed model analysis, data was adjusted for study visits (Trimester 1, 2 and 3 and postpartum visit)

[5]Marginal difference between Trimester1 and 3, $p = 0.054$

[6]Marginal difference between Trimester1 and postpartum, $p=0.058$

[a] Significantly different from Trimester 1 within a characteristic, $p \leq 0.01$

[b] Significantly different from Trimester 2 within a characteristic, $p \leq 0.01$

[c] Significantly different from Trimester 3 within a characteristic, $p \leq 0.01$

**Table 4.3: Observed change in fat mass (kg) during pregnancy and postpartum among women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study (APrON) study by pre-pregnancy BMI**

| Characteristics | Observed change in fat mass (kg) Mean ± S.D (n) | | | | | |
|---|---|---|---|---|---|---|
| | Total Fat Mass Accretion | | Fat Loss | | Fat Retention | |
| | Mean ± S.D | p value | Mean ± S.D | p value | Mean ± S.D | p value |
| Pre-pregnancy BMI | | | | | | |
| Normal | 3.5 ± 2.2[a] (65) | 0.035[1] | - 2.0 ± 2.8[a] (314) | 0.003[1] | 1.8 ± 2.9 (65) | 0.29[1] |
| Overweight | 2.5 ± 3.0[a] (23) | | -1.4 ± 3.7[ab] (92) | | 2.4 ± 3.4 (23) | |
| Obese | 1.5 ± 3.4[b] (19) | | - 0.3 ± 3.9[b] (57) | | 1.3 ± 4.7 (19) | |
| Age (yrs) | | | | | | |
| 17 to 30 | 2.9 ± 3.1 (52) | 0.99[2] | -1.7 ± 3.3 (220) | 0.98[2] | 2.7 ± 3.6 (50) | 0.02[2] |
| 31 to 45 | 2.9 ± 2.4 (57) | | -1.7 ± 3.1 (257) | | 1.2 ± 3.0 (58) | |
| Parity | | | | | | |
| 0 | 3.1 ± 2.6 (50) | 0.36[2] | -1.8 ± 3.3 (266) | 0.27[2] | 1.5 ± 3.5 (49) | 0.53[2] |
| 1 | 3.0 ± 2.9 (49) | | -1.6 ± 3.1 (154) | | 2.2 ± 3.3 (50) | |
| 2 | 1.5 ± 2.1 (7) | | -1.0 ± 2.9 (48) | | 1.7 ± 3.0 (7) | |
| Marital Status | | | | | | |
| Married | 2.9 ± 2.8 (106) | 0.86[2] | -1.7 ± 3.2 (461) | 0.56[2] | 1.9 ± 3.3 (107) | 0.15[2] |
| Other | 2.4 ± 0 (1) | | -1.2 ± 3.2 (15) | | -2.9 ± 0 (1) | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Smoking Status | | | | | | |
| Never smoked | 2.3 ± 2.8 (64) | 0.003[2] | -1.5 ± 3.3 (310) | 0.03[1] | 1.8 ± 2.9 (64) | 0.68[1] |
| Ever smoked | 4.0 ± 2.3 (39) | | -2.2 ± 2.7 (147) | | 1.8 ± 3.9 (39) | |
| Ethnicity | | | | | | |
| Caucasian | 2.9 ± 2.8 (96) | 0.86[2] | -1.7 ± 3.2 (413) | 0.41[2] | 1.8 ± 3.4 (97) | 0.51[2] |
| Other | 3.0 ± 2.2 (11) | | -1.4 ± 2.9 (63) | | 2.5 ± 2.5 (11) | |
| Family Income | | | | | | |
| Low (≤ $69 000) | 4.0 ± 1.9 (17) | 0.51[2] | -0.84 ± 2.8[a] (87) | 0.003[1] | 3.8 ± 2.8[a] (17) | 0.01[2] |
| Medium ($70 000-$99 000) | 2.8 ± 3.1 (29) | | -1.47 ± 3.8[ab] (118) | | 1.8 ± 4.0[ab] (28) | |
| High (≥ $100 000) | 2.5 ± 2.7 59 | | -2.03 ± 2.9[b] (263) | | 1.2 ± 2.8[b] (61) | |
| Education | | | | | | |
| High school/ diploma/ certificate | 2.7 ± 3.1 (28) | 0.65[2] | -1.4 ± 3.6 (142) | 0.36[1] | 2.0 ± 4.1 (30) | 0.86[2] |
| University degree/ post graduate degree | 3.0 ± 2.7 (79) | | -1.8 ± 3.0 (334) | | 1.8 ± 3.0 (78) | |
| Breastfeeding | | | | | | |
| >12 weeks | 3.0 ± 2.7 (88) | 0.69[2] | -1.8 ± 2.9 (390) | 0.002[1] | 1.7 ± 3.2 (90) | 0.18[2] |
| ≤ 12 weeks | 2.6 ± 3.2 (8) | | -0.15 ± 4.8 (41) | | 3.3 ± 3.8 (8) | |

[1] Kruskal-Wallis non parametric test and post-hoc estimation by two-sample Wilcoxon rank-sum test

[2] One-way ANOVA with a Bonferroni correction

**Table 4.4: Skinfold thickness at trimester 1, 2 and 3 during pregnancy and at postpartum by pre-pregnancy BMI categories**

| Skinfold | Pre-pregnancy BMI | Skinfold thickness (mm) Mean ± S.D (n) [1] | | | | β[3] | p value |
|---|---|---|---|---|---|---|---|
| | | Trimester 1[2] | Trimester 2 | Trimester 3 | Postpartum | | |
| Triceps | Normal | 19.0 ± 4.4 (77) | 20.9 ± 5.0[a] (364) | 22.1 ± 5.2[a,b] (330) | 21.1 ± 5.5[a,c] (322) | Reference | |
| | Overweight [#] | 25.7 ± 4.6 (27) | 26.5 ± 5.3 (106) | 27.7 ± 5.5[a,b] (100) | 25.9 ± 6.0[c] (95) | 5.4 (4.4-6.3) | <0.001 |
| | Obese | 31.2 ± 4.8 (25) | 32.8 ± 6.2 (68) | 31.3 ± 6.3 (58) | 31.1 ± 6.2[b] (62) | 10.8 (9.6-11.9) | <0.001 |
| Subscapula | Normal | 12.4 ± 4.0 (77) | 14.3 ± 5.2[a] (363) | 16.7 ± 5.3[a,b] (328) | 15.4 ± 5.3[a,b,c] (321) | Reference | |
| | Overweight | 19.8 ± 5.9 (26) | 19.4 ± 5.9 (106) | 21.2 ± 6.0[a,b] (100) | 22.5 ± 6.6[a,b,c] (95) | 5.4 (4.4-6.4) | <0.001 |
| | Obese | 25.2 ± 6.7 (24) | 24.9 ± 6.4 (68) | 26.2 ± 6.6[b] (58) | 27.9 ± 6.6[a,b,c] (59) | 11.0 (9.8-12.2) | <0.001 |
| Suprailiac | Normal | 21.2 ± 7.4 (77) | 24.7 ± 6.8[a] (363) | 27.3 ± 6.7[a,b] (323) | 22.1 ± 6.4[b,c] (321) | Reference | |
| | Overweight | 30.9 ± 7.5 (27) | 30.7 ±7.9 (106) | 32.9 ± 7.0[a,b] (99) | 29.4 ± 5.6[c] (95) | 6.3 (5.1-7.6) | <0.001 |
| | Obese | 35.9 ± 8.8 (25) | 35.0 ± 7.9 (68) | 35.5 ± 7.9 (58) | 33.2 ± 6.9[a,c] (59) | 10.5 (9.1-12.0) | <0.001 |
| Thigh | Normal | 27.1 ± 8.1 (76) | 30.3 ± 8.4[a] (356) | 33.0 ± 8.2[a,b] (326) | 31.1 ± 7.5[a,b,c] (320) | Reference | |
| | Overweight | 37.5 ± 8.2 (27) | 36.5 ± 9.2 (101) | 40.2 ± 8.7[a,b] (96) | 37.2 ± 8.0[c] (94) | 6.5 (5.2-8.1) | <0.001 |
| | Obese[†] | 44.2 ± 8.6 (22) | 46.7 ± 8.4[a] (65) | 44.6 ± 9.4 (55) | 44.1 ± 8.6[b] (57) | 14.5 (12.7-16.4) | <0.001 |

[1] Univariate linear mixed model analysis, data was stratified by pre-pregnancy BMI categories for each skinfold site and adjusted for study visit (Trimester1, 2 and 3 and postpartum visit)

[2] Trimester 1 = 10.7 ± 2.3 weeks gestation, Trimester 2 = 19.2 ± 3.7 weeks gestation, Trimester 3 = 32.4 ± 1.4 weeks gestation, postpartum = 11.6 ± 1.8 weeks postpartum

[3]Univariate linear mixed model analysis, data was adjusted for study visits (Trimester1, 2 and 3 and postpartum visit)

[a] Significantly different from Trimester 1 within a characteristic, $p \leq 0.01$

[b] Significantly different from Trimester 2 within a characteristic, $p \leq 0.01$

[c] Significantly different from Trimester 3 within a characteristic, $p \leq 0.01$

[#]Marginal difference between Trimester 2 and 3, $p = 0.053$

[†] Marginal difference between Trimester 2 and 4, $p = 0.054$

**Table 4.5: Rate of change in skinfold thickness (mm/wk) during pregnancy according to pre-pregnancy BMI categories**

| Skinfold | Pre-pregnancy BMI | Rate of change in skinfold thickness (mm/wk) | | | |
|---|---|---|---|---|---|
| | | Early Pregnancy | | Late Pregnancy | |
| | | Mean ± S.D (n) | p value | Mean ± S.D (n) | p value |
| Triceps | Normal | 0.09 ± 0.43 (68) | 0.65[1] | 0.10 ± 0.37[a] (327) | 0.0003[1] |
| | Overweight | 0.20 ± 0.71 (25) | | 0.11 ± 0.47[a] (100) | |
| | Obese | 0.19 ± 0.73 (19) | | -0.11 ± 0.47[b] (58) | |
| Subscapula | Normal | 0.20 ± 0.77 (68) | 0.27[2] | 0.17 ± 0.36 (324) | 0.59[1] |
| | Overweight | 0.004 ± 0.54 (24) | | 0.13 ± 0.47 (100) | |
| | Obese | - 0.05 ± 0.55 (19) | | 0.14 ± 0.53 (58) | |
| Suprailiac | Normal | 0.25 ± 0.92 (68) | 0.29[2] | 0.21 ± 0.57[a] (320) | 0.02[1] |
| | Overweight | 0.05 ± 1.13 (25) | | 0.14 ± 0.64[ab] (99) | |
| | Obese | - 0.15 ± 1.29 (19) | | 0.06 ± 0.99[b] (58) | |
| Thigh | Normal | 0.14 ± 0.82 (67) | 0.84[2] | 0.22 ± 0.55[a] (315) | 0.002[1] |
| | Overweight | 0.01 ± 1.10 (24) | | 0.31 ± 0.80[a] (92) | |
| | Obese | 0.10 ± 0.78 (17) | | - 0.10 ± 0.85[b] (53) | |

[1] Kruskal-Wallis non parametric test and post-hoc estimation by two-sample Wilcoxon rank-sum test

[2] One-way ANOVA with a Bonferroni correction

**Table 4.6: Observed change in skinfold thickness (mm) during pregnancy and postpartum by pre-pregnancy BMI**

| Skinfold | Pre-pregnancy BMI | Observed change in skinfold thickness (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Trimester 1 - 3 | | Trimester 1 - Postpartum | | Trimester 3 - Postpartum | |
| | | Mean ± S.D (n) | p value | Mean ± S.D (n) | p value | Mean ± S.D (n) | p value |
| Triceps | Normal | 2.00 ± 4.47 (65) | 0.58[1] | 1.68 ± 4.25 (65) | 0.68[2] | -1.06 ± 5.14 (313) | 0.62[2] |
| | Overweight | 0.72 ± 4.99 (23) | | 2.33 ± 6.23 (23) | | -1.38 ± 5.98 (93) | |
| | Obese | 1.78 ± 6.86 (19) | | 0.94 ± 7.15 (19) | | - 0.44 ± 7.50 (57) | |
| Subscapula | Normal | 3.93 ± 3.64 (65) | 0.22[1] | 2.43 ± 4.71 (65) | 0.12[1] | -1.31 ± 4.31[a] (310) | 0.001[2] |
| | Overweight | 2.49 ± 3.96 (23) | | 5.08 ± 6.30 (22) | | 1.49 ± 5.99[b] (93) | |
| | Obese | 2.69 ± 4.69 (19) | | 3.69 ± 5.67 (19) | | 1.70 ± 5.76[b] (57) | |
| Suprailiac | Normal | 5.18 ± 6.64[a] (64) | 0.001[1] | 0.62 ± 7.25 (65) | 0.37[2] | -5.19 ± 6.28[a] (306) | 0.007[1] |
| | Overweight | 1.63 ± 6.86[ab] (23) | | - 0.87± 6.09 (23) | | -3.54 ± 7.20[ab] (92) | |
| | Obese | -2.91 ± 9.29[b] (19) | | -1.85 ± 8.63 (19) | | -2.25 ± 7.64[b] (57) | |
| Thigh | Normal | 4.71 ± 6.91 (64) | 0.24[1] | 4.17 ± 7.29 (63) | 0.27[1] | -2.06 ± 7.21 (307) | 0.59[2] |
| | Overweight | 2.25 ± 9.17 (23) | | 1.76 ± 9.02 (23) | | -2.58 ± 9.12 (93) | |
| | Obese | 1.98 ± 7.30 (17) | | 1.17 ± 10.45 (18) | | -0.75 ± 9.63 (54) | |

[1] One-way ANOVA with a Bonferroni correction

[2] Kruskal-Wallis non parametric test and post-hoc estimation by two-sample Wilcoxon rank-sum test

**Figure 4.2: Fat mass (unadjusted mean ± S.D) during pregnancy and early postpartum among women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study (APrON) who were classified as having a pre-pregnancy BMI in the Normal ( —◆—), Overweight ( —■—), or Obese (—▲—) categories.**

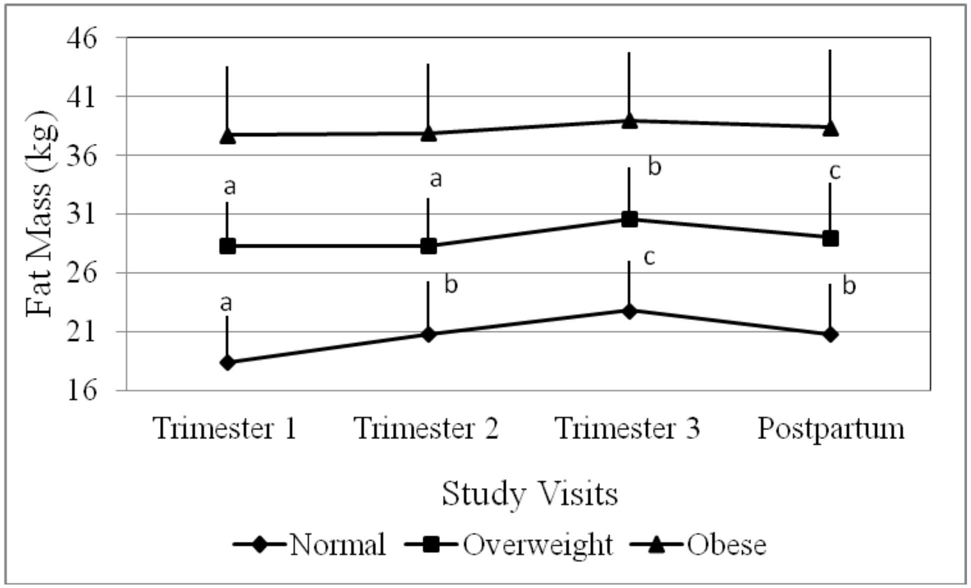
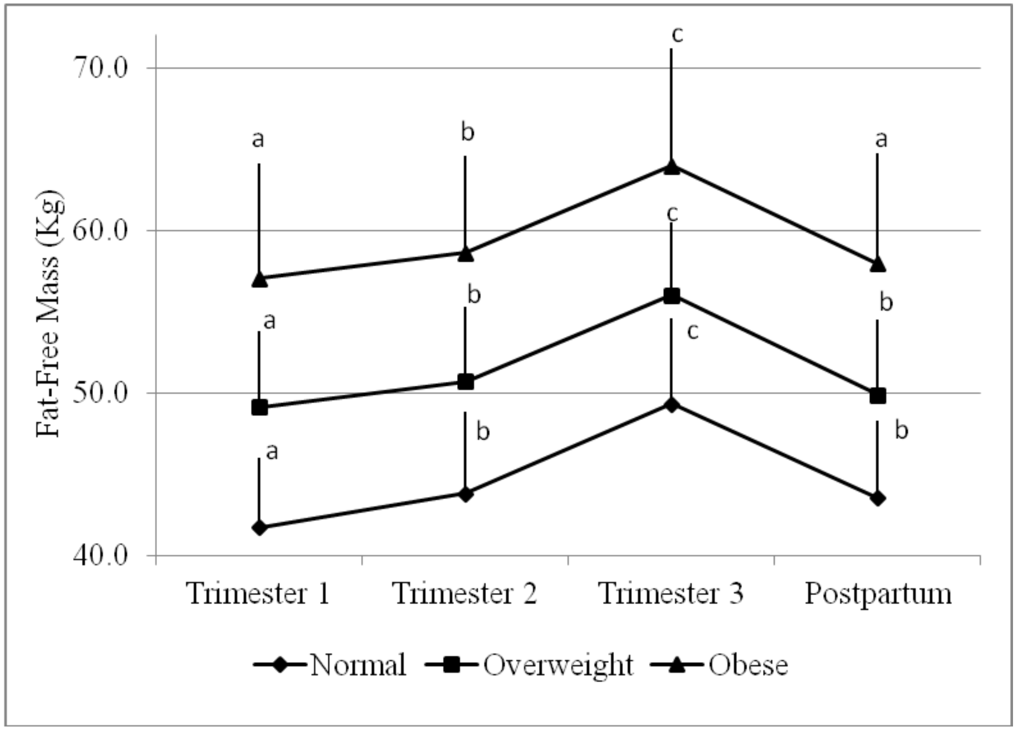


**Figure 4.3: Fat-free mass (unadjusted mean ± S.D) during pregnancy and early postpartum among women enrolled in the Alberta Pregnancy Outcomes and Nutrition Study (APrON) who were classified as having a pre-pregnancy BMI in the Normal ( ─◆─), Overweight ( ─■─), or Obese (─▲─) categories**



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# CHAPTER 5: Energy and Macronutrient Intake, Physical Activity and Resting Energy Expenditure and Their Association with Body Composition Changes during Pregnancy

## 5.1 Introduction

One half of Canadian women in childbearing age enter pregnancy with excessive body weight and adiposity (1). These women are also more likely to exceed gestational weight above clinical recommendations (2), thus increasing the risk for short and long-term health impairments in the mother and her infant (3). Data from the literature provide strong evidence that increased risk of excessive GWG is strongly associated with maternal pre-pregnancy BMI (2-5). A few recent studies have also indicated that sociodemographic variables such as maternal age and parity are also associated with excessive weight gain in pregnancy (5, 6). However, limited longitudinal data examining the influence of energy intake and expenditure on weight gain and changes in adiposity during pregnancy are available. Results from studies in the past have demonstrated an association between GWG and energy intake (7-9).

Nevertheless, evidence in the literature is insufficient to draw conclusions about the influence of energy intake and expenditure on GWG (2). This is a key gap in the literature, given the importance and complexity of these variables. Pregnancy is a period associated with an increased demand for energy, the total energy cost of pregnancy being ~71654 kcal (10). This increased need for energy is essential to support fetal growth, to allow for the synthesis of new maternal tissues and fat stores which support fetal growth and lactation, and to provide for maternal basal metabolic energy demands (11). The energy requirement of pregnancy may be influenced by maternal nutritional status prior to pregnancy (e.g., fat stores) (12, 13); by lifestyle factors such as quality and quantity of diet and physical activity; by the presence of chronic diseases; and by individual metabolic adaptations during pregnancy. There is vast variability in how the increased energy demands are met; it may be achieved by increasing energy intake and/or decreasing physical activity energy expenditure and modifying basal energy requirements (11, 14).

Longitudinal assessments of energy intake and physical activity expenditure have been limited to studies with very few study participants (11, 14, 15); but in these studies, variations in energy intake/ expenditure by maternal pre-pregnancy BMI have not been understood well. The association between maternal pre-pregnancy BMI and basal energy requirements remains unclear. Studies indicate that undernourished women slow their basal energy requirements, while well-nourished women show increased metabolic rate; again these studies are limited by small sample size (16). Hence, examining longitudinal changes in diet, physical activity and basal energy expenditure during pregnancy could help in identifying the reasons for excessive weight gain and adiposity during pregnancy.

The objective of this study, accordingly, was to describe changes in energy intake, physical activity and resting energy expenditure among women with different pre-pregnancy BMIs, and to examine the associations between longitudinal changes in energy intake, physical activity and resting energy expenditure with changes in fat mass and adherence to weight gain recommendations during pregnancy.

## 5.2 Methods

### 5.2.1 Study Design

Study participants were the first 600 pregnant women enrolled in a prospective longitudinal cohort, the Alberta Pregnancy Outcomes and Nutrition (APrON) study. The women were ≥16 years of age, able to read and write in English and ≤ 27 weeks in gestation, and they resided in the metropolitan areas of Edmonton and Calgary, Alberta, Canada. Participants included in these analyses entered the study between June 2009 and March 2010 and were recruited by advertising in local media and physicians' offices. Data were collected at three visits during pregnancy corresponding to trimester 1, trimester 2 and trimester 3 in pregnancy at gestational ages (Mean ± S.D) 10.7 ± 2.3 weeks, 19.2 ± 3.7 weeks, 32.4 ± 1.4 weeks respectively and at 11.6 ± 1.8 weeks at postpartum. Data on anthropometrics, dietary intake and physical activity were collected at each study visit. Ethical approval for this study was obtained from the Health Research Ethics Boards at the University of Alberta (Pro 00002954) and the University of Calgary (E22101). All women provided their written and informed consent for participation in the study prior to enrolment.

### 5.2.2 Study Variables

#### 5.2.2.1 Demographics

Women completed questionnaires detailing their demographic information, and their medical and smoking history prior to and during pregnancy. Maternal and socio-demographic characteristics considered as covariates for change in fat mass and adherence to GWG guidelines included maternal age (16 - 30 years or over 30 years), parity (nulliparous (no children), primiparous (1child) or multiparous ( ≥ 2 children)), marital status (married (married/common law) or unmarried (single/divorced)), smoking status (never smoked (no smoking history) or ever smoked (women who smoked but quit prior to or during pregnancy or those who still smoked)), ethnicity (Caucasian or other (African American, Latin American, Native or Asian)), family income (low (< 20k – 69k/year), medium (70k - 99 k/year), or high (above 100k/year)), maternal education (high school/ diploma/certificate (< high school, high school, diploma or certificate), or university degree(s)) and gestational age at term.

#### 5.2.2.2 Anthropometric Measurement

Weight was measured with light clothing to the nearest 0.01 kg (Healthometer Professional 752KL, Pelstar LLC, IL, USA), and height was measured to the nearest 0.1 cm by trained research staff using a digital stadiometer (Charder HM200P Portstad Portable Stadiometer, USA). Pre-pregnancy weight and the highest weight during pregnancy were self-reported. Pre-pregnancy BMI was calculated as pre-pregnancy weight (kg) divided by height ($m^2$), and women were classified as underweight (< 18.5), normal (18.5 - 24.9) overweight (< 25.0 – 29) or obese (≥ 30) according to their pre-pregnancy BMI (17). GWG was calculated as the difference between pre-pregnancy body weight and the highest weight during pregnancy. Women with different pre-pregnancy BMIs were categorised based on whether they were "Below," "Met" or "Above" the Health Canada 2010 guidelines for total GWG, detailed method for classification has been described in Chapter 3.

Skinfold thickness was measured at four sites (biceps, triceps, sub scapular, suprailiac) using Lange skinfold calipers (Beta Technologies, Inc., Cambridge, MD) following the procedures of Lohman et al (1988) (18). Body density was calculated from the sum of four skinfold thicknesses (biceps, triceps, subscapular, suprailiac) using the Durnin and Womersley equation (19). Fat mass was computed from body weight and body density using a pregnancy-specific equation (20). Fat-free mass was calculated as the difference between body weight and fat mass at each study visit.

### 5.2.2.3 Energy and Macronutrient Intake

Dietary intake was assessed using the food recall interview conducted by trained research assistants using the “multiple pass method” (21). Women were asked to describe in detail the type and amount of all food consumed in the previous 24-hour period (midnight to midnight). Food models helped women estimate portion sizes, and probes included details such as cooking methods, location and time of eating, and food brand names. All of the information was reviewed with the women to ensure that it had been correctly recorded. Data were entered using nutritional software (ESHA Food Processor version 10.6.0, Salem, OR, USA). Energy and macronutrient intake was evaluated using the USDA National Nutrient Database (Release 22) (22) and Canadian Nutrient File (version 2010) (23).

Estimated energy intake (EER) (Kcal/day) during each trimester in pregnancy for women aged 19 years and older was calculated using equations provided by the IOM (24). A PA (physical activity coefficient) of 1.16 was applied which represents moderate daily physical activity for 30-60 minutes.

EER1 (trimester1) = 354 - (691 x age[y]) + PA x (9.36 x pre-pregnancy weight [kg]) + (726 x height [m])

EER 2 (trimester 2) = EER1+ 340

EER 3 (trimester3) = EER1 + 452

The macronutrient (carbohydrate, protein and fibre) intake of the participants was evaluated using the recommended dietary allowance (RDA) for macronutrients, and the fat intake was compared to the adequate macronutrient distribution range (AMDR) defined by the Food and Nutrition Board of the U.S. National Academies (25).

### 5.2.2.4 Resting Energy Expenditure

Resting energy expenditure during pregnancy (REE) was estimated from body weight measured at each study visit during pregnancy (W), height (H ) and age (A) using a predictive equation for resting energy expenditure for pregnancy which was a modified version of the Harris-Benedict equation (26).

$$REE = 346.43943 + 13.962564 \times W + 2.700416 \times H - 6.826376 \times A$$

Energy intake above resting energy expenditure at each trimester was defined as the difference between energy intake and resting energy expenditure during each study visit.

### 5.2.2.5 Physical Activity Energy Expenditure

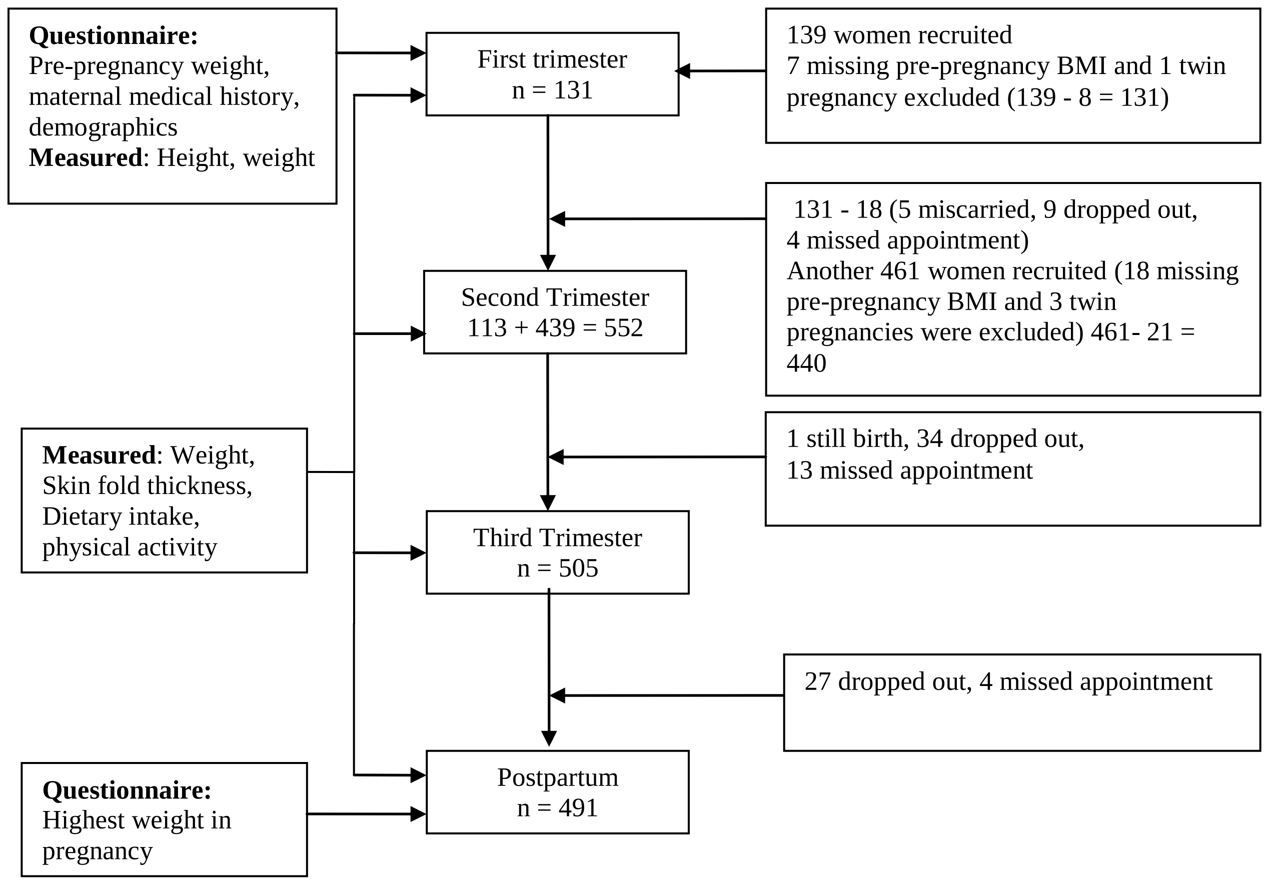
Physical activity was assessed using the Baecke questionnaire referring to daily activities (27). This questionnaire has previously been used in another study to examine changes in physical activity during pregnancy (28). The questions from the Baecke questionnaire could be grouped into three categories: work, sport and leisure time activities excluding sport. Questions on work and leisure time were scored using a five-point Likert scale. Sports score was calculated based on the intensity of sports, amount of time spent per week and the proportion of year spent playing a sport. Scores for work, sport and leisure were calculated and an overall total score including all of the above scores was also computed.

### 5.2.3 Statistical Analysis

Longitudinal changes in energy (kcal/day) and macronutrient intake (g/1000 kcal/day), and physical activity and estimated resting energy expenditure (kcal/day) by pre-pregnancy BMI groups were analysed using a univariate linear mixed method adjusted for the time of study visits (trimester 1, 2 and 3). The longitudinal effects of energy intake, physical activity and resting energy expenditure on fat mass, fat free mass and adherence to GWG respectively were analyzed using a univariate linear mixed method. A multilinear mixed-method analysis adjusted for time of study visit, maternal age, parity, ethnicity, marital status, education, prenatal smoking status, family income and gestational age was used to determine the contribution of energy and macronutrient intake, and of physical activity and resting energy expenditure, to longitudinal changes in fat mass and fat free mass during pregnancy. Interactions between pre-pregnancy BMI and energy and macronutrient intake were tested. A multinomial regression analysis was done to determine the contribution of energy and macronutrient intake, and of physical activity and resting energy expenditure, to adherence to GWG. Differences in energy and macronutrient intake and RDA were evaluated using one sample *t* test. Data were analysed using STATA (Version 11, StataCorp LP, TX, USA). A p value of <0.05 was considered statistically significant in all cases.

## 5.3 Results

**Figure 5.1: Participant Recruitment and Follow-up**



Of the 600 women recruited, 571 were included in the data analysis (25 women were missing pre-pregnancy weight and 4 twin pregnancies were excluded). Complete data were available from 131 women in their first trimester, 552 women in their second trimester and 504 women in their third trimester. Sixty five percent of the women had a normal pre-pregnancy BMI, and 3%, 19% and12% were categorized into the pre-pregnancy BMI categories of underweight, overweight and obese respectively (Table 5.1). GWG guidelines were met by 32% of women overall (64.3%, 38.0%, 16.1% and 14.3 % of women in the underweight, normal, overweight and obese BMI categories, respectively), and 56% gained above recommendations (28.6%, 46.0%, 80.7% and 80.4% of women in the underweight, normal, overweight and obese BMI categories, respectively). Only 12% women gained weight below recommendations (7.1%, 16.0%, 3.2% and 5.4 % of women in the underweight, normal, overweight and obese BMI categories, respectively). Study participants were predominantly Caucasian (84%), married/in common-law relationships (93%), and university graduates (67%), and had high family incomes (53% >$100 000/year). Women in the underweight pre-pregnancy BMI category were not included in the final analyses due to the small sample size (n=16).

### 5.3.1 Energy and macronutrient intake by pre-pregnancy BMI categories

#### 5.3.1.1 Energy intake by pre-pregnancy BMI categories

Overall there was a significant increase in energy intake (kcal/day) by all women in trimester 3 compared to that in trimester 1 ($\beta$ = 175.7, 95% C.I = 60.6 -

290.8, p = 0.003). When data were stratified according to pre-pregnancy BMI, women in the normal pre-pregnancy category showed a significant increase in their energy intake at trimester 2 (p=0.013) and 3 (p<0.001) compared to their energy intake at trimester 1 (Table 5.2). There was no significant change in energy intake across different study visits by women from the overweight or obese pre-pregnancy BMI groups. Interactions between energy intake according to pre-pregnancy BMI categories and study visits were tested. Significant interactions were observed between being obese and trimester 2 and 3 study visit. Compared to normal-weight women, obese women's energy intake during trimester 2 (β = -346, 95 % C.I. = - 645 - - 46, p = 0.02) and trimester 3 was significantly less (β = - 439, 95 % C.I. = -752 - -126, p = 0.006).

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The estimated energy requirement (EER) (Mean ± S.D) for normal, overweight and obese women at each trimester in pregnancy was: normal (trimester 1: 1985 ± 115 kcal/day, trimester 2: 2325 ± 115 kcal/day, trimester 3: 2437 ± 115 kcal/day); overweight (trimester 1: 2151± 105 kcal/day, trimester 2: 2491 ± 105 kcal/day, trimester 3: 2603 ± 105 kcal/day); obese ( trimester 1: 2357 ± 153 kcal/day, trimester 2: 2697 ± 153 kcal/day, trimester 3: 2809 ± 153 kcal/day).

When women's energy intake at each trimester was compared to their EER, overweight women had significantly low energy intake (p<0.001) in trimester 2 (2209 ± 709 kcal/day) and trimester 3 (2300 ± 823 kcal/day). Similarly, obese women had significantly low energy intake (p<0.001) in trimester 2 (2217±587 kcal/day) and trimester 3 (2197 ± 545 kcal/day), while normal-weight women had significantly low energy intake ($p<0.01$) at trimester 3 (2349 ± 656 kcal/day).

### 5.3.1.2 Carbohydrate intake

Overall, the carbohydrate intake (g/1000kcal/day) of all women at trimester 2 ($\beta = 4.5$, 95% C.I = 0.24 - 8.8, $p = 0.04$) and trimester 3 ($\beta = 4.7$, 95% C.I = 0.32 - 9.0, $p = 0.04$) were significantly higher than that at trimester 1. When stratified by pre-pregnancy BMI, obese women's carbohydrate intake at trimester 3 was significantly higher ($p=0.047$) than at trimester 1, and a marginal difference was observed in their trimester 2 intake ($p=0.052$) compared to that in trimester 1(Table 5.2). There was no significant change in carbohydrate intake across different study visits by women from the normal or overweight pre-pregnancy BMI groups. Longitudinally, there was no significant difference in carbohydrate intake by women from the overweight or obese pre-pregnancy BMI categories when compared to that of to normal-weight women. Interactions between carbohydrate intake according to pre-pregnancy BMI categories and study visits were tested. No significant interactions were observed.

Compared to the RDA for carbohydrate intake during pregnancy (175g/day), all women from different pre-pregnancy BMI categories had a significantly higher carbohydrate intake ($p<0.0001$) in all trimesters during pregnancy: normal (trimester 1: 278 ± 87g/day, trimester 2: 313 ± 100 g/day, trimester 3: 322 ± 98 g/day), overweight (trimester 1: 281 ± 93 g/day, trimester 2:

310 ± 107 g/day, trimester 3: 325 ±118 g/day), obese (trimester 1: 311 ± 114 g/day, trimester 2: 312 ± 89 g/day, trimester 3: 310 ± 85 g/day).

#### 5.3.1.3 Protein intake

Overall, there was a significant decrease in protein intake (g/1000 kcal/day) of all women at trimester 3 ($\beta$ = -2.3, 95% C.I = -4.5 - -0.020, p = 0.03) than at trimester 1. When stratified according to pre-pregnancy BMI, normal-weight women showed a significant decrease in their protein intake at trimester 3 compared to their trimester 1 protein intake (p = 0.026). There was no significant change in protein intake across different study visits by women from the overweight or obese pre-pregnancy BMI groups respectively. Longitudinally, there was no significant difference in protein intake by women from the overweight or obese pre-pregnancy BMI categories when compared to that of normal-weight women (Table 5.2). Interactions between protein intake according to pre-pregnancy BMI categories and study visits were tested. No significant interactions were observed.

Compared to the RDA for protein intake during pregnancy (71g/day), all women from different pre-pregnancy BMI categories had significantly higher protein intake ($p<0.0001$) in all trimesters during pregnancy: normal (trimester 1: 90 ± 31 g/day, trimester 2: 93 ± 33 g/day, trimester 3: 95 ± 32 g/day), overweight (trimester 1: 87 ± 32 g/day, trimester 2: 92 ± 33 g/day, trimester 3: 92 ± 30 g/day), obese (trimester 1: 99 ± 29 g/day, trimester 2: 88 ± 28 g/day, trimester 3: 90 ± 29 g/day).

#### 5.3.1.4 Fat intake

Overall, there was no significant change in fat intake (g/1000 kcal/day) among women across different study visits similar results were observed when data were stratified according to pre-pregnancy BMI. Longitudinally, there was no significant difference in fat intake by women from the overweight or obese pre-pregnancy BMI categories when compared to that of normal weight women (Table 5.2). Interactions between fat intake according to pre-pregnancy BMI categories and study visits were tested. No significant interactions were observed.

When women's fat intake at each trimester was compared to the AMDR for fat intake during pregnancy (20-35% kcal from fat), all women from different pre-pregnancy BMI categories met the fat intake requirements in all trimesters during pregnancy: normal (trimester 1: 31% kcal/day, $p < 0.001$; trimester 2: 30% kcal/day, $p<0.0001$; trimester 3: 30% kcal/day, $p<0.0001$), overweight (trimester 1: 34% kcal/day, $p<0.01$; trimester 2: 28% kcal/day, $p<0.0001$; trimester 3: 29% kcal/day, $p<0.0001$), obese (trimester 1: 31% kcal/day, $p = 0.04$; trimester 2: 31% kcal/day, $p<0.0001$; trimester 3: 28% kcal/day, $p<0.0001$).

#### 5.3.1.5 Fibre intake

Overall there was no significant change in fibre intake (g/1000 kcal/day) across different study visits. When data were stratified according to pre-pregnancy BMI, overweight women showed a significant increase in their fibre intake at trimester 2 ($p<0.05$) and trimester 3 ($p<0.05$) as compared to their trimester 1 intake. Longitudinally, there was no significant difference in fibre intake by women from the overweight or obese pre-pregnancy BMI categories when compared to that of normal-weight women (Table 5.2). Interactions between fibre intake according to pre-pregnancy BMI categories and study visits were tested. Significant interactions appeared between being overweight and trimester 2 and 3 study visit. Compared to normal-weight women, overweight women's fibre intake during trimester 2 ($\beta$ = 2.5, 95 % C.I. = 0.6 - 4.4, p = 0.01) and trimester 3 was significantly high ($\beta$ = 2.8, 95 % C.I. = 0.89 - 4.8, p = 0.004).

When women's fibre intake during each trimester in pregnancy was compared to the RDA for fibre intake during pregnancy (28 g/day), women from all of the pre-pregnancy BMI categories had significantly lower fibre intake ($p<0.0001$) in all trimesters during pregnancy: normal (trimester 1: 23 ± 10 g/day, trimester 2: 24 ± 10 g/day, trimester 3: 25 ± 10 g/day), overweight (trimester 1: 20 ± 8 g/day, trimester 2: 25 ± 14 g/day, trimester 3: 26 ± 13 g/day), obese (trimester 1: 25 ± 14 g/day, trimester 2: 23 ± 10 g/day, trimester 3: 24 ± 9 g/day).

### 5.3.2 Physical activity by pre-pregnancy BMI categories

On the whole, there was a significant decrease in total physical activity score at trimester 2 ($\beta$ = -0.18, 95% C.I = -0.36 - -0.005, p = 0.044) and trimester 3 ($\beta$ = -0.66, 95% C.I = -0.84 - -0.47, p <0.0001) as compared to that at trimester1 among our study participants. When data were stratified according to pre-pregnancy BMI, women from the normal pre-pregnancy BMI group showed a decrease in their total physical activity score at trimester 2 and 3 as compared to their trimester1 total physical activity score ($p<0.01$) (Table 5.2). Overweight and obese women showed a decrease in their trimester 3 total physical activity score as compared to their trimester 2 total physical activity score ($p<0.01$), but there was no significant difference between trimester 1 and trimester 3 scores.

In general, there was no change in the women's work score at trimester 2 or trimester 3 as compared to that at trimester 1.When data was stratified according to pre-pregnancy BMI, there was no significant change in the work score of women from the overweight or obese pre-pregnancy BMI groups across study visits. Normal-weight women showed a significant decrease in their work score at trimester 3 compared to that at trimester 1 or 2 ($p<0.01$).

Overall there was a significant decrease in women's sports score at trimester 2 ($\beta$ = -0.13, 95% C.I = -0.25- -0.02, p = 0.022) and trimester 3 ($\beta$ = -0.53, 95% C.I = -0.65 - -0.41, p <0.0001) as compared to that at trimester 1 among our study participants. When stratified by pre-pregnancy BMI categories, all women showed a significant decrease in sports score at trimester 3 as compared to their trimester 1 and 2 scores ($p<0.01$).

Overall, there was a significant decrease in women's leisure score at trimester 3 ($\beta$ = -0.13, 95% C.I = -0.21 - -0.05, p = 0.001) as compared to that at trimester 1. When stratified according to pre-pregnancy BMI, normal and overweight women showed a significant decline in leisure scores at trimester 3 as compared to their trimester 1 leisure scores ($p<0.01$). There was no significant change in leisure score of obese women across any study visit during pregnancy.

Longitudinally compared to normal-weight women, women who were overweight and obese prior to pregnancy had a lower total physical activity score (overweight: $p = 0.04$, obese: $p = 0.02$), sports score (overweight: $p<0.01$, obese: $p = 0.02$) and leisure score (obese: $p = 0.02$).

### 5.3.3 Resting energy expenditure by pre-pregnancy BMI categories

Overall, there was a significant increase in resting energy expenditure (REE) at trimester 2 ($\beta = 37.4$, 95% C.I = 29.3 - 5.5, $p<0.0001$) and trimester 3 ($\beta = 139.2$, 95% C.I = 130.8 - 147.6, $p<0.0001$) as compared to that at trimester 1 among all women in our study. When data were stratified according to pre-pregnancy BMI, women from all pre-pregnancy BMI categories showed a significant increase in REE at each subsequent visit compared to the preceding visit ($p<0.01$). Longitudinally compared to normal-weight women, overweight ($p<0.01$) and obese ($p<0.01$) women had a significantly higher resting energy expenditure (Table 5.2).

The amount of energy intake above the estimated resting energy expenditure at trimester 1, 2 and 3 by women from different pre-pregnancy BMI groups was as follows: trimester 1 (normal: 649 ± 571 kcal/day, n=68; overweight: 451 ± 643 kcal/day, n=26; obese: 432 ± 648 kcal/day, n=24); trimester 2 (normal: 781 ± 661 kcal/day, n=330; overweight kcal/day: 537 ± 707, n=99; obese: 286 ± 623 kcal/day, n=63); trimester 3 (normal: 770 ± 682 kcal/day, n=274; overweight kcal/day: 553 ± 835, n=87; obese: 145 ± 542 kcal/day, n = 48).

### 5.3.4 Energy and macronutrient intake, physical activity and resting energy expenditure and their association with fat mass, among women with different pre-pregnancy BMIs

There was no significant association between energy and macronutrient intake on longitudinal changes in fat mass during pregnancy (Table 5.3). Total physical activity score ($p = 0.03$), sports score ($p<0.01$) and resting energy expenditure ($p<0.001$) were significantly associated with longitudinal changes in fat mass. In a multivariate linear mixed model, sports score ($p<0.0001$) and resting energy expenditure ($p<0.0001$) remained significantly associated with longitudinal changes in fat mass.

Data were stratified according to pre-pregnancy BMI and the associations between fat mass (kg) and energy (kcal/day) and macronutrient intake (g/1000 kcal/day); and physical activity score and resting energy expenditure (kcal/day) were analysed using a multivariate linear mixed model adjusted for maternal sociodemographic variables and time of study visits. Among normal-weight women, significant predictors of fat mass changes were sports score ($\beta = -0.59$, 95% C.I = -0.94 - -0.23, $p = 0.001$) and resting energy expenditure ($\beta = 0.03$, 95% C.I = 0.02 - 0.03, $p<0.001$). Among the overweight women, energy ($\beta = -0.001$, 95% C.I = -001 - -0.0001, $p = 0.015$), carbohydrate ($\beta = 0.04$, 95% C.I = 0.01 - 0.07, $p = 0.002$), fat ($\beta = 0.05$, 95% C.I = 0.01 - 0.10, $p = 0.03$) and fibre intake ($\beta = -0.16$, 95% C.I = -0.25 - -0.06, $p = 0.001$); sports score ($\beta = -0.66.$, 95% C.I = -1.32 - -0.004, p = 0,048); and resting energy expenditure ($\beta = 0.03$, 95% C.I = 0.02 - 0.03, $p<0.001$) were associated with fat mass changes longitudinally.

Longitudinal changes in resting energy expenditure were associated with changes in fat mass among the obese women ($\beta$ = 0.03, 95% C.I = 0.03 - 0.04, p<0.001).

### 5.3.5 Energy and macronutrient intake, physical activity and resting energy expenditure, and their association with fat-free mass, among women with different pre-pregnancy BMIs

There was no significant association between energy and macronutrient intake, physical activity, and longitudinal changes in fat-free mass during pregnancy (Table 5.4). Resting energy expenditure was significantly associated with longitudinal changes in fat-free mass (p<0.001). In a multivariate linear mixed model sports physical activity score (p<0.0001) and resting energy expenditure (p<0.0001) were significantly associated with longitudinal changes in fat-free mass (Table 5.4).

Data were stratified according to pre-pregnancy BMI, and the associations between fat-free mass (kg), energy (kcal/day) and macronutrient intake (g/1000 kcal/day), physical activity score and resting energy expenditure (kcal/day) were analysed using a multivariate linear mixed model adjusted for maternal sociodemographic variables and time of study visits. Among normal-weight women, significant predictors of fat free mass changes were fibre intake ($\beta$ = -0.06, 95% C.I = -0.12 - -0.001, p = 0.047), sports score ($\beta$ = 0.60, 95% C.I = 0.28 - 0.92, p < 0.0001) and resting energy expenditure ($\beta$ = 0.03, 95% C.I = 0.032 - 0.037, p<0.001). Among the overweight women, carbohydrate ($\beta$ = -0.047, 95% C.I = -0.07 - -0.02, p <0.0001), fat ($\beta$ = -0.07, 95% C.I = - 0.11 - -0.02, p = 0.006) and fibre intake (β = 0.17, 95% C.I = 0.09 - 0.26, p <0.0001); sports score (β = 0.64., 95% C.I = 0.02- 1.26, p = 0.042); and resting energy expenditure (β = 0.04, 95% C.I = 0.034 - 0.04, p<0.0001) were associated with fat-free mass changes longitudinally. Longitudinal changes in resting energy expenditure were associated with changes in fat-free mass among the obese women (β = 0.035, 95% C.I = 0.031 - 0.039, p<0.001).

### 5.3.6 Energy and macronutrient intake by adherence to gestational weight gain recommendations

Women who gained above GWG recommendations significantly increased their energy intake (kcal/day) at trimester 3 (p<0.05) compared to their energy intake at trimester 1 and 2 **(**Table 5.5). Women who gained above GWG recommendations had a marginal increase in their carbohydrate intake at trimester 3 (p=0.058) when compared to their carbohydrate intake at trimester 1. There was no significant change in energy or carbohydrate intake across study visits by women who met GWG recommendations, or gained amounts below those recommendations. Women who met the GWG recommendations showed a significant decrease in their protein intake at trimester 3 compared to their trimester1 protein intake. There was no significant change in protein intake across different study visits by women who gained above or below the GWG recommendations. There was no significant change in fat intake across different study visits by women, irrespective of their adherence to GWG recommendations. Women who gained above the GWG showed a significant increase in their fibre intake at trimester 2

($p<0.05$) and trimester 3 ($p<0.05$) as compared to their trimester 1 intake. Longitudinally, energy and macronutrient intake were not significantly different among women, irrespective of adherence to GWG recommendations (Table 5.5).

### 5.3.7 Physical activity score by adherence to gestational weight gain recommendations

Women who met or gained above GWG recommendations showed a significant decrease in their total physical activity score and work score at trimester 3 ($p<0.05$) as compared to those at trimester 1 or 2. All women, irrespective of adherence to weight gain recommendations, showed a decrease in their sports score in trimester 3 as compared to that at trimester 1 or 2 ($p<0.05$). Women who gained above GWG recommendations showed a significant decrease in their leisure activity score at trimester 3 ($p<0.05$) as compared to that at trimester 1 or 2, but women who met or gained below gestational weight recommendations did not show a significant change in their leisure activity score across study visits. There was no significant change in total physical activity score or work score across study visits by women who gained below the GWG recommendations. Longitudinally, physical activity scores were not significantly different among women, irrespective of adherence to GWG recommendations (Table 5.5).

### 5.3.8 Resting energy expenditure by adherence to gestational weight gain recommendations

All women, irrespective of adherence to weight gain recommendations, showed a significant increase in their resting energy expenditure at each subsequent visit compared to the preceding visit ($p<0.01$). Longitudinally, as compared to women who met the GWG recommendations, women who gained above GWG recommendations had a significantly higher resting energy expenditure ($p<0.001$), whereas women who gained below recommendations had a lower resting energy expenditure ($p=0.04$) (Table 5.4).

### 5.3.9 Energy and macronutrient intake, physical activity and resting energy expenditure and their association with adherence to gestational weight gain recommendations

There was no significant difference in the energy, macronutrient and physical activity score at trimester 3 as compared to those at trimester 2. Hence the mean of the second and third trimester energy and macronutrient intake and physical activity scores were used in the multinomial logistic regression analysis. Results from this analysis indicated that, compared to women who met the GWG recommendations, women who gained above recommendations had higher resting energy expenditure at all study visits during pregnancy ($p<0.001$). Energy (kcal/day) and macronutrient intake (g/1000 kcal/day) and physical activity score were not significantly different among women irrespective of adherence to weight gain recommendations.

## 5.4 Discussion

Studying energy and macronutrient intake, physical activity and energy expenditure during pregnancy will help in identifying the reasons for differences in weight gain and adiposity during pregnancy. This clinical information could be valuable in designing intervention programs to support optimal weight gain and adiposity during pregnancy.

Results from the previous analysis of our study participants indicated that overweight women gained a total amount of gestational weight similar to that of women with pre-pregnancy BMI in the normal range. Obese women gained less weight than normal or overweight women. However, when adherence to GWG recommendations was examined, we found that 80% of the women from overweight and obese pre-pregnancy BMI categories exceeded weight gain recommendations (Chapter 3). Our study results also indicated that women from all BMI categories gained a similar amount of fat mass in pregnancy, but that the rate of fat mass gain was incremental from the first to the third trimester in the case of normal weight women. However, while overweight women showed a significant gain in fat mass accumulation during the second and third trimesters, obese women showed increases only in the third trimester (Chapter 5).

Results from this chapter indicate that longitudinally, the energy intake among all our study participants increased progressively during pregnancy, and there was no significant difference between women from different pre-pregnancy BMI groups. Our study results also indicate that REE increased progressively with pregnancy. However, women from overweight and obese pre-pregnancy BMI categories had higher resting energy expenditure (REE) longitudinally during pregnancy than did normal-weight women. The rise in REE occurred in tandem with increasing weight and fat mass during pregnancy. In a multivariate analysis, higher REE was a significant predictor of higher fat mass and fat-free mass accumulation longitudinally during pregnancy. Results from previous cross-sectional and longitudinal studies indicate that REE increases progressively through pregnancy; it was positively associated with fat mass, fat-free mass, weight gain and pre-pregnancy BMI (2).

To provide for the increased energy demand which occurs with progressing gestation, an increase in energy intake of 340 kcal/day and 452 kcal/day above non-pregnant energy requirements in the second and third trimester respectively have been suggested (25). We observed that normal-weight women met their estimated energy requirements throughout pregnancy except in the third trimester, when their energy intake fell short by 3% of the estimated requirements. However, overweight women met only 88% of their EER during trimesters 2 and 3; similarly, obese women met 82 % and 78% of their EER at trimester 2 and 3 respectively. Considering the higher resting energy demand of women during pregnancy, and based on their energy intake, the percentage of energy left after satisfying REE among women in the overweight and obese categories at trimester 1 (overweight: 12%, obese: 11%), trimester 2 (overweight: 16%, obese: 4%), and trimester 3 (overweight: 14%, obese: 1%) seemed to be very low. As a compensatory mechanism to save energy in the context of this situation, overweight and obese women in our study showed a significant reduction in their total physical activity score, and more specifically, their sports score, at trimester 2 and 3, as compared to normal-weight women. Previous studies have observed a similar decline in physical activity during pregnancy (29, 30). They found that the total cost for physical activity expenditure in pregnancy amounted to 10% of total energy demands.

Thus it appears that the increased demand for energy during pregnancy is not entirely met by increasing energy intake and/or reducing physical activity. It is evident that the mechanism of favouring fat mass accretion and weight gain in the context of this situation seems to be influenced by metabolic adaptations, which may be different among women with high pre-pregnancy BMI – most notably among overweight women. Hence future studies examining the metabolic parameters in detail– for example, by measuring energy expenditure using calorimetry, and by measuring insulin sensitivity, glucose tolerance, circulating levels of fatty acids, triglycerides and adipokines at different stages in pregnancy – could help to identify the reasons for variations in weight gain and adiposity during pregnancy. Another reason could be the overestimation of energy requirements during pregnancy for women who enter pregnancy with a higher pre-pregnancy BMI. It must be noted that energy requirements during pregnancy (31) were established based on evidence from the 1970s, when the prevalence of underweight and low birth weight was a concern, and the incidence of high pre-pregnancy BMI and chronic metabolic conditions were limited. Hence, revisiting the energy requirements during pregnancy may be necessary to prevent excess weight gain and adiposity during pregnancy.

Results from our study also indicate that an increase in participants' sports activity scores was associated with a decrease in fat mass and an increase in lean mass longitudinally during pregnancy. However, we were unable to find an association between physical activity scores and adherence to GWG. Results from a meta-analysis of physical activity studies published in 2005 (32) also failed to reveal an association between physical activity and GWG. However, the studies included in the meta-analysis did not consider the level of physical activity-related energy expenditure on GWG. On the contrary, a recent study showed an inverse association between vigorous physical activity and excess GWG (33). Hence, future studies examining the influence of intensity and frequency of physical activity energy expenditure on GWG and body composition changes are warranted.

**Limitations**

Resting energy expenditure in our study was an estimated value computed from body weight during pregnancy, height and age using a predictive equation for resting energy expenditure. Hence these estimates may not accurately represent the actual individual metabolic adaptations during pregnancy. During pregnancy as expected all women in our study showed an increase in body weight during each study visit compared to their body weight in the previous visit. In the estimation of REE in our study body weight was a significant confounder. Since measured body weight was used in estimating REE, it appears that REE was also increasing at each visit compared to the previous visit. Further REE was significantly higher among overweight and obese women compared to the normal-weight women. This could be due to the higher body weight among the former women compared to the latter. Also women who gained “Above” GWG recommendations had had higher REE than women who gained "Below" or "Met" GWG recommendations which also appears due to the confounding effect of body weight. REE was positively associated with exceeding GWG recommendations and with higher body fat mass and fat-free mass accumulation.

Overweight and obese women are more likely to under-report energy intake than normal-weight women (34-36); hence this could be the plausible reason why the energy intake of overweight and obese women was less than their estimated EER during trimester 2 and 3 in pregnancy in our study. We also found that overweight and obese women's energy intake was similar to that of normal-weight women; however their physical activity scores were lower than normal-weight women. Hence it is possible that since overweight and obese women had low physical activity their energy intake levels were also low, thus they did not meet their EER during trimester 2 and 3 in pregnancy.

We were unable to calculate the energy expenditure from physical activity as the questionnaire used to estimate physical activity in this study provided a score to indicate how much physical activity was performed by an individual; a high score represented higher physical activity, whereas a low score was assigned when physical activity was low.

## 5.5 Conclusion

Recommendations for energy intake for pregnant women should be revised based on current evidence of changes in lifestyle patterns and specific to maternal pre-pregnancy BMI.

**Table 5.1: Anthropometric and socio-demographic characteristics, gestational age at delivery of study participants**

| Characteristic | n [1] | Underweight [2] | Normal | Overweight | Obese |
|---|---|---|---|---|---|
| Pre-pregnancy BMI ($kg/m^2$)[3] | 571 | 17.7 ± 0.7 | 21.7 ± 1.6 | 26.8 ± 1.3 | 33.8 ± 3.8 |
| Height (cm)[3] | 571 | 168.1 ± 5.8 | 165.7 ± 6.7 | 166.5 ± 5.3 | 166.1 ± 6.6 |
| Pre-pregnancy weight (kg)[3] | 571 | 50.0 ± 4.6 | 59.6 ± 6.6 | 74.3 ± 6.2 | 93.3 ± 11.5 |
| Body weight (kg)[3] | | | | | |
| Trimester 1[4] | 131 | 54.1 ± 0.42 | 60.2 ± 7.2 | 77.5 ± 7.3 | 94.7 ± 11.9 |
| Trimester 2 | 552 | 56.0 ± 5.2 | 64.6 ± 7.9 | 79.1 ± 7.2 | 96.5 ± 10.8 |
| Trimester 3 | 505 | 62.7 ± 6.0 | 72.2 ± 8.1 | 86.6 ± 7.5 | 103.0 ± 1.7 |
| Fat Mass (kg)[3] | | | | | |
| Trimester 1[4] | 131 | 14.1 ± 0.99 | 18.4 ± 3.9 | 28.3 ± 3.7 | 37.7 ± 5.9 |
| Trimester 2 | 552 | 15.5 ± 2.8 | 20.8 ± 4.5 | 28.3 ± 4.1 | 37.9 ± 5.9 |
| Trimester 3 | 504 | 17.1 ± 3.8 | 22.8 ± 4.2 | 30.6 ± 4.4 | 39.0 ± 5.8 |
| Total Gestational Weight Gain (kg)[3] | | | | | |
| Below[5] | 52 | 11.6 ± 0 | 9.3 ± 2.5 | 5.9 ± 1.3 | 2.8 ± 1.6 |
| Met | 142 | 14.2 ± 1.6 | 14.1 ± 1.4 | 9.9 ± 1.5 | 7.4 ± 1.2 |

| | | | | | |
|---|---|---|---|---|---|
| Above | 256 | 23.9 ± 3.7 | 20.7 ± 4.1 | 17.7 ± 4.4 | 15.4 ± 5.9 |
| Age (yrs)[3] | | | | | |
| 17 to 30 | 265 | 27.3 ± 3.0 | 27.9 ± 2.3 | 27.9 ± 2.7 | 27.8 ± 2.1 |
| 31 to 45 | 306 | 33.6 ± 2.7 | 34.8 ± 2.7 | 34.9 ± 3.0 | 34.4 ± 2.4 |
| Parity | | | | | |
| 0 | 305 | 37.5% | 31.8% | 42.5% | 29.6% |
| 1 | 184 | 56.3% | 58.5% | 48.1% | 54.9% |
| 2 + | 56 | 6.2% | 9.7% | 9.4% | 15.5% |
| Marital Status | | | | | |
| Married | 531 | 93.7% | 97.2% | 97.2% | 91.5% |
| Other | 20 | 6.3% | 2.8% | 2.8% | 8.4% |
| Smoking Status | | | | | |
| Never smoked | 372 | 78.6% | 66.0% | 68.9% | 75.7% |
| Ever smoked | 174 | 21.4% | 33.4% | 31.1% | 24.3% |
| Ethnicity | | | | | |
| Caucasian | 480 | 75.0% | 85.5% | 92.5% | 90.1% |
| Other | 70 | 25.0% | 14.5% | 7.5% | 9.9% |
| Family Income [6] | | | | | |
| Low (≤ $69 000) | 106 | 43.7% | 18.5% | 20.0% | 17.4% |
| Medium | 135 | 25.0% | 22.7% | 23.8% | 37.7% |

| | | | | | |
|---|---|---|---|---|---|
| ($70 000 - $99 000) | | | | | |
| High (≥ $100 000) | 302 | 31.3% | 58.8% | 56.2% | 44.9% |
| Maternal Education | | | | | |
| High school/ diploma/certificate | 168 | 37.5% | 25.4% | 32.0% | 52.2% |
| University degree/ postgraduate degree | 382 | 62.5% | 74.6% | 68.0% | 47.8% |
| Gestational Age (wks) [3] | 508 | 38.6 ± 1.4 | 40.0 ± 1.7 | 38.8 ± 1.7 | 39.2 ± 1.4 |

[1] n = 571 (underweight = 16, normal = 373, overweight = 108, obese = 74); sample sizes within a particular characteristic may not total 571 due to missing responses.

[2]Based on their pre-pregnancy BMI ($kg/m^2$) women were classified as underweight (< 18.5 $kg/m^2$), normal (18.5 - 24.9 $kg/m^2$) overweight (< 25.0 – 29 $kg/m^2$) or obese (≥ 30 $kg/m^2$) (Health Canada, 2003)

[3] Values reported are mean ± S.D.

[4] Trimester 1 = 10.7 ± 2.3 weeks gestation, Trimester 2 = 19.2 ± 3.7 weeks gestation, Trimester 3 = 32.4 ± 1.4 weeks gestation

[5] Designated as “Below”, “Met” or “Above” gestational weight gain guidelines (Health Canada, 2010)

[6] Statistics Canada (2011), Median total income by family type, by census metropolitan area, CANSIM, table 111-0009. http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil107a-eng.htm

**Table 5.2: Energy and macronutrient intake, physical activity index scores and resting energy expenditure during pregnancy by pre-pregnancy BMI categories**

| Pre-pregnancy BMI | Trimester 1[1] | Trimester 2[1] | Trimester 3[1] | β[3] | 95% C.I | p |
|---|---|---|---|---|---|---|
| | Mean ± S.D[2] (n) | | | | | |
| Energy (kcal/day) | | | | | | |
| Normal[4] | 2073 ± 554 (69) | 2271 ± 661[a] (340) | 2349 ± 656[a,b] (305) | NA[5] | | |
| Overweight | 2097 ± 632 (27) | 2209 ± 709 (101) | 2300 ± 823 (93) | | | |
| Obese | 2351 ± 632 (24) | 2217 ± 587 (70) | 2197 ± 545 (59) | | | |
| Carbohydrate (g/1000kcal/day) | | | | | | |
| Normal | 134 ± 23 (69) | 138 ± 22 (340) | 138 ± 21 (305) | Reference | | |
| Overweight | 136 ± 24 (27) | 141 ± 24 (101) | 141 ± 21 (93) | 3.1 | -0.6 - 6.8 | 0.10 |
| Obese[6] | 131 ± 26 (24) | 141 ± 21[a] (70) | 142 ± 22[a] (59) | 2.4 | -1.9 - 6.7 | 0.27 |
| Protein (g/1000kcal/day) | | | | | | |
| Normal[7] | 44 ± 12 (69) | 41 ± 11[a] (340) | 41 ± 10[b] (305) | Reference | | |
| Overweight | 41 ± 11 (27) | 42 ± 12 (101) | 41 ± 12 (93) | 0.67 | -1.2 - 2.6 | 0.48 |
| Obese | 44 ± 15 (24) | 40 ± 9 (70) | 41 ± 9 (59) | -0.35 | -2.5 - 1.8 | 0.75 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fat (g/1000kcal/day) | | | | | | |
| Normal | 11 ± 4 (69) | 11 ± 4 (340) | 11 ± 4 (305) | Reference | | |
| Overweight | 10 ± 4 (27) | 12 ± 5 (101) | 12 ± 6 (93) | -1.1 | -2.6 - 0.4 | 0.14 |
| Obese | 10 ± 5 (24) | 11 ± 5 (70) | 12 ± 4 (59) | -0.9 | -2.6 - 0.8 | 0.32 |
| Fibre (g/1000kcal/day) | | | | | | |
| Normal | 11 ± 3 (69) | 11 ± 4 (340) | 10 ± 3 (305) | NA[5] | | |
| Overweight | 10 ± 4 (24) | 11 ± 5[a] (101) | 12 ± 5[a] (93) | | | |
| Obese | 9 ± 3 (27) | 11 ± 4 (70) | 11 ± 4 (59) | | | |
| Physical activity – Total score[8] | | | | | | |
| Normal | 8.01 ± 1.42 (73) | 7.81 ± 1.42[a] (305) | 6.86 ± 1.26[a,b] (174) | Reference | | |
| Overweight | 7.46 ± 1.07 (23) | 7.41 ± 1.23 (96) | 6.87 ± 1.07[b] (57) | -0.33 | -0.61- -0.05 | 0.04 |
| Obese | 7.43 ± 1.38 (18) | 7.40 ± 1.19 (60) | 7.01 ± 1.07[b] (40) | -0.34 | -0.7- -0.01 | 0.02 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Physical activity – Work score[8] | | | | | | |
| Normal | 2.42 ± 0.60 (73) | 2.44 ± 0.66 (305) | 2.36 ± 0.63[a,b] (174) | Reference | | |
| Overweight | 2.32 ± 0.59 (23) | 2.38 ± 0.57 (96) | 2.37 ± 0.56 (57) | -0.05 | -0.2 - 0.1 | 0.49 |
| Obese | 2.34 ± 0.81 (18) | 2.48 ± 0.55 (60) | 2.42 ± 0.62 (40) | 0.04 | -0.1 - 0.2 | 0.59 |
| Physical activity – Sports score[8] | | | | | | |
| Normal | 2.92 ± 0.86 (73) | 2.76 ± 0.85[a] (305) | 2.09 ± 0.59[a,b] (174) | Reference | | |
| Overweight | 2.42 ± 0.69 (23) | 2.47 ± 0.71 (96) | 2.05 ± 0.45[a,b] (57) | -0.25 | -0.4 - -0.1 | 0.001 |
| Obese | 2.60 ± 0.67 (18) | 2.50 ± 0.69 (60) | 2.20 ± 0.56[a,b] (40) | -0.22 | -0.4 - -0.04 | 0.02 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Physical activity – Leisure score[8] | | | | | | |
| Normal | 2.65 ± 0.49 (73) | 2.60 ± 0.54 (305) | 2.41 ± 0.49[a,b] (174) | Reference | | |
| Overweight | 2.72 ± 0.44 (23) | 2.56 ± 0.47 (96) | 2.45 ± 0.51[a] (57) | -0.03 | -0.13 - 0.08 | 0.60 |
| Obese | 2.65 ± 0.49 (18) | 2.41 ± 0.51 (60) | 2.38 ± 0.44 (40) | -0.15 | -0.28 - -0.03 | 0.02 |
| Resting energy expenditure (kcal/day)[9] | | | | | | |
| Normal | 1420 ± 111 (77) | 1480 ± 126[a] (363) | 1585 ± 129[a,b] (330) | Reference | | |
| Overweight | 1659 ± 120 (27) | 1684 ± 114[a] (106) | 1789 ± 117[a,b] (100) | 209.4 | 181.9 - 237.0 | <0.001 |
| Obese | 1908 ± 180 (25) | 1927 ± 160[a] (67) | 2016 ± 176[a,b] (59) | 467.3 | 435.3 - 499.3 | <0.001 |

[1]Trimester1 = 10.7 ± 2.3 weeks gestation, trimester 2 = 19.2 ± 3.7 weeks gestation, trimester 3 = 32.4 ± 1.4 weeks gestation

[2] Univariate linear mixed model analysis, data was stratified by pre-pregnancy BMI categories and adjusted for 3 study visits (trimester 1, 2 and 3)

[3] Univariate linear mixed model analysis, data was adjusted for 3 study visits (trimester 1, 2 and 3)

[4] Significant difference between trimester1 and 2 ($p = 0.013$), trimester 1 and 3 ($p<0.001$), marginal difference between trimester 2 and 3 $p=0.056$

[NA] Interactions observed between pre-pregnancy BMI and study visits (details see pg 157 and 161)

[6] Marginal difference between trimester 1 and 2 ($p=0.052$), significant difference between trimester 1and 3 ($p=0.047$)

[7] Marginal difference between trimester 1 and 2 ($p=0.066$), significant difference between trimester 1and 3 ($p=0.026$)

[8] Physical activity scores were determined using Baecke's physical activity questionnaire

[9] Resting energy expenditure was computed using modified Harris-Benedict equation

[a] Significantly different from trimester 1 within a BMI category, $p \leq 0.01$

[b] Significantly different from trimester 2 within a BMI category, $p \leq 0.01$

**Table 5.3: Energy and macronutrient intake, physical activity scores and resting energy expenditure and their association with longitudinal changes in fat mass during pregnancy**

| Covariates | Fat mass (kg) | | | | | |
|---|---|---|---|---|---|---|
| | $\beta^1$ | 95% C.I | p value | $\beta^2$ | 95% C.I | p value |
| Daily Nutrient Intake | | | | | | |
| Energy | -0.0001 | -0.0004 -0.0002 | 0.52 | 0 | -0.001- 0.001 | 0.54 |
| Carbohydrate | 0.008 | -0.001 - 0.02 | 0.08 | 0.001 | -0.02 - 0.2 | 0.87 |
| Protein | -0.01 | -0.03 - 0.01 | 0.36 | -0.01 | -0.03 - -0.01 | 0.31 |
| Fat | -0.01 | -0.04 - 0.01 | 0.21 | 0.004 | -0.03 - 0.04 | 0.84 |
| Fibre | 0.02 | -0.03 - 0.07 | 0.51 | -0.01 | -0.06 - 0.04 | 0.67 |
| Energy Expenditure | | | | | | |
| Total Physical Activity Score | -0.29 | -0.5 - -0.04 | 0.025 | - | - | - |
| Work Score | -0.1 | -0.7 - 0.4 | 0.68 | - 0.21 | -0.54 - 0.13 | 0.22 |
| Sports Score | -0.7 | -1.1 - -0.3 | 0.001 | -0.67 | -0.96 - -0.37 | <0.0001 |
| Leisure Score | 0.04 | -0.6 - 0.7 | 0.9 | 0.35 | -0.08 - 0.77 | 0.11 |
| Resting energy expenditure | 0.03 | 0.03 - 0.04 | <0.001 | 0.03 | 0.02 - 0.03 | <0.0001 |

[1] Univariate linear mixed model analysis, data was adjusted for 3 study visits (trimester1, 2 and 3)

[2] Multivariate linear mixed model, data was adjusted for maternal pre-pregnancy BMI, age, parity, marital status, smoking status, ethnicity,  family income, maternal education and gestational age at term and study visits (trimester1, 2 and 3)

**Table 5.4: Association between fat free mass and energy and macronutrient intake, physical activity index scores and resting energy expenditure during pregnancy**

| Covariates | Fat free mass (kg) | | | | | |
|---|---|---|---|---|---|---|
| | β[1] | 95% C.I | p value | β[2] | 95% C.I | p value |
| Daily Nutrient Intake | | | | | | |
| Energy (kcal) | 8.82 | -0.0003 - 0.0003 | 0.96 | -0.0001 | -0.004 - 0.0001 | 0.38 |
| Carbohydrate (g/1000kcal) | 0.002 | -0.007 - 0.01 | 0.67 | -0.004 | -0.02 - 0.01 | 0.63 |
| Protein (g/1000kcal) | -0.02 | -0.04 - 0.001 | 0.057 | 0.006 | -0.02 - 0.03 | 0.61 |
| Fat (g/1000kcal) | 0.002 | -0.02 - 0.02 | 0.83 | -0.003 | -0.04 - 0.03 | 0.87 |
| Fibre (g/1000kcal) | 0.02 | -0.03 - 0.07 | 0.55 | 0.001 | -0.044 - 0.05 | 0.96 |
| Daily Energy Expenditure | | | | | | |
| Total Physical Activity Score | 0.11 | -0.14 - 0.37 | 0.39 | - | - | - |
| Work Score | 0.12 | -0.44 - 0.68 | 0.68 | 0.12 | -0.19 - 0.42 | 0.46 |
| Sports Score | 0.25 | -0.16 - 0.66 | 0.23 | 0.58 | 0.31 - 0.84 | <0.0001 |
| Leisure Score | -0.05 | -0.67 - 0.57 | 0.89 | -0.17 | -8.34 - 2.09 | 0.40 |
| Resting energy expenditure (kcal/d) | 0.03 | 0.03 - 0.04 | <0.001 | 0.04 | 0.03 - 0.04 | <0.0001 |

[1] Univariate linear mixed model analysis, data was adjusted for study visits (trimester 1, 2 and 3)

[2] Multivariate linear mixed model, data was adjusted for maternal pre-pregnancy BMI, age, parity, marital status, smoking status, ethnicity, family income, maternal education and gestational age at term and study visits (trimester 1, 2 and 3)

**Table 5.5: Energy and macronutrient intake, physical activity index scores and resting energy expenditure during pregnancy according adherence to total weight gain recommendations**

| Total Weight Gain | Trimester 1[1] | Trimester 2[1] | Trimester 3[1] | β[2] | 95% C.I | p |
|---|---|---|---|---|---|---|
| Energy (kcal/day) | | | | | | |
| Below | 2078 ± 703 (9) | 2296 ± 703 (53) | 2441 ± 668 (50) | 41.4 | -129.8 - 212 | 0.64 |
| Met | 2194 ± 611 (29) | 2282 ± 637 (138) | 2251 ± 605 (128) | Reference | | |
| Above | 2159 ± 534 (56) | 2233 ± 675 (243) | 2354 ± 759[a,b] (218) | -10.9 | -123 - 101 | 0.85 |
| Carbohydrate (g/1000kcal) | | | | | | |
| Below | 134 ± 24 (9) | 141 ± 22 (53) | 134 ± 23 (50) | -0.7 | -6.0 - 4.6 | 0.79 |
| Met | 132 ± 28 (29) | 139 ± 21 (138) | 139 ± 21 (128) | Reference | | |
| Above[3] | 134 ± 21 (56) | 138 ± 23 (243) | 140 ± 21[a] (218) | 0.02 | -3.5 - 3.5 | 0.99 |
| Protein (g/1000kcal) | | | | | | |
| Below | 39 ± 12 (9) | 40 ± 10 (53) | 42 ± 10 (50) | -0.4 | -3.1 - 2.3 | 0.77 |
| Met | 46 ± 14 (29) | 41 ± 10[a] (138) | 41 ± 11[a] (128) | Reference | | |
| Above | 43 ± 11 (56) | 41 ± 11 (243) | 40 ± 11 (218) | -0.3 | -2.1 - 1.5 | 0.73 |
| Fat (g/1000kcal) | | | | | | |
| Below | 36 ± 7 (9) | 32 ± 8 (53) | 35 ± 9 (50) | 0.63 | -1.5 - 2.8 | 0.56 |
| Met | 35 ± 10 | 32 ± 8 | 32 ± 8 | Reference | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (29) | (138) | (128) | | | |
| Above | 34 ± 8 (56) | 33 ± 8 (243) | 33 ± 10 (218) | 0.55 | -0.85 - 1.9 | 0.44 |
| Fibre (g/1000kcal) | | | | | | |
| Below | 11 ± 3 (9) | 10 ± 4 (53) | 11 ± 4 (50) | 0.35 | -0.7 - 1.5 | 0.53 |
| Met | 11 ± 4 (29) | 10 ± 3 (138) | 10 ± 3 (128) | Reference | | |
| Above | 9 ± 3 (56) | 11 ± 5[a] (243) | 11 ± 4[a] (218) | 0.63 | -0.1 - 1.3 | 0.09 |
| Physical Activity - Total Score | | | | | | |
| Below | 7.94 ± 1.48 (10) | 7.82 ± 1.38 (49) | 7.15 ± 1.36 (33) | 0.21 | -0.19 - 0.60 | 0.31 |
| Met | 7.62 ± 1.63 (31) | 7.64 ± 1.51 (130) | 6.84 ± 1.27[a,b] (84) | Reference | | |
| Above | 7.88 ± 1.35 (52) | 7.65 ± 1.27 (235) | 6.91 ± 1.09[a,b] (141) | 0.01 | -0.26 - 0.27 | 0.95 |
| Physical Activity - Work Score | | | | | | |
| Below | 2.47 ± 0.72 (10) | 2.47 ± 0.66 (49) | 2.47 ± 0.61 (33) | 0.04 | -0.15 - 0.23 | 0.69 |
| Met | 2.41 ± 0.58 (31) | 2.42 ± 0.63[a] (130) | 2.38 ± 0.63[a] (84) | Reference | | |
| Above | 2.36 ± 0.66 (52) | 2.45 ± 0.65 (235) | 2.35 ± 0.61[b] (141) | -0.01 | -0.14 - 0.11 | 0.82 |
| Physical Activity - Sports Score | | | | | | |
| Below | 2.91 ± 0.87 (10) | 2.73 ± 0.84 (49) | 2.14 ± 0.66[a,b] (33) | 0.09 | -0.14 - 0.31 | 0.45 |
| Met | 2.70 ± 1.03 (31) | 2.66 ± 0.88 (130) | 2.06 ± 0.59[a,b] (84) | Reference | | |
| Above | 2.82 ± 0.75 (52) | 2.66 ± 0.77[a] (235) | 2.14 ± 0.50[a,b] (141) | 0.01 | -0.13 - 0.16 | 0.86 |
| Physical Activity - Leisure Score | | | | | | |
| Below | 2.57 ± 0.48 | 2.62 ± 0.46 | 2.54 ± 0.55 | 0.08 | -0.07 - 0.23 | 0.27 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (10) | (49) | (33) | | | |
| Met | 2.51 ± 0.55 (31) | 2.56 ± 0.55 (130) | 2.40 ± 0.52 (84) | Reference | | |
| Above | 2.70 ± 0.47 (52) | 2.55 ± 0.51[a] (235) | 2.42 ± 0.46[a] (141) | 0.01 | -0.08 - 0.11 | 0.81 |
| Resting Energy Expenditure (kcal/day)[4] | | | | | | |
| Below | 1464 ± 169 (13) | 1455 ± 182[a] (55) | 1530 ± 176[a,b] (51) | -57.6 | -112 - -2.9 | 0.04 |
| Met | 1505 ± 226 (34) | 1506 ± 169[a] (148) | 1595 ± 161[a,b] (148) | Reference | | |
| Above | 1612 ± 217 (56) | 1629 ± 189[a] (264) | 1744 ± 186[a,b] (259) | 135 | 99.4 - 171.4 | < 0.001 |

[1]Trimester1 = 10.7 ± 2.3 weeks gestation, trimester 2 = 19.2 ± 3.7 weeks gestation, trimester 3 = 32.4 ± 1.4 weeks gestation

[2] Univariate linear mixed model analysis, data was adjusted for study visits (trimester1, 2 and 3)

[3] Marginal difference in carbohydrate intake between trimester1 and 3, p=0.058

[4]Marginal difference in resting energy expenditure at trimester 1 between women who met the weight gain recommendations vs. those who gained above recommendations, p = 0. 073; significant differences at trimester 2 and 3 respectively between women who met the weight gain recommendations vs. those who gained above recommendations, below = met < above, p<0.01

[a] Significantly different from trimester 1 within a weight gain category, p ≤ 0.05

[b] Significantly different from trimester2 within a weight gain category, p ≤ 0.05

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# CHAPTER 6: Higher Pre-Pregnancy BMI and Excessive Gestational Weight Gain are Risk Factors for Rapid Growth in Infants [2]

## 6.1 Introduction

Childhood obesity is rising significantly globally and in North America. In Canada, 26% of children aged 6 years and older are currently classified as either overweight or obese (1). Among the many determinants of childhood obesity, maternal pre-pregnancy body mass index (BMI) and GWG appear to play a vital role in child and adolescent body weight (2). Part of this role may be through an ongoing influence on birth weight. For example, underweight women who gain insufficient weight during pregnancy are at higher risk for small for gestational age babies (3). These infants are more likely to experience "catch up growth" early in life, which increases risk of childhood obesity. As the prevalence of low body weight among women of childbearing age has decreased and the prevalence of overweight and obesity have increased (4), the effects of higher maternal body weight on child growth have come under scrutiny. Recent studies have shown that children of women with higher pre-pregnancy BMIs and excessive GWG have increased risk of high birth weight (5, 6), high body weight at 6 months(7) and high BMI in childhood (8, 9) and adolescence (10). Less is known about the early postnatal growth patterns of these infants. Recent reviews of the determinants of postnatal growth have identified rapid growth in early postnatal life as an

[2] A version of this chapter has been submitted for publication as: "Higher Pre-Pregnancy BMI and Excessive Gestational Weight Gain are Risk Factors for Rapid Growth in Infants, J of Pediatrics"

important predictor of childhood obesity and chronic health risks later in life (11, 12). Thus, studying the influences of maternal pre-pregnancy BMI and GWG on early phases of infant growth may provide additional information on the potential role that maternal body weight and weight gain may play on a child's early postnatal growth.

The objective of this study was to describe the effects of maternal pre-pregnancy BMI and GWG on infant anthropometrics at birth and 3 months, and infant growth rates between birth and 3 months.

## 6.2 Methods

### 6.2.1 Study Design

Study participants were the first 600 pregnant women and their newborn infants enrolled in a prospective longitudinal cohort, the Alberta Pregnancy Outcomes and Nutrition (APrON) study(13). Women were ≥16 years of age, able to read and write in English, ≤ 27 weeks gestation, residing in the Edmonton or Calgary, Alberta, Canada metropolitan areas. Participants included in these analyses entered the study between June 2009 and March 2010 and were recruited through advertising in local media and physicians' offices. Data were collected at 2-3 study visits during pregnancy that were spaced to coincide with each trimester and one follow-up visit at approximately 3 month postpartum. Information about birth was collected from medical charts. Ethics approval for this study was obtained from the Health Research Ethics Boards at the University of Alberta (Pro 00002954) and the University of Calgary (E22101). All women provided their written and informed consent for their own and their infant's participation in the study prior to enrolment.

### 6.2.2 Study Variables

#### 6.2.2.1 Demographics

Women completed questionnaires detailing their demographic information, medical and smoking history prior to and during pregnancy, as well as after the birth. Maternal and socio-demographic characteristics considered as covariates for infant anthropometric outcomes included: maternal age (16 - 30 years or over 30 years), parity (nulliparous (no children), primiparous (1 child) or multiparous ( $\geq$ 2 children)), marital status (married (married/common law) or unmarried (single/divorced)), smoking status (never smoked (no smoking history) or ever smoked (women who smoked but quit prior to or during pregnancy or those who still smoked)), ethnicity (Caucasian or other (African American, Latin American, Native or Asian)), family income (low (< 20k - 69k/year), medium (70k - 99 k/year), or high (above 100k/year)), maternal education (high school/ diploma/certificate (< high school, high school, diploma or certificate), or university degree(s)) and gestational age at term. Additional covariates considered for infant anthropometrics at 3 months were breastfeeding (exclusive breastfeeding (only breastfed for $\geq$ 12 weeks) or mixed feeding (fed both infant formula and breast milk) or exclusive formula feeding (only formula fed for $\geq$ 12 weeks).

#### 6.2.2.2 Maternal Anthropometrics

Detailed methods for the assessment of maternal anthropometrics have been previously reported (14). Maternal height was measured to the nearest 0.1cm using a digital stadiometer (Charder HM200P Portstad Portable Stadiometer, USA) by trained study staff at the first visit during pregnancy. Pre-pregnancy weight and the highest weight during pregnancy were self-reported. Pre-pregnancy BMI was calculated as pre-pregnancy weight (kg) divided by height ($m^2$) and women were classified as underweight (< 18.5), normal (18.5 - 24.9) overweight (< 25.0 - 29) or obese (≥ 30) (15). GWG was calculated as the difference between pre-pregnancy body weight and the highest weight in pregnancy. Women with different pre-pregnancy BMIs were categorised based on whether they were "Below", "Met" or "Above" the Health Canada 2010 guidelines for total GWG (14, 16); detailed method for classification has been previously reported (14).

#### 6.2.2.3 Infant Anthropometrics

Infant birth weight, gestational age at birth and gender were obtained from birth records. Birth length was not consistently reported in the birth records and was reported by the mother (n = 422). Infant body weight at 3 months (n = 453) was measured in the study clinic as the difference in body weight between the mother holding her infant (undressed except for a dry diaper) and the mother alone (average of 3 measurements) (Healthometer Professional 752KL, Pelstar LLC, IL, USA). Measurements were recorded to the nearest 0.01 kg. Infant age (n

= 453) and length at 3 months (n = 282) were reported by the mother.

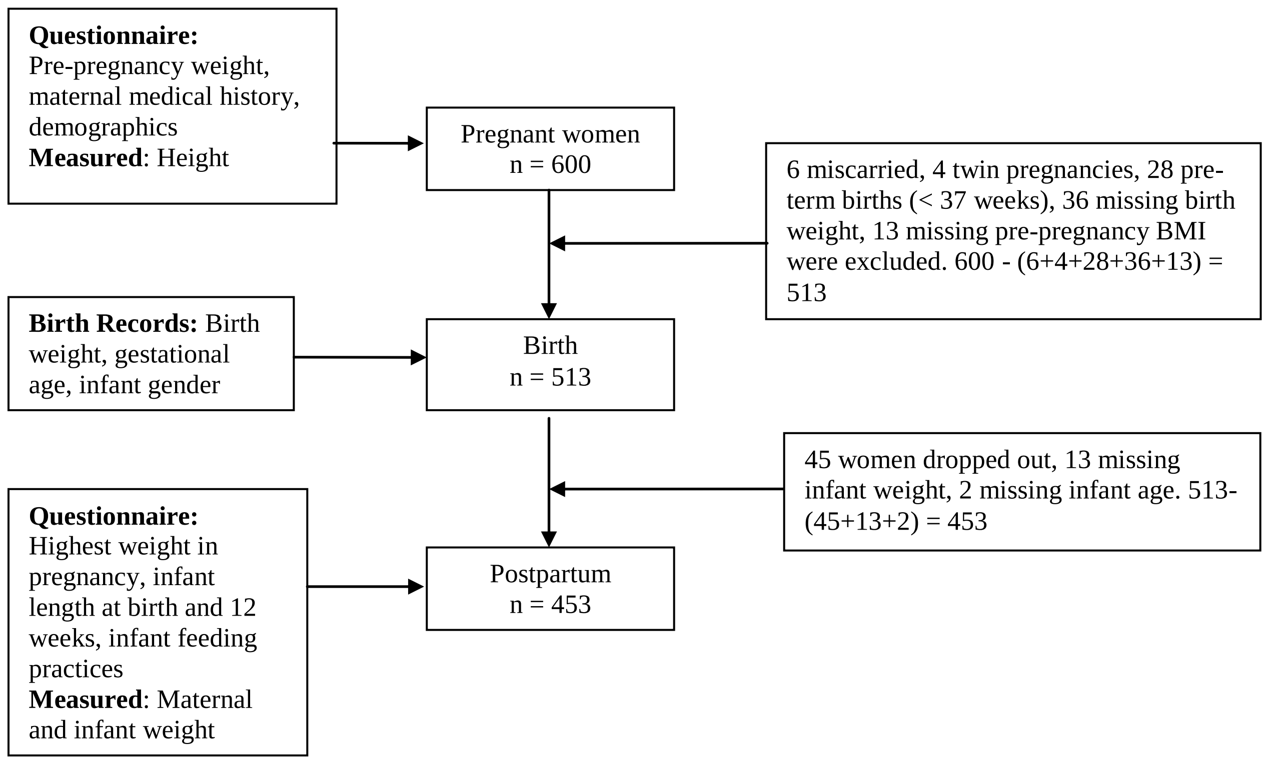
Infant birth weights were converted to gestational age and gender specific z-scores (17). Infant weight, length, weight-for-length and BMI at 3 months were converted into gender and age-specific z-scores according to WHO growth standards (18). Rapid postnatal growth was defined as an increase of > 0.67 in weight-for-age z-score between birth and 3 months; this difference is considered clinically significant since it represents an upward crossing of one percentile line on the infant growth charts (19). Infants were classified as experiencing rapid weight gain (yes) or not (no; change in weight-for-age z-scores < 0.67).

### 6.2.3 Statistical analysis

Differences in infant birth weight and 3 month weight-for-age, length-for-age, weight-for-length and BMI z-score according to maternal characteristics were tested using one-way ANOVA with a Bonferroni correction or Kruskal Wallis non-parametric tests and Wilcoxon rank-sum tests as appropriate. Multilinear regression was used to determine associations between pre-pregnancy BMI, GWG and infant anthropometric variables. Regression models for birth weight z-score analysis were adjusted for maternal age, parity, marital status, prenatal smoking status, ethnicity, education, family income, infant gender and gestational age at birth. Regression analyses of the infant weight-for-age and BMI z-scores at 3 months were adjusted for maternal age, parity, marital status, prenatal smoking status, ethnicity, education, family income and breastfeeding practices. Infant length-for age and weight-for length z-scores were adjusted for the variables listed above as well as birth length and weight gain between birth and 3 months of age. These analyses were adjusted separately for birth weight z-score since birth weight z-score was considered to be a factor on the causal pathway between maternal pre-pregnancy BMI, GWG and infant anthropometrics. The interaction of pre-pregnancy BMI categories and GWG were tested in crude and full models by using interaction terms. Multinomial logistic regression was used to determine the association between maternal pre-pregnancy BMI and GWG adherence and the occurrence of rapid postnatal growth. The multinomial regression analyses were adjusted for maternal pre-pregnancy BMI, age, parity, ethnicity, education, marital status, family income, prenatal smoking status, baby's gender, birth weight z-score, and breastfeeding practices; results from these analyses are presented as adjusted odd ratios (AOR). All data were analysed using STATA (Version 11, StataCorp LP, TX, USA). A p-value of $< 0.05$ was considered statistically significant in all cases.

## 6.3 Results

**Figure 6.1: Participant Recruitment and Follow-up**



Sixty five percent of the women had a normal pre-pregnancy BMI and 3%, 19% and12% were categorized into the pre-pregnancy BMI categories of underweight, overweight and obese respectively (Table 6.1). GWG guidelines were met by 32% of women overall (64.3%, 37.5%, 17.1% and 14.6 % of women in the underweight, normal, overweight and obese BMI categories, respectively) and 57% gained above recommendations (28.6%, 46.8%, 80.7% and 80% of women in the underweight, normal, overweight and obese BMI categories, respectively). Only 11% women gained weight below recommendations (7.1%, 15.7%, 2.3% and 5.6% of women in the underweight, normal, overweight and obese BMI categories, respectively). Study participants were predominantly Caucasian (84%), married/common law (94%), held university degrees (68%) and had high family incomes (54% >100K).The mean gestational age of the infants at birth was 39.3 ± 1.2 weeks, 53% of babies were male and 47 % were female, and 50% of the infants were exclusively breastfed for 3 months.

### 6.3.1 Relationship between Maternal Characteristics and Infant Birth Weight

Birth weight z-scores of infants born to women with a pre-pregnancy BMI in the overweight ($p < 0.01$) or obese ($p < 0.05$) categories were significantly higher than infants born to women with a normal or underweight pre-pregnancy BMI. There was no significant difference in birth weight z-score of babies born to women with an underweight vs. normal pre-pregnancy BMI ($p > 0.05$) or in babies born to women with an overweight vs. obese pre-pregnancy BMI ($p > 0.05$) (Table 6.2). The association between pre-pregnancy BMI and birth weight z-scores remained significant after adjusting for covariates among women with an overweight or obese BMI compared to women with a normal pre-pregnancy BMI (overweight: $\beta = 0.30$, 95% CI = 0.09 - 0.51, $p < 0.01$; obese: $\beta = 0.34$, 95% CI = 0.09 - 0.60, $p < 0.01$). A one unit increase in maternal pre-pregnancy BMI was associated with a 16.4 g increase in birth weight ($p < 0.001$, 95 % C.I. = 8.4 - 24.4).

Infants born to women who gained above the total weight gain recommendations had higher birth weight z-scores ($p < 0.001$) than infants born to women who gained below or who met the recommendations. Infants whose mothers gained below or met recommendations had similar birth weight z-scores ($p > 0.05$) (Table 6.2). The association between GWG above recommendations and higher birth weight z-scores remained significant after adjusting for covariates ($\beta = 0.39$, 95% CI = 0.15 - 0.63; $p<0.01$). A one kilogram increase in maternal GWG was associated with a 19.7 g increase in birth weight ($p < 0.001$, 95 % C.I = 10.7 – 28.8).

When women were stratified by both pre-pregnancy BMI and adherence to GWG guidelines, infants born to women in the normal or overweight categories for pre-pregnancy BMI who gained above GWG recommendations had higher birth weight z-scores than infants born to women who met the weight gain recommendations in these pre-pregnancy BMI categories (infants born to normal pre-pregnancy BMI women: Above = 0.14 ± 0.94 z-score units; Met = - 0.25 ± 0.85 z-score units, ß = 0.35, p = 0.004, 95% C.I. = 0.11- 0.59; infants born to overweight pre-pregnancy BMI women: Above = 0.33 ± 0.85 z-score units; Met

= - 0.28 ± 0.75 z-score units, ß = 0.79, $p < 0.003$, 95 % C.I = 0.28 - 1.29). Within women in the underweight and obese pre-pregnancy BMI categories, there were no significant differences in infant birth weight z-scores irrespective of maternal adherence to GWG recommendations.

Maternal characteristics that were associated with significantly higher birth weight z-scores were: being primiparous vs. nulliparous ($p < 0.01$); being Caucasian ($p < 0.05$) vs. belonging to other ethnic backgrounds; and having a medium ($p < 0.05$) or high ($p <0.05$) family income vs. a low family income (Table 6.2). Family income remained significantly associated with birth weight z-scores after adjusting for covariates (infants born to women with a medium family income: ß = 0.43, 95 % C.I = 0.15 - 0.70, $p = 0.003$; infants born to women with a high family income: ß = 0.43, 95 % C.I = 0.18 - 0.69; $p = 0.001$, vs. low family income).

### 6.3.2 Relationship between Maternal Characteristics and Infant Anthropometric Characteristics at 3 months of age

Weight-for-age z-score at 3 months of age did not differ significantly among infants born to women with different pre-pregnancy BMI ($p > 0.05$) (Table 6.3) although after adjustment for covariates, infants born to women with an overweight pre-pregnancy BMI had higher weight-for-age z-scores than infants born to women with a normal BMI (ß = 0.32, $p = 0.02$, 95% C.I. = 0.06 - 0.58). The addition of infant birth weight z-score to this model attenuated this association ($p = 0.26$).

Infants born to women who gained above recommendations had higher weight-for-age z-scores ($p < 0.001$) than those who were born to women who gained below or met the GWG recommendations. Weight-for-age z-scores of infants whose mothers who gained below or met weight gain recommendations did not differ significantly from each other ($p > 0.05$). These associations did not change after adjusting for maternal and infant characteristics (weight-for-age z-score of infants whose mothers gained above recommendations: $\beta = 0.43$; 95% CI = 0.20 - 0.66; $p < 0.01$; infants whose mothers gained below recommendations: $\beta = - 0.11$; 95% CI = - 0.45 = 0.23; $p > 0.05$). When infant birth weight z-score was included in the regression model, marginal association was observed between GWG and weight-for-age z-score among infants whose mothers gained above recommendations (ß = 0.21, p = 0.053, 95% C.I. = - 0.002 - 0.42).

When women were stratified by both pre-pregnancy BMI and adherence to GWG guidelines, infants born to women with normal or overweight pre-pregnancy BMI and who exceeded recommendations had a higher weight-for-age z-score than infants born to women in these pre-pregnancy BMI groups who met the GWG recommendations [(infants born to women with normal pre-pregnancy BMI: Above GWG guidelines = 0.43 ± 0.95 weight-for-age z-score units; Met GWG guidelines = 0.08 ± 0.98 weight-for-age z-score units, ß = 0.30, p = 0.04, 95 % C.I = 0.01 - 0.58); (infants born to women with overweight pre-pregnancy BMI: Above GWG recommendations = 0.64 ± 0.85 weight-for-age z-score units; Met GWG recommendations = 0.06 ± 0.84 weight-for-age z-score units, ß = 0.59, p = 0.04, 95 % C.I = 0.04 - 1.15)]. These associations were attenuated in both pre-pregnancy BMI categories ($p > 0.05$) when the regression model was adjusted for birth weight z-scores and other covariates. A 1-unit increase in maternal pre-pregnancy BMI was associated with a 21.3 g in increase in infant weight at 3 months ($p = 0.014$, 95 % C.I. = 4.4 - 38.2) and a 1 kg increase in GWG was associated with a 20.6 g increase in infant weight at 3 months ($p = 0.03$, 95 % C.I = 2.4 - 38.9) when adjusted for maternal pre-pregnancy BMI and other covariates.

Infants born to women who gained above GWG recommendations had higher BMI z-scores at 3 months compared to infants whose mothers gained below or met the weight gain recommendations (Table 6.3), and this association remained significant after adjusting for covariates (ß = 0.56, $p = 0.02$, 95 % C.I. = 0.09 – 1.03). This association was not statistically significant after adjusting for birth weight z-scores (ß = 0.47, $p = 0.059$, 95 % C.I = - 0.02 - 0.95).

There were no significant differences in length-for-age or weight-for-length z-scores among infants when categorized by maternal pre-pregnancy BMI ($p > 0.05$) or maternal adherence to GWG recommendations ($p > 0.05$). Length-for-age at 3 months was associated with birth length (ß = 0.10, $p = 0.016$, 95% C.I = 0.02 - 0.18) when adjusted for covariates. There was no evidence for an interaction between GWG and pre-pregnancy BMI for infant birth-weight z scores and weight-for-age, weight-for-length, length-for age or BMI-z scores at 3 months.

Excess GWG was significantly associated with rapid postnatal growth in infants at 3 months of age (Figure 6.1). After adjusting for birth weight z-score, infants born to women who gained excessive weight during pregnancy were nearly twice as likely to experience rapid weight gain between birth and 3 months of age compared to infants born to women who met the GWG recommendations, ($\beta$ =1.9, 95% C.I.= 1.15 - 3.16, p = 0.011). When data was adjusted for maternal pre-pregnancy BMI and other covariates in addition to birth weight z-score, infants born to women who gained excessive weight during pregnancy were more than twice as likely to experience rapid weight gain between birth and 3 months of age compared to infants born to women who met the GWG recommendations ($\beta$ = 2.1, 95% C.I. = 1.15 - 3.83, p = 0.016). Rapid postnatal growth between birth and 3 months was not associated with maternal pre-pregnancy BMI. When the infant growth data were stratified by both maternal pre-pregnancy BMI and adherence to GWG guidelines, infants born to women who had a pre-pregnancy BMI categorized as overweight and who gained excessive gestational weight were more likely to experience rapid weight gain in the first 3 months of life (AOR = 8.7, p = 0.04, 95% C.I = 1.09 - 69.4) than infants born to overweight women who met the weight gain recommendations.

## 6.4 Discussion

There is extensive evidence pointing to gestation as a critical period in fetal development during which foundations are laid for obesity and other chronic conditions. This evidence identifies significant associations between maternal pre-pregnancy BMI and infant birth weight (6), and between GWG and infant/child adiposity at birth, in childhood at 4 and 6 years (20) and in adolescents aged 9-14 years (10). As yet, few studies have examined the role of maternal weight characteristics on infant anthropometrics during the early postnatal period. Results from our study identified strong associations between excessive maternal weight gain in pregnancy, high infant weight-for-age at 3 months and an increased likelihood of rapid growth rates between birth and 3 months. Infants born to women with excessive GWG were over 2 times more likely to experience rapid growth compared to infants born to women who met the GWG recommendations. Moreover, the detrimental effects of excessive weight gain were more pronounced in infants born to women with an overweight pre-pregnancy BMI who gained above GWG recommendations. These infants were over 8 times more likely to experience rapid postnatal growth compared to infants born to women with an overweight pre-pregnancy BMI who met the GWG recommendations. Rapid postnatal growth is an important predictor of childhood obesity and the increase in infant weight observed in infants over this relatively short time is clinically important since it represents moving up one full percentile in the growth chart (11, 21).

Factors contributing to the relationship between excessive maternal weight gain in pregnancy and infant growth in early life deserve further attention. In a prospective pregnancy cohort Deierlein et al (7) examined whether the amount of excessive weight gain during pregnancy was related to infant weight-for-age (n = 354) and length-for-age z-scores (n = 346) in 6 month old infants (adjusted for birth weight). They reported that gaining 200% or more above the recommended gestational weight was associated with higher weight-for-age and length-for-age z-scores in these infants, but maternal weight gains that exceeded recommendations by less than 200% had no effect on infant outcomes. However in a multilinear regression analysis that was adjusted for birth weight z-scores and other maternal covariates, we were unable to observe a similar association between exceeding ≥ 200% above recommended gestational weight and infant weight- for-age at 3 months in our sample. Our data for the present analysis included only a small number of women who gained ≥ 200% above recommendations (n = 27). Further examination of women from the entire APrON cohort (which will eventually exceed 2000) might delineate the effect of ranges of excessive GWG that may influence maternal and/or infant health outcomes.

Recent studies examining hormonal and soluble factors such as leptin and inflammatory markers in breast milk as potential contributors to infant growth suggest that breast milk from heavier women would likely limit, rather than promote, rapid weight gain in young infants (22, 23). Factors related to infant feeding other than breast milk composition may also influence early infant postnatal growth but have not been explored in detail. These factors could include infant feeding style or schedule (24). We did not observe any association between the breastfeeding variables available in our database (categorized as exclusive breast feeding, mixed feeding and exclusive formula feeding) and weight-for-age z-scores or rapid growth. This may be due to the relatively homogenous population in our study since 56% women exclusively breastfed for the first 3 months and 36% used a “mixed feeding” approach (consisting of breast feeding with occasional formula feeds); only 9 women (2%) indicated that they exclusively formula fed their infants and information on breastfeeding practices were not available for 26 participants (6%). Detailed analysis of interactions between maternal anthropometrics and infant feeding practices could be important to elucidate in future studies.

Our study results confirm that adherence to GWG recommendations is essential to minimize the risk of childhood obesity, hence it is important to identify means to help women achieve optimal body weights both prior to and during pregnancy. Such efforts could help to optimize birth outcomes and influence postnatal growth patterns. Since less weight gain is recommended for women with higher pre-pregnancy BMIs it is likely challenging to adhere to these recommendations during pregnancy. Future studies developing intervention programs to support optimal weight gain during pregnancy that are specifically targeted to women with higher pre-pregnancy BMI are warranted.

The positive relationship between maternal pre-pregnancy BMI and infant birth weight is consistent with several other studies in different parts of the world (25, 26). Results from this project confirm these observations in a Canadian population that is primarily Caucasian, highly educated, with high income and receiving socialized health care. High maternal pre-pregnancy BMI continued to be associated with higher infant weight-for-age z-scores at 3 months of age although this appeared to be mediated through effects on birth weight since the addition of birth weight as a covariate attenuated this association. Examining factors such as infant feeding and sociodemographic variables in addition to maternal weight characteristics would add further information to understand this topic.

In contrast to a recent study (7) we did not observe a significant association between pre-pregnancy BMI or excessive GWG and infant length-for-age z-score or weight-for-length z-score at ~3 months respectively. It is not clear whether the absence of these associations reflects the early time point that was the focus of the present analyses. Linear growth follows weight gain during infancy and childhood (27) and further follow-up of infants in the APrON cohort could clarify the relationships reported by others with respect to linear growth.

**Limitations**

The APrON participants included in these analyses comprise a relatively homogenous group with respect to socio-demographic variables which may limit our ability to identify associations between infant anthropometrics and maternal ethnicity, age, education, marital status, parity or breastfeeding practices. Our study results indicate that belonging to a low income family was associated with a lower birth weight (28, 29) when compared to belonging to a middle or high income family. Further studies that focus on women in specific risk groups are required to understand the association between maternal socio-demographic characteristics and birth weight and postnatal growth.

The relatively small numbers in some of the pre-pregnancy BMI groups, particularly the underweight and obese BMI groups, and GWG strata likely contributes to non-significant associations observed with infant characteristics in these categories. These relationships may be better defined within the APrON study once the full cohort is available.

### 6.5 Conclusion

Excessive GWG is an important predictor of birth weight and infant weight, adiposity and rapid postnatal growth. Infants born to overweight and obese women are more vulnerable to unfavourable effects of excessive GWG. Clinicians and health care professionals should encourage women to enter pregnancy with a healthy BMI and adhere to the current GWG recommendations. Future studies may be needed to design tools and intervention programs for supporting weight loss prior to pregnancy and appropriate weight gain during pregnancy. Such programs would have the potential to positively affect maternal health and early infant growth and could lower risk of childhood obesity.

**Table 6.1: Anthropometric, gestational weight gain and socio-demographic characteristics, of mother-infant pairs enrolled in the Alberta Pregnancy Outcomes and Nutrition Study (APrON)**

| Characteristics[1] | n[2] | Underweight[3] | Normal | Overweight | Obese |
|---|---|---|---|---|---|
| Maternal Characteristics | | | | | |
| Pre-pregnancy weight (kg) | 513 | 50.0 ± 4.6 | 59.6 ± 6.6 | 74.3 ± 6.2 | 93.3 ± 11.5 |
| Height (cm) | 513 | 168.1 ± 5.8 | 165.7 ± 6.7 | 166.5 ± 5.3 | 166.1 ± 6.6 |
| Pre-pregnancy BMI(kg/m$^2$) | 513 | 17.6 ± 0.8 | 21.7 ± 1.6 | 26.8 ± 1.3 | 33.6 ± 3.6 |
| Gestational Weight Gain[4] (kg) | | | | | |
| Below | 52 | 11.6 ± 0 | 9.3 ± 2.5 | 6.6 ± 0.3 | 2.8 ± 1.6 |
| Met | 142 | 14.2 ± 1.6 | 14.1 ± 1.4 | 9.9 ± 1.5 | 7.4 ± 1.2 |
| Above | 256 | 23.9 ± 3.7 | 20.7 ± 4.1 | 17.9 ± 4.5 | 15.5 ± 5.9 |
| Age (yrs) | | | | | |
| 17-30 | 230 | 27.2 ± 3.1 | 27.9 ± 2.3 | 27.8 ± 2.8 | 27.9 ± 2.1 |
| 31-45 | 283 | 33.6 ± 2.7 | 34.7 ± 2.7 | 35.1 ± 3.1 | 34.1 ± 2.2 |
| Parity (%) | | | | | |
| 0 | 276 | 2.9 | 67.9 | 17.3 | 11.9 |
| 1 | 165 | 3.6 | 61.3 | 24.8 | 10.3 |
| 2 + | 52 | 2.0 | 59.6 | 19.2 | 19.2 |
| Marital Status (%) | | | | | |
| Married | 486 | 2.9 | 65.4 | 20.0 | 11.7 |
| Other | 14 | 7.1 | 57.1 | 14.3 | 21.4 |
| Smoking Status (%) | | | | | |
| Never Smoked | 335 | 3.0 | 63.9 | 20.3 | 12.8 |
| Ever Smoked | 155 | 1.9 | 67.7 | 20.0 | 10.3 |
| Ethnicity (%) | | | | | |
| Caucasian | 433 | 2.5 | 64.0 | 21.3 | 12.2 |
| Other | 67 | 6.0 | 73.0 | 10.5 | 10.5 |
| Family Income[5] (%) | | | | | |
| Low (≤ 69K) | 95 | 7.4 | 61.1 | 20.0 | 11.6 |

| | | | | | |
|---|---|---|---|---|---|
| Medium (70-99K) | 118 | 2.5 | 59.3 | 17.0 | 21.2 |
| High(≥ 100K) | 280 | 1.8 | 68.9 | 19.3 | 10.0 |
| Maternal Education (%) | | | | | |
| High School/ Diploma/Cert | 150 | 4.0 | 54.7 | 20.0 | 21.3 |
| Univ. Degree/ Post Grad | 350 | 2.6 | 69.7 | 19.1 | 8.6 |
| Infant Characteristics Birth | | | | | |
| Gestational Age Term (wks) | 513 | 38.9 ± 1.1 | 39.4 ± 1.2 | 39.1 ± 1.2 | 39.3 ± 1.2 |
| Weight (gm) | 513 | 3157 ± 471 | 3393± 438 | 3526 ± 423 | 3537 ± 479 |
| Length (cm) | 422 | 49.7 ± 4.1 | 51.3 ± 3.1 | 52.2 ± 2.8 | 51.4 ± 3.6 |
| Baby's Gender (%) | | | | | |
| Male | 272 | 2.2 | 65.6 | 21.3 | 11.0 |
| Female | 241 | 3.7 | 64.7 | 17.8 | 13.7 |
| 3 Month | | | | | |
| Age (wks) | 454 | 11.5 ± 1.0 | 11.7 ± 1.7 | 11.6 ± 1.5 | 11.5 ± 2.0 |
| Weight (gm) | 454 | 6021 ± 762 | 6068 ± 782 | 6308 ± 753 | 6138 ± 785 |
| Length (cm) | 282 | 58.0 ± 3.3 | 59.5 ± 3.2 | 60.5 ± 3.6 | 59.2 ± 2.8 |
| Infant Feeding (%)(0-3 months) | | | | | |
| Exclusive Breastfeeding | 255 | 3.9 | 69.1 | 17.2 | 9.8 |
| Mixed Feeding | 163 | 2.5 | 58.9 | 24.5 | 14.1 |
| Exclusive Formula Feeding | 9 | - | 77.8 | 11.1 | 11.1 |

[1] Values reported for parity, marital status, smoking status, ethnicity, family income, maternal education, baby`s gender and infant feeding are % of population responding to the question; values for all other characteristics are Mean ± S.D

[2] Sample sizes within a particular characteristic may not total 513 due to missing responses

[3] Based on their pre-pregnancy BMI ($kg/m^2$) women were classified as underweight (< 18.5 $kg/m^2$), normal (18.5 - 24.9 $kg/m^2$) overweight (< 25.0 – 29 $kg/m^2$) or obese (≥ 30 $kg/m^2$) (Health Canada, 2003)

[4] Designated as below, met or above gestational weight gain guidelines (Health Canada, 2010)

[5] Statistics Canada (2011), Median total income by family type, by census metropolitan area, CANSIM, table 111-0009. http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil107a-eng.htm

**Table 6.2: Infant birth weight z-score according to maternal anthropometric and socio-demographic characteristics among participants in the Alberta Pregnancy Outcomes and Nutrition (APrON) Study**

| Characteristics | Birth weight z-score[1] | |
|---|---|---|
| | N | Mean ± S.D |
| Pre-pregnancy BMI[2] | | |
| Underweight | 15 | - 0.50 ± 0.97[a] |
| Normal | 334 | - 0.13 ± 0.90[a] |
| Overweight | 101 | 0.21 ± 0.85[b] |
| Obese | 63 | 0.21 ± 1.03[b] |
| Gestational Weight Gain(kg)[2] | | |
| Below | 52 | - 0.34 ± 0.79[c] |
| Met | 141 | - 0.29 ± 0.83[c] |
| Above | 256 | 0.20 ± 0.95[d] |
| Maternal Age[2] | | |
| 17-30 | 230 | - 0.07 ± 0.92 |
| 31-45 | 283 | 0.001 ± 0.93 |
| Parity[2] | | |
| Nulliparous | 276 | - 0.15 ± 0.89[a] |
| Primiparous | 165 | 0.12 ± 0.95[b] |
| Multiparous | 52 | 0.08 ± 0.84[ab] |
| Marital Status[2] | | |
| Married | 485 | - 0.04 ± 0.92 |
| Other | 14 | 0.07 ± 0.79 |
| Prenatal Smoking Status[2] | | |
| Never Smoked | 335 | - 0.02 ± 0.95 |
| Ever Smoked | 154 | 0.01 ± 0.85 |
| Ethnicity[2] | | |
| Caucasian | 433 | 0.004 ± 0.90[c] |
| Other | 66 | -0.29 ± 1.03[d] |
| Family Income[2] | | |
| Low (≤ 69K) | 95 | - 0.35 ± 0.89[c] |
| Medium (70-99K) | 118 | 0.15 ± 0.85[d] |
| High (≥ 100K) | 279 | 0.01 ± 0.94[d] |
| Maternal Education[2] | | |

| | | |
|---|---|---|
| High School/ Diploma/Cert | 150 | - 0.08 ± 0.98 |
| Univ.Degree / Post Grad | 349 | - 0.01±0.89 |
| Infant Gender [2] | | |
| Male | 272 | - 0.01 ± 0.92 |
| Female | 241 | - 0.05 ± 0.93 |

[1]Sample sizes within a particular characteristic may not equal to the total n due to missing responses

[2] One-way ANOVA with Bonferroni corrections

[a, b] Values with different superscripts are significantly different from each other, $p \leq 0.05$

[c, d] Values with different superscripts are significantly different from each other, $p < 0.01$

**Table 6.3: Infant weight-for-age z-scores and BMI z-scores at approximately 3 months of age according to by maternal anthropometric and socio-demographic characteristics among infants born to women participating in the Alberta Pregnancy Outcomes and Nutrition (APrON) Study**

| Characteristics | Weight-forage z-score[1] | | | BMI z-score[1] | | |
|---|---|---|---|---|---|---|
| | n | Mean ± S.D | p value | n | Mean ± S.D | p value |
| Pre-pregnancy BMI | | | | | | |
| Underweight | 14 | 0.28 ± 0.97 | 0.057[2] | 7 | 0.48 ± 1.08 | 0.41[2] |
| Normal | 298 | 0.20 ± 0.98 | | 178 | 0.29 ± 1.52 | |
| Overweight | 87 | 0.50 ± 0.86 | | 53 | 0.37 ± 1.59 | |
| Obese | 54 | 0.41 ± 1.03 | | 39 | 0.73 ± 1.21 | |
| Gestational Weight Gain(kg) | | | | | | |
| Below | 51 | -0.09 ± 0.89[a] | 0.001[2] | 32 | - 0.13 ± 1.34[a] | 0.001[2] |
| Met | 140 | 0.05 ± 0.94[a] | | 90 | 0.09 ± 1.49[a] | |
| Above | 246 | 0.49 ± 0.94[b] | | 147 | 0.66 ± 1.44[b] | |
| Maternal Age | | | | | | |
| 17-30 | 209 | 0.34 ± 0.86 | 0.17[3] | 131 | 0.45 ± 1.34 | 0.41[3] |
| 31-45 | 245 | 0.23 ± 1.05 | | 146 | 0.30 ± 1.61 | |
| Parity | | | | | | |
| Nulliparous | 253 | 0.22 ± 0.99 | 0.31[2] | 165 | 0.27 ± 1.47 | 0.20[2] |
| Primiparous | 145 | 0.37 ± 0.94 | | 82 | 0.60 ± 1.56 | |
| Multiparous | 47 | 0.32 ± 0.93 | | 24 | 0.17 ± 1.31 | |
| Marital Status | | | | | | |
| Married | 440 | 0.27 ± 0.97 | 0.30[2] | 270 | 0.36 ± 1.50 | 0.98[3] |
| Other | 12 | 0.56 ± 0.75 | | 5 | 0.35 ± 0.54 | |
| Prenatal Smoking Status | | | | | | |
| Never Smoked | 294 | 0.29 ± 0.99 | 0.81[2] | 179 | 0.31 ± 1.48 | 0.17[2] |

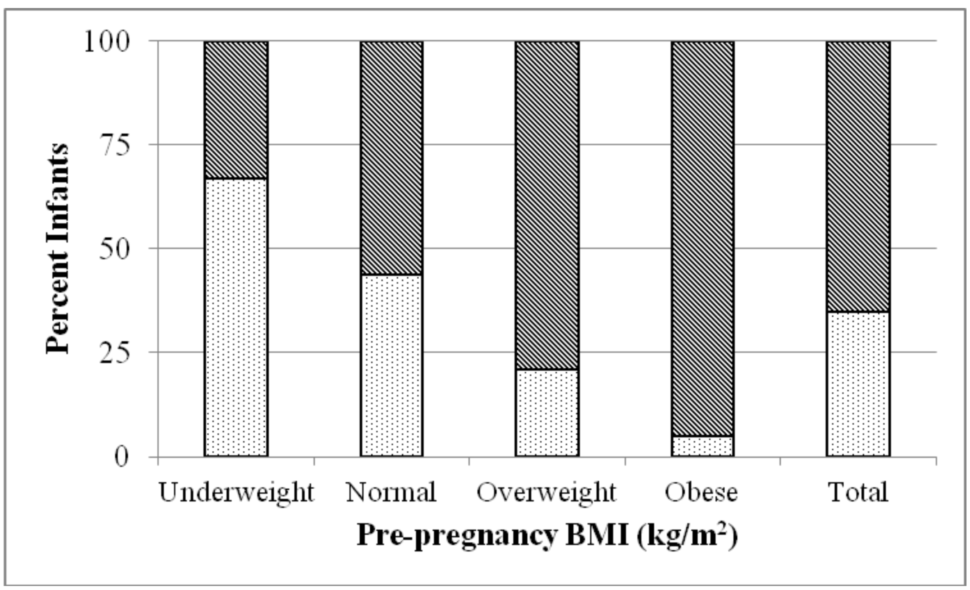
| | | | | | | |
|---|---|---|---|---|---|---|
| Ever Smoked | 140 | 0.31 ± 0.93 | | 86 | 0.58 ± 1.53 | |
| Ethnicity | | | | | | |
| Caucasian | 391 | 0.29 ± 0.97 | 0.84[2] | 240 | 0.36 ± 1.50 | 0.71[2] |
| Other | 61 | 0.24 ± 0.95 | | 35 | 0.47 ± 1.43 | |
| Family Income | | | | | | |
| Low (≤ 69K) | 84 | 0.12 ± 0.98 | 0.15[2] | 45 | 0.24 ± 1.46 | 0.76[2] |
| Medium (70-99K) | 112 | 0.39 ± 1.02 | | 71 | 0.44 ± 1.53 | |
| High (≥ 100K) | 249 | 0.28 ± 0.95 | | 147 | 0.33 ± 1.48 | |
| Maternal Education | | | | | | |
| High School/ Diploma/Cert | 134 | 0.23 ± 0.91 | 0.45[2] | 83 | 0.52 ± 1.47 | 0.26[2] |
| Univ.Degree/ Post Grad | 318 | 0.30 ± 1.00 | | 192 | 0.30 ± 1.50 | |
| Infant Gender | | | | | | |
| Male | 239 | 0.25 ± 0.98 | 0.57[2] | 149 | 0.42 ± 1.59 | 0.55[2] |
| Female | 215 | 0.31 ± 0.96 | | 128 | 0.32 ± 1.37 | |
| Infant feeding | | | | | | |
| Exclusive Breastfed ≥12 weeks | 245 | 0.35 ± 0.93 | 0.99[2] | 143 | 0.40 ± 1.51 | 0.96[2] |
| Mixed Feeding | 158 | 0.13 ± 1.04 | | 103 | 0.34 ± 1.47 | |
| Exclusive Formula Feeding | 9 | 0.77 ± 1.16 | | 6 | 0.40 ± 1.46 | |

[1]sample sizes within a particular characteristic may not equal to the total n due to missing responses

[2] One-way ANOVA with Bonferroni corrections

[3] Kruskal-Wallis non-parametric test and post-hoc estimation by two-sample Wilcoxon rank-sum test

**Figure 6.2: Percentage of infants who experienced rapid growth between birth to 3 months born to women who "Met" gestational weight gain recommendations [underweight (n=4), normal weight (n=34), overweight (n=6) and obese(n=1)] or who gained "Above" the recommended amounts of gestational weight [underweight (n=2), normal weight (n=43), overweight (n=23) and obese(n=18)] enrolled in the Alberta Pregnancy Outcomes and Nutrition Study (APrON)**



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# CHAPTER 7: Final Discussion and Conclusions

## 7.1 Review of Study Questions and Conclusions

**<u>Study Questions from Chapter 3</u>**

**1. Among women with different pre-pregnancy BMI what is the**

- **a) total weight gain in pregnancy;**
- **b) weekly weight gain between second and third trimester during pregnancy; and**
- c) **postpartum weight retention?**

1a. Total weight gained by women from the underweight, normal, overweight and obese pre-pregnancy BMI categories was 16.8 ± 5.2 kg, 16.3 ± 5.3 kg, 16.1 ± 5.3 kg and 13.6 ±6.5 kg respectively. There was no significant difference in total weight gain among underweight, normal-weight and overweight women ($p>0.05$); however, obese women gained less total gestational weight than normal-weight women ($p<0.01$).

1b. The rate of weekly weight gain between the second and third trimester of pregnancy was not significantly different among underweight (0.51 ± 0.19 kg/wk), normal (0.58 ± 0.21 kg/wk) and overweight women (0.56 ± 0.22 kg/wk) ($p>0.05$); however, obese women gained weight at a slower rate (0.46 ±0.27 kg/wk) than did women from other pre-pregnancy BMI categories ($p<0.01$).

1c. There was no significant difference in postpartum weight retention irrespective of pre-pregnancy BMI categories ($p>0.05$).

**2. Do women in all of the pre-pregnancy BMI categories adhere to the 2010 total and weekly weight gain recommendations from Health Canada?**

Overall, total GWG recommendations were met by 32% of women; 57% of women gained above recommendations and 11% women gained below recommendations. The percentage of women in the underweight, normal-weight, overweight and obese pre-pregnancy BMI categories who met the total GWG recommendations were 64.3%, 38%, 16.1% and 14.2 % respectively. Approximately 30%, 46%, 80% and 80% of women in the underweight, normal, overweight and obese pre-pregnancy BMI categories respectively gained above total GWG recommendations. Overweight (OR = 5.5, $p<0.001$) and obese (OR = 6.5, $p<0.001$) women were more likely than normal-weight women to exceed GWG guidelines. Overall weekly weight gain recommendations were exceeded by 71% of women (38% in the underweight, 66% in the normal-weight, 87% in the overweight and 76% in the obese pre-pregnancy BMI categories). Overweight women were more likely to exceed weekly weight gain recommendations than normal weight women (OR = 2.97, $p<0.01$).

**3. Is there an association between adherence to the total gestational weight gain recommendations and postpartum weight retention?**

Measured postpartum weight retention, according to adherence to total GWG recommendations, was as follows: women who met recommendations retained 3.3 ± 3.3 kg, women who gained above recommendations retained 5.9 ± 5.1 kg, and women who gained below recommendations retained 0.66 ± 2.6 kg body weight at postpartum. Compared to women who met the total weight gain recommendations, women who gained above weight gain recommendations retained more weight at postpartum ($p<0.001$), whereas women who gained below the weight gain recommendations retained less weight ($p<0.001$).

**Study Questions from Chapter 4**

**4. Among women with different pre-pregnancy BMI what is the**

- **a) pattern of fat mass accretion during pregnancy;**
- **b) amount of fat loss between third trimester in pregnancy to postpartum;**
- **c) amount of fat retained at postpartum; and**
- **d) pattern of fat distribution in pregnancy and at postpartum?**

4a. Normal-weight women showed an incremental gain in fat mass at each trimester during pregnancy compared to that measured in the preceding study visit ($p<0.01$). Overweight women showed an increase in fat mass at trimester 3 in pregnancy compared to that at trimester 1 ($p<0.05$). Obese women showed a marginal but non-significant increase in their trimester 3 fat mass when compared to their trimester 1 fat mass ($p = 0.071$). The total fat mass gained during pregnancy, measured according to normal, overweight and obese pre-pregnancy BMI categories, was 3.5 ± 2.2 kg, 2.5 ± 3.0 kg and 1.5 ± 3.4 kg respectively. Obese women gained significantly less total fat mass than normal-weight and overweight women ($p<0.01$).

4b. Fat loss between trimester 3 in pregnancy and postpartum among women with pre-pregnancy BMI in the, normal, overweight and obese categories, was -2.0 ± 2.8,-1.4 ± 3.7 and -0.3 ± 3.9 respectively. Obese women lost less fat mass than women from the normal or overweight pre-pregnancy BMI categories ($p<0.01$).

4c. There was no significant difference in the amount of fat mass retained at postpartum based on pre-pregnancy BMI categories ($p>0.05$).

4d. The skinfold thicknesses at all sites (triceps, subscapula, suprailiac and thigh) were significantly higher among the overweight and obese women than among normal-weight women at all study visits during pregnancy ($p<0.01$). Women from the normal and overweight pre-pregnancy BMI groups gained higher amounts of fat mass at all skinfold sites during pregnancy ($p<0.05$). However, obese women gained a significant amount of fat mass only at the subscapular skin fold site. At postpartum, normal-weight women lost significant skinfold thickness at the subscapula and suprailiac sites; however, overweight and obese women increased skinfold thickness at the subscapula region relative to the normal women ($p\leq0.01$) and lost fat mass more slowly at the suprailiac region than did normal-weight women. At postpartum, the waist:hip ratio of overweight and obese women was higher than that of normal-weight women ($p<0.01$).

**5. Among women with different pre-pregnancy BMI, what is the pattern of fat-free mass accretion during pregnancy and postpartum?**

All women showed an incremental gain in fat-free mass at each trimester during pregnancy compared to that at the preceding study visit ($p<0.01$), followed by a significant decline in fat-free mass at postpartum ($p<0.01$). Compared to their fat-free mass at trimester 1, normal and overweight women retained a significantly higher amount of fat-free mass at postpartum ($p<0.01$), while obese women showed no significant difference ($p>0.05$).

**<u>Study Questions from Chapter 5</u>**

**6. Among women with different pre-pregnancy BMI what is the pattern of**

- **a) energy and macronutrient intake during pregnancy;**
- **b) physical activity during pregnancy; and**
- **c) resting energy expenditure during pregnancy?**

6a.Energy intake of obese women was significantly less than that of normal-weight women at trimester 2 and 3. There was no significant difference in macronutrient intake during pregnancy among women from different pre-pregnancy BMI categories ($p>0.05$).

6b. Women from the overweight ($p = 0.04$) and obese ($p = 0.02$) pre-pregnancy BMI categories had a significantly lower total physical activity score (and most notably, a lower sports score) at all study visits during pregnancy ($p<0.05$) than normal-weight women. Obese women had a lower leisure score than did to normal-weight women ($p = 0.02$).

6c. Women from all pre-pregnancy BMI categories showed an incremental increase in REE compared to their REE at the preceding study visits ($p<0.01$). However, compared to normal-weight women, overweight ($p<0.01$) and obese ($p<0.01$) women had a significantly higher REE at all study visits during pregnancy.

**7. What is the association between energy intake, physical activity and resting energy expenditure during pregnancy with**

- **a) changes in fat mass during pregnancy;**
- **b) changes in fat-free mass during pregnancy;**
- c) **adherence to weight gain recommendations during pregnancy?**

Energy and macronutrient intake were not significantly associated with changes in fat mass ($p>0.05$) and fat-free mass ($p>0.05$) during pregnancy, or with adherence to total weight gain recommendations ($p>0.05$). The sports physical activity score was inversely associated with fat mass accretion ($p<0.01$) and positively associated with fat-free mass accretion ($p<0.01$) during pregnancy. REE was positively associated with fat mass ($p<0.001$) and fat-free mass ($p<0.001$) accretion during pregnancy, and with gaining above total GWG recommendations ($p<0.001$).

**Study Questions from Chapter 6**

**8. Among women with different pre-pregnancy BMI what is the**

- **a) infant birth weight;**
- **b) weight, length and BMI at 3 months;**
- **c) infant rapid growth between birth to 3 months?**

8a. Infants born to women from the underweight, normal, overweight and obese pre-pregnancy BMI categories weighed (Mean ± S.D) 3157 ± 471g, 3393 ± 438g, 3526 ± 423g and 3537 ± 479g respectively at birth. Birth weight z-scores of infants born to overweight (0.21 ± 0.85, $p<0.05$) and obese (0.21 ± 1.03, $p<0.05$) women were higher than those of infants born to normal-weight women (- 0.13 ± 0.90).

8b. The weight of infants born to underweight, normal, overweight and obese women at 3 months was (Mean ± S.D) 6021 ± 762g, 6068 ± 782g, 6308 ± 753g and 6138 ± 785g respectively. The weight-for-age z-score of infants born to overweight women (0.50 ± 0.86) was higher than that of infants born to women with a normal pre-pregnancy BMI (0.20 ± 0.98, $p<0.05$). There was no significant difference in length-for-age, weight-for-length and BMI z-scores, irrespective of maternal pre-pregnancy BMI ($p>0.05$).

8c. There was no significant difference in rapid postnatal growth between birth and 3 months among infants irrespective of maternal pre-pregnancy BMI ($p>0.05$).

9**. Is there an association between maternal adherence to gestational weight gain recommendations and:**

**a) infant birth weight;**

**b) weight, length and BMI at 3 months; and**

c) **infant rapid growth between birth to 3 months?**

9a. Infants born to women who gained the recommended weight, gained above recommendations or gained below recommendations weighed 3316.1 ± 392.6 g, 3549.2 ± 452.7g and 3255.3 ± 410.8 respectively. The birth weight z-scores of infants born to women who gained above recommendations were significantly higher than those of infants born to women who met the total weight recommendations ($p<0.01$).

9b. At 3 months, body weight of infants born to women who gained weight according to recommendations, gained above recommendations or gained below recommendations was (Mean ± S.D) 5935 ± 728g, 6275 ± 762g and 5826 ± 696g respectively. The weight-for age and BMI z -scores of infants born to women who gained above recommendations were significantly higher than those of infants born to women who met the total weight recommendations (p<0.01). Length-for-age and weight-for-length z-scores were not significantly different irrespective of maternal adherence to weight gain recommendations (p>0.05).

9c. Infants born to women who gained gestational weight above recommendations experienced more rapid postnatal growth from birth to 3 months than did infants of women who met weight gain recommendations (OR = 2.1, p = 0.016).

**7.2 Discussion**

This thesis has examined the changes in body weight and composition during pregnancy and early in the postpartum period; the influence of maternal physical, socio-demographic, behavioural and physiological factors on these changes were analysed. This thesis also examined the consequences of maternal adherence to gestational weight recommendations on infant outcomes at birth and 3 months and on maternal postpartum weight retention. The main finding of this research is that over 50% women gain gestational weight above clinical recommendations. This is especially true of women with a higher pre-pregnancy BMI. There is an inverse association between high pre-pregnancy BMI and total fat mass gain during pregnancy; however, both overweight and obese women deposit fat mass selectively in the truncal and abdominal regions during pregnancy and retain it at postpartum. Physical activity, changes in resting energy expenditure and sociodemographic factors such as parity, ethnicity, education and income also influence changes in body weight and adiposity. Higher GWG was significantly associated with postpartum weight retention and with higher infant weight at birth and at 3 months, and with rapid postnatal growth in infants at 3 months. These consequences may put both the mother and her infant at an increased risk of developing chronic conditions in their later life.

### 7.2.1 Changes in Body Weight and Composition during Pregnancy and Postpartum

Chapter 3 examined weight gain during pregnancy and weight retention at postpartum. A significant proportion of women form the overweight and obese pre-pregnancy BMI categories gained above the total GWG recommendations and weekly weight gain recommendations. These findings were consistent with previous studies conducted in other countries (1-4). Although previous studies have reported excessive weight gain by pregnant women, the overall proportion of women exceeding the total GWG recommended in the present study were significantly higher (57%) than those reported by others (42-49%) (1, 2). When measured according to BMI categories, 80% of the women in the overweight and obese categories and 46% of the normal-weight women gained excessive total GWG. This is, moreover, the first Canadian study to report adherence to weekly weight gain recommendations. On the whole, 71% women exceeded the rate of GWG recommendations between the second and third trimesters. The findings of Chapter 3 also showed that excessive GWG, irrespective of pre-pregnancy BMI, was significantly associated with postpartum weight retention, as has been reported in a few other studies (4, 5). We also showed that BMI increased by 1.5 $kg/m^2$ from pre-pregnancy to postpartum across all pre-pregnancy BMI categories. In addition, among women who had a normal pre-pregnancy BMI, those women who gained above recommended GWG were more than four times more likely to move to a BMI classified as overweight at postpartum than were women who met recommendations (OR = 4.1, 95% CI 1.96-8.64, $p<0.05$). These findings suggest that gaining above the recommended weight ranges during pregnancy is a significant risk factor for the development of overweight and obesity in women later in life. In the context of increasing levels of obesity in Canadian society, this situation is alarming as it may significantly contribute to these trends.

Chapter 4 examined body composition changes during pregnancy and postpartum. Its findings were consistent with previous study results suggesting that high pre-pregnancy BMI is inversely associated with fat mass accretion (6); obese women in this study gained less total fat mass, and experienced a slower rate of fat accretion in late pregnancy, than did normal weight women. However, they lost less fat mass between trimester 3 and postpartum than did normal-weight women. Overweight women gained a quantity of total fat mass similar to that gained by normal-weight women, but they were unable to mobilize fat mass as efficiently at postpartum as were the latter. Furthermore, overweight and obese women were at an increased risk of higher postpartum fat retention, particularly in the truncal and abdominal regions (7, 8).

A major conclusion drawn from the above findings (Chapters 3 and 4) is that a significant proportion of women from all pre-pregnancy BMI categories exceeded GWG recommendations; this is especially true for women from the overweight and obese pre-pregnancy BMI categories. Excessive GWG was positively associated with postpartum weight retention irrespective of pre-pregnancy BMI. In addition, all women irrespective of pre-pregnancy BMI retained a higher amount of fat mass at postpartum compared to their trimester 1 fat mass; slow fat mass loss and higher fat retention in the truncal/abdominal region was more common in the overweight and obese women at postpartum. These findings are of particular concern in light of growing rates of overweight and obesity among women of child-bearing age, as excessive GWG and retention of fat, especially central adiposity, could exacerbate the risk of developing chronic diseases in all women, and particularly in women with a higher BMI, in the future.

### 7.2.2. Factors associated with Adherence to Gestational Weight Gain Recommendations and Changes in Body Composition during Pregnancy and Postpartum

Maternal sociodemographic, lifestyle (diet and physical activity) and physiological (resting energy expenditure) factors associated with weight gain and adiposity were examined in Chapters 3, 4 and 5. Pre-pregnancy BMI, parity, maternal smoking status, ethnicity, age and family income were associated with weight gain and adiposity during pregnancy and postpartum. Nulliparity and maternal smoking status were significantly associated with excessive GWG and with faster rates of fat accumulation in late pregnancy. Belonging to a younger age group (17-30 years) was associated with higher GWG (though at a level that was not significant after adjusting for other covariates) and with a faster rate of fat mass accretion in late pregnancy. Significant differences in GWG and adiposity were also observed on the basis of ethnicity, and belonging to low income was a significant predictor of higher postpartum weight and fat retention, and of low birth weight. These results were consistent with previous studies of pregnant women (4, 5, 9, 10). In addition longer duration of breast feeding was associated with higher fat mass loss at postpartum (11).

Results from Chapter 5 indicate that sports activity score was a significant predictor of fat mass and fat-free mass accretion during pregnancy, after adjusting for all covariates. In a study yielding comparable findings, Stuebe et al.(12) examined 1388 pregnant women and reported that greater physical activity was associated with lower risk of excessive GWG. In the "Active Mothers Postpartum" study, which included 450 overweight and obese postpartum women; Ostbye et al.(13) found that postpartum weight retention was significantly associated with being less physically active. Results from the present study also showed a positive association between resting energy expenditure was and fat mass, fat free mass, and excessive GWG during pregnancy. Unlike Stuebe et al, however, we were unable to find any associations between energy intake and GWG (12) or adiposity in pregnancy. The main reasons for this may be due to the fact that though women from different pre-pregnancy BMI groups in this study consumed similar amount of energy intake throughout pregnancy their actual requirement of energy intake maybe different. Further the effect of consuming specific food groups and nutrients such as sugar and saturated fat may also contribute to variations in weight gain and adiposity; however answering these questions was not the objective of this study.

The findings of Chapters 3,4 and 5 thus suggest that the significant predictors of changes in weight and adiposity during pregnancy are maternal parity, smoking status, ethnicity, age, family income, physical activity and resting energy expenditure.

### 7.2.3. Outcomes of Excessive Gestational Weight Gain on Infant Anthropometrics

Chapter 6 examined the association between maternal pre-pregnancy BMI and weight gain within and outside the recommended gestational weight ranges, and considered their effects on infant outcomes at birth and 3 months. Results from this research show a positive association between high maternal pre-pregnancy BMI and GWG, which has an influence on infants' weight at birth and 3 months ($p<0.01$). These findings are consistent with previous findings (1, 14). However there is limited evidence concerning the influence of GWG on early postnatal growth trajectories. Rapid postnatal growth has recently been identified as a potential risk factor for childhood obesity (15, 16); results from this research demonstrate that higher GWG may predispose rapid postnatal growth at an early age. Furthermore, the detrimental effects of excess GWG are exacerbated when women are overweight prior to pregnancy. Infants born to overweight women who exceeded GWG recommendations were more than eight times more likely to experience rapid postnatal growth (AOR = 8.7, $p = 0.04$, 95% C.I = 1.09 - 69.4) than were infants born to women with an overweight pre-pregnancy BMI who met the GWG recommendations.

A major conclusion from Chapter 6 is that higher pre-pregnancy BMI and excessive GWG are associated with higher infant weight at birth and 3 months; excessive GWG is also associated with higher BMI z-scores and rapid postnatal growth between birth and 3 months.

## 7.3. Strengths and Limitations

This is one of the first prospective studies in Canada to examine maternal weight gain and composition of weight gain during pregnancy and at early postpartum. Measurements of maternal weight and adiposity were obtained two or three times during pregnancy and once at early postpartum which allowed for analysis of both longitudinal and cross-sectional comparisons. The data obtained provided an accurate estimation of changes in weight and adiposity during pregnancy, and this was not biased by recall bias or misreporting. Further longitudinal changes in fat mass and fat-free mass of women according to pre-pregnancy BMI categories were examined. Literature in this context is limited. Hence, this information is of clinical significance. The results generated from this research highlight that among healthy pregnant women the pattern of metabolic adaptations and energy expenditure during pregnancy differs according to pre-pregnancy BMI; hence differences in patterns of weight and adiposity accretion are observed. This information may be useful for future intervention studies that intend to implement optimal GWG among pregnant women.

The results from this study are based on observation of pregnant women who were predominantly Caucasian, who were healthy with no previous chronic health risks, who belonged to high-income families, and who had a high education. Although women from this study were healthy, well educated and belonged to families who were economically stable and had access to health care facilities, we observed that a significant proportion of women exceeded the total gestational weight gain and weekly weight gain recommendations. The plausible causes for this could be that many women may be unaware of the gestational weight gain recommendations, which may arise due to lack of communication on this topic between the health care team and the pregnant women. Further despite the homogeneity in the socio-demographic characteristics of our study participants, we were able to find significant associations between low income, nulliparity, ethnicity and weight and adiposity during pregnancy and postpartum. In addition, low income was associated with low birth weight. Findings from this study should be cautiously generalized when being applied to women from other parts of North America who may differ in their education, income, ethnic background, presence of chronic health conditions and the in availability of health care.

A further limitation of this study was the relatively small number of women included in some of the pre-pregnancy BMI groups, particularly the underweight and obese BMI groups. This limited our ability to examine variations in adiposity, energy and macronutrient intake, physical activity, and infant outcomes among these women. However we observed that obesity was inversely associated with total and weekly weight gain, total fat mass accretion and physical activity during pregnancy, and was positively associated with infant birth weight. Similar observations have been reported by previous studies of obese women (1). Furthermore, it must be recognized that the incidence of underweight women is decreasing in Canada (17) and United States (18); hence, fewer women in this category are to be anticipated. The other reason for the small sample size in the present study was that it being a part of an ongoing larger prospective cohort was limited to analysis of interim data generated in the first year of the cohort study.

Another weakness of this study was that resting energy expenditure, which appeared as a significant predictor of important study outcomes such as fat mass and excessive GWG, was not measured but was estimated using a pre-pregnancy specific (modified Harris Benedict) equation (19). In a study of 152 healthy pregnant Czech women, estimates of REE using this equation were highly concordant with REE measured using the indirect calorimetric technique at 4 different time points during pregnancy (19). Hence in this research the estimated REE obtained based on this validated equation may not be erroneous.

### 7.4. Recommendations for Future Studies

From this research it is apparent that overweight and obese women are at an increased risk for excess GWG, for weight retention and central adiposity postpartum and for high birth weight in infants. The trend of exceeding GWG recommendations is not limited to women from higher pre-pregnancy BMI groups; over 45% normal-weight women exceeded GWG recommendations and were thus susceptible to the health risks associated with it. Furthermore, this research confirmed that optimal GWG could reduce the risk of postpartum weight retention and higher weight in infants. Optimal GWG may therefore improve maternal and infant health outcomes. Hence we recommend that future studies develop educational tools and intervention programs to promote healthy weight gain among all women, especially the overweight and obese women. In addition it should also be noted that despite being healthy prior to pregnancy, being well educated and belonging to high income families with access to health care facilities, a significant proportion of pregnant women in the present study exceeded the GWG recommendations. Hence future qualitative studies should understand the barriers to effective communication between healthcare team and the pregnant women and develop programs/policy to bridge the gap in knowledge translation between the healthcare team and the pregnant women.

Weight gain during pregnancy is a complex process; it is very important to understand metabolic factors associated with variations in weight gain/adiposity in order to design an effective intervention program. This research revealed variations in weight gain and adiposity according to pre-pregnancy BMI. Obese women show differences from normal-weight women in the amount of weight gain and pattern of fat mass accretion during pregnancy. However, overweight women seem to follow patterns similar to those of normal-weight women in weight gain and adiposity, with some deviations which are similar to those observed in obese women. But the total GWG recommendations for overweight

(7-11.5 kg) and obese women (5-9 kg) are significantly lower than normal women (11.5-16 kg). Hence health care professionals in contact with pregnant women should understand the importance of gaining weight with the recommended range and motivate /support women to adhere to these recommendations. The obstetricians dealing with pregnant women are mainly concerned at minimizing the complications at birth and reducing the risks of infant mortality. However it has been well established that adhering to GWG recommendations can optimize both the health outcomes of the mother-infant. Hence programs/policy to educate the healthcare team could be an important step in disseminating research evidence to healthcare professionals involved in caring pregnant women.

As in previous studies, differences in REE were reported according to maternal pre-pregnancy BMI (20), and REE emerged as a significant predictor of fat mass and fat-free mass accretion in pregnancy. REE was an estimated value in this study; future studies measuring REE are warranted to understand its effect on patterns of weight gain and adiposity. Data from literature suggests, in particular, that insulin sensitivity influences the variations in REE during pregnancy (21). Modulation of insulin sensitivity is a normal physiological adaptation of pregnancy and is controlled by hormones secreted by the feto/placental unit; however, the presence of cytokines such as leptin and other pro-inflammatory cytokines secreted by the maternal adipocytes may also contribute to variations in insulin sensitivity (22). Hence future studies assessing REE may also consider examining insulin sensitivity, glucose tolerance and cytokine concentrations to understand their contribution to metabolic variability during pregnancy.

In the present study, the energy intake seemed not to reflect the overall cost of energy expenditure associated with pregnancy. This was especially true for women with high pre-pregnancy BMI; the potential reason for this could be due to under-reporting of dietary intake by the overweight and obese women. Further considering the higher resting energy demand of women during pregnancy, and based on their energy intake, the percentage of energy left after satisfying REE among women in the overweight and obese categories at all trimesters in pregnancy was very low. To provide for the increased energy demand during pregnancy, the current dietary recommendations prescribe identical increments of energy in the second and third trimesters during pregnancy for all pregnant women, irrespective of the fact that variations in pre-pregnancy BMI, metabolic adaptations and physical activity are present. In the context of existing differences in energy expenditure and fat stores the energy intake requirements may not be identical for all women. Intervention studies providing dietary advice during pregnancy (23) or exercise trials during pregnancy (24) were effective in decreasing total GWG and long-term postpartum weight retention. Intervention programs involving patient-centered dietary intake and physical activity counselling improved pregnancy outcomes (18). Hence revisiting the recommendations for energy requirements during pregnancy may be necessary in order to prevent excess weight gain and adiposity during pregnancy. Future studies are warranted to estimate the optimal range of dietary intake for healthy pregnancy outcomes based on individual nutritional status, lifestyle habits and metabolic status prior to and during pregnancy. In addition to energy intake, energy density and the composition of diet play a significant role in weight gain and body composition; further analysis of data collected from the "APrON" study will be able to shed light on these questions.

Results from this study indicated variations in weight gain /adiposity by ethnicity, income and parity; future studies examining barriers to optimal weight gain in the populations at risk are therefore also warranted.

## 7.5. Conclusion

High pre-pregnancy BMI is significantly associated with higher total and weekly GWG; however, a significant proportion of women from the underweight and normal BMI groups are also gaining quantities of weight higher than the clinically recommended gestational weight ranges. Excessive GWG could be an important contributor to the growing prevalence of higher BMI among women; not only is it associated with higher postpartum weight retention, but it also increases the risk of moving up on the BMI scale. Excess GWG is also associated with high infant weight at birth and 3 months, and with rapid postnatal growth in infants from birth to 3 months. In addition, all women gain a significant amount of fat mass during pregnancy but are unable to return to baseline levels at 3 months postpartum. This was especially true of women with a high pre-pregnancy BMI who were also more likely to develop central adiposity by the end of pregnancy, which could further exacerbate their risk of developing chronic health conditions in future.

This research supports the suggestion that optimal GWG could reduce postpartum weight retention and decrease the risk of high birth weight and rapid postnatal growth in infants.  It could thus improve health outcomes in both mothers and their infants. Future intervention studies designing tools and programs to encourage normal pre-pregnancy BMI and to implement and monitor adequate GWG are warranted.

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## APPENDIX A: Maternal Information Sheet

**TITLE:** Alberta Pregnancy Outcomes and Nutrition (APrON)[3]

**INVESTIGATORS:**, Catherine J. Field[2], Bonnie J. Kaplan,[1]Deborah Dewey[1], Rhonda Bell[2], Francois Bernier[1], Marja Cantell[1], Michael Eliasziw[1], Anna Farmer[2], Lisa Gagnon[1], Laksiri A. Goonewardene[2], Libbe Kooistra[1], Donna Manca[2], Linda McCargar[2], Maeve O'Beirne[1], Victor J.M. Pop[3], Nalini Singhal[1]

[1]University of Calgary, [2]University of Alberta, [3]University of Tilburg (The Netherlands)

Edmonton contact: **780-492-4667 or 780-240-1133**; Project Manager Dave Johnston at 403-955-2771

**BACKGROUND AND PURPOSE**

What we eat and drink tends to influence our health, both mental and physical. We would like to learn more about how nutrition influences pregnancy. Specifically we are interested in the role(s) of nutrition in women's health, baby's health, and the long term health and development of the child.

*To help answer these questions, we are inviting you to join us in a study of 2,000*

[3] The full title is the AHFMR Interdisciplinary Team Grant on the Impact of Maternal Nutrient Status during Pregnancy on Maternal Mental Health and Child Development.

*pregnant Albertan women and their children.* The purpose of APrON is to learn how nutrition during pregnancy may affect women's physical and mental health, the health of the baby, and child health and development later on. The results of the study will be presented to parent groups, health professionals, food producers, day cares, and school boards. Our findings may improve the health and wellness of women and the health and development of children.

**WHAT WOULD I HAVE TO DO?**

Because this study will follow women through pregnancy and for several years after their babies are born, many measures will be collected over time:

Questionnaires. We are asking you to complete questionnaires at 8 time points:

When you first agree to be in the study (which will hopefully be in your first trimester)

Between 13-27 weeks of pregnancy (second trimester)

Between 28-40+ weeks of pregnancy (third trimester)

2 - 3 months after your baby is born

Six months after your baby is born

Twelve months after your baby is born

Two years after your baby is born

Three years after your baby is born

The questionnaires will ask about *what you eat, how you feel, and what your pregnancy experience is like*. After your baby is born, the questionnaires will also ask you about *your baby's health, eating, crying, and behaviour.*

The questionnaires do not have to be done all at once; they can be completed in more than one sitting. Some of the questionnaires can be completed on: a) a secure University internet site, b) paper, or c) by telephone interview. In other words, *we will try to make these questionnaires fit into your busy life*. We estimate the questionnaires will take about two hours to complete at each of the eight time points.

Blood samples from you. You will be asked to provide a blood sample a total of 4 times during the study (3 times during pregnancy and once more, 3 months after your baby is born). The blood will allow us to look at the nutrient levels in your blood (e.g., vitamins, hormones, and measures of how they break down in your blood). Each blood sample is about 2.5 Tablespoons. On 2 occasions we will also ask you for a urine sample. The urine will be used to look at other nutrients. Each blood sample will take about 15 minutes.

Cheek swab or saliva sample from you. If there is no blood sample from you, we may ask you to rub a small brush inside your cheek (a cheek swab), or to provide a saliva (spit) sample. The cheek swab or saliva sample will be put in a plastic bag and returned to us in a pre-addressed and stamped, confidential envelope. The cheek swab or saliva sample will determine how genetics might relate to nutrition and health.

Body measurements. On 3 occasions during your pregnancy and at least one after birth we will measure your height and weight, arm and waist circumferences, and skin-fold thickness. We estimate this will take about 15 minutes.

Biological father questionnaires, and cheek swab or saliva sample. Around the middle of your pregnancy we will invite the biological father to participate in the study. The biological father is not required to take part. If you give us permission to contact him we will ask him to: a) complete a questionnaire during the pregnancy and after the delivery, and b) rub a small brush inside of his cheek or to provide a sample of his saliva. The sample and consent form are to be returned to us pre-addressed and stamped, confidential envelope. The cells from inside the cheek or the saliva will allow us to study whether the biological father's genetics relate to the child's health and development. We estimate this will take 5 minutes of his time.

Breast milk sample. If you are breast-feeding, we will ask you to provide a few drops of your breast milk about 3 months after your baby is born. We will examine the nutrient content of the breastmilk. A small piece of paper will be provided for this. The paper can be mailed back to us in a pre-addressed and stamped envelope or given to us when you meet with a member of our group. We estimate this will take about 5 minutes.

Blood sample from your baby. About 3 months after your baby is born we will ask if you are willing to allow us to take a small blood sample of about 1 teaspoon. Blood samples will be taken by a trained nurse or technician. As with your own blood sample, your baby's blood sample will allow us to look at the nutrient levels in the blood (e.g., vitamins, and hormones). From the blood, we will also look at how genetics might relate to the nutrition and health of your baby. Your baby's blood sample should take about 15 minutes and it will be done when you are providing your own blood sample. Other options for getting samples from your baby may be available, including cheek swabs or saliva samples for genetics and heel pricks for nutrition.

Assessment of your child. When your child reaches three years of age, we may ask if we can assess his/her development, thinking, and learning ability. If you agree, a series of tests will be used to look at your child's learning and behavioural development. These tests will take about 1 ½ to 2 hours and will take place at a time of your choosing. Trained professionals will conduct these tests. You will be provided with verbal and written feedback about your child's performance.

Access to health records. We are asking for permission to access the health records for your pregnancy, delivery, and your child. Also, if you move and we lose touch with you, we ask your permission to contact Alberta Health and Wellness for your contact information so we can find out if you would like to continue your participation.

We estimate that the total time commitment for you and your child for study participation will be approximately 30-35 hours over the 4 year period.

**WHAT ARE THE RISKS OF MY PARTICIPATING?**

Blood samples: Blood will be taken from an arm vein by a person trained to draw blood (nurse, technician). Risks associated with blood draws include infection, bruising, blood clots, or inflammation. Steps will be taken to limit or avoid these risks.

Cheek swabs or saliva samples: A small brush will be used to rub against the inside of the cheek (cheek swab). A saliva sample will be provided by spitting on a piece of paper. The cheek swab or saliva sample poses no risk.

Heel pricks: If you do not wish your infant to have a needle for blood draws, a heel prick may be used instead. A few drops of blood will be collected on a piece of paper by pricking the infant's heel. Some minor bruising may occur and it may cause a small amount of pain to your infant.

All other measures: It is possible that answering questions about your health history or mental state may raise some feelings of sadness or distress. If at any point during the study you are having any difficulty with your mood or stress level, or feel you need some help with your mental health, please call your family doctor, the Distress Line at 780-482-4357 or the Edmonton Mental Health Clinic at 780-427-4444.

**WILL I BENEFIT IF I TAKE PART?**

If you agree to take part in this study there may or may not be a direct benefit to you. If your child takes part in the in-depth testing at age 3, we will provide you a summary of his/her results. If the testing identifies early development or learning problems, we would recommend that you discuss the results with your child's regular doctor. By participating in APrON you will become a member of our team of participants and have access to a special website that will keep you updated on how the study is going.

**DO I HAVE TO PARTICIPATE?**

Taking part in this study is voluntary. You may choose not to answer some questions, not to take part in some tests, or to withdraw from the study at any time without affecting your health care. You can withdraw by contacting the Edmonton Project Coordinator at **780-492-4667 or 780-240-1133**.

Similarly, if you are unable to complete the study information in a suitable timeframe, the study staff may withdraw you.

**WHAT ELSE DOES MY PARTICIPATION INVOLVE?**

APrON will be following participants over a period of 3-4 years. At the end of the study, all samples (blood, cheek swabs) including DNA and all clinical data will be securely held by the researchers. It is possible more studies will develop from APrON. As a result, participants and their children may be followed beyond the first period of 3-4 years. You and your child may be asked to take part in these future studies. Access to the data and the samples will only be allowed for studies that have been approved by a Research Ethics Board. By signing below, you agree to have your information and left over samples examined in the future by other researchers. If at any point you decide you do not want researchers to keep your samples and data, by providing researchers with a written request you can always ask that your data and samples be destroyed.

*I agree to have my own and my child's left over biological samples (blood and DNA) available to researchers for future studies which have been approved by a Research Ethics Board. No further consent will be needed from me in order for this to happen. I understand that these samples will only be released with non-identifying information. I can still request my samples be destroyed at any time*

***Signature:* ___________________________________________**

***Date:* __*day* ___*month* ______*year***

**WILL I BE PAID FOR PARTICIPATING, OR DO I HAVE TO PAY FOR ANYTHING?**

You will not be paid for participating, but we also want to ensure that your participation does not cost you anything. We will reimburse any traveling or parking costs related to you taking part in this study.

**WILL MY RECORDS BE KEPT PRIVATE?**

The consent forms and any questionnaire information you provide will be kept in locked filing cabinets or scanned and shredded in a locked confidential bin. Your privacy and your identity will be kept confidential. The questionnaire and study information you provide will only be accessed by the researchers and will be kept locked in a secure research area. The study database will be stored on a computer drive protected by a password.

All samples will be stored in locked freezers in a secure research facility. The labeling of samples will be done with a study code number and will not identify you by name, health care number or initials.
By signing the consent form you give permission for the collection and use of your medical records. Even if you withdraw from the study, the medical information that is obtained from you for study purposes will not be destroyed, unless a written request is received from you.

All participants will receive regular newsletters, updating them on the progress of this study. At the end the whole study, or even at completion of parts of the study, we will send a summary to each participant. All the information contained in our summaries will be anonymous, and based on group data. Any report published as a result of this study will not identify you by name, address or any other personal information.

**IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?**

In the event that you suffer injury as a result of participating in this research, you will not be compensated in any way by the funder (AHFMR,) the University of Calgary, Calgary Health Region, the University of Alberta, Capital Health

Region, Alberta Health Services, or the Researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

If you have further questions related to this research, please contact:

Dr. Catherine Field (APrON Edmonton) **780- 492-4667**

Or

APrON Project Manager: Dave Johnston at 403-955-2771

If you have any concerns about any aspect of the study, please contact Health Research Ethics Board office, University of Alberta 780-492-9724.

## APPENDIX B: Maternal Consent Form

**Title of Project:** **Alberta Pregnancy Outcomes and Nutrition (APrON)**

**Principal Investigator:** Dr**.** Catherine Field Phone: 780-492-4667

**Co-Investigators:** Dr. Linda McCargar, Dr. Rhonda Bell, Dr. Anna Farmer, Dr. Donna Manca

**Please circle your answers:**

| | |
|---|---|
| Do you understand that you have been asked to take part in a research study? | Yes No |
| Have you received and read a copy of the attached Information Sheet? | Yes No |
| Do you understand the benefits and risks involved in taking part in this research study? | Yes No |
| Have you had an opportunity to ask questions and discuss this study with the researchers? | Yes No |
| Do you understand that you can refuse to participate or withdraw from the study at any time? | Yes No |

You do not need to give a reason for withdrawing. Refusing to participate or withdrawing will not affect the medical care you receive.

| | |
|---|---|
| Has the issue of confidentiality been explained to you? | Yes No |
| Do you understand who will have access to your information? | Yes No |
| Do you want the investigators to inform your family doctor that you are participating in this research study? Doctor's name: ____________________________ | Yes No |
| Do you agree to be contacted for future research studies and programs? | Yes No |

**I agree to take part in this research study.**

| | | |
|---|---|---|
| Printed Name of Participant | Signature of Participant | Date |
| Printed Name of Witness | Signature of Witness | Date |

I believe that the person signing this form understands this study and voluntarily agrees to participate.

| | | |
|---|---|---|
| Printed Name of Investigator | Signature of Investigator | Date |

## APPENDIX C: Parental Consent Form

**Title of Project:** **Alberta Pregnancy Outcomes and Nutrition (APrON)**

**Principal Investigator:** Dr**.** Catherine Field Phone: 780-492-4667

**Co-Investigators:** Dr. Linda McCargar, Dr. Rhonda Bell, Dr. Anna Farmer, Dr. Donna Manca

**Please circle your answers:**

| | | |
|---|---|---|
| Do you understand that you have been asked to include your child(ren) in a research study? | Yes | No |
| Have you received and read a copy of the attached Information Sheet? | Yes | No |
| Do you understand the benefits and risks involved in including your child(ren) in this research study? | Yes | No |
| Have you had an opportunity to ask questions and discuss this study with the researchers? | Yes | No |
| Do you understand that you can refuse to participate or withdraw your child(ren) from the study at any time? | Yes | No |

You do not need to give a reason for withdrawing. Refusing to participate or withdrawing will not affect the medical care your family receives.

| | | |
|---|---|---|
| Has the issue of confidentiality been explained to you? | Yes | No |
| Do you understand who will have access to your child(ren)'s information? | Yes | No |
| Do you want the investigators to inform your family doctor or pediatrician that your child(ren) is/are participating in this research study?<br>Doctor's name: ____________________ | Yes | No |
| Do you agree to be contacted for future research studies and programs? | Yes | No |

**I agree to allow my child to take part in this research study.**

Child's Name: ____________________________

| | | |
|---|---|---|
| ________________________ | __________________________ | ________ |
| Printed Name of Parent /Guardian | Signature of Parent /Guardian | Date |
| ____________________ | _____________________ | _________ |
| Printed Name of Witness | Signature of Witness | Date |

_________________________________________________________________

I believe that the person signing this form understands this study and voluntarily agrees to allow their child(ren) to participate.

| | | |
|---|---|---|
| _____________________ | _____________________ | ________ |
| Printed Name of Investigator | Signature of Investigator | Date |

**APPENDIX D: Ethics Approval Form - Feb 2009**

Date: February 26, 2009

Principal Investigator: Catherine Field

Study ID: Pro00002954

Study Title: Alberta Pregnancy Outcomes and Nutrition (APrON): the impact of Maternal nutrient status during pregnancy on maternal mental health and child development.

Date of Informed Consent:

| Approval Date | Expiration Date | Approved Document |
|---|---|---|
| 2/12/2009 | 2/11/2010 | paternal consent |
| 2/12/2009 | 2/11/2010 | maternal consent |
| 2/12/2009 | 2/11/2010 | parental (for child) consent |

Sponsor/Funding Agency AHFMR - Alberta Heritage Foundation for Medical Research AHFMR

Thank you for submitting the above study to the Health Research Ethics Board (Biomedical Panel). Your application has been reviewed and approved on behalf of the committee. We have also approved the informed consent documents (all dated November 30, 2008) which include the consent forms referenced above, and the WCHRI Brochure and OB checklist which will be used as recruitment material. The lengthy lists of questionnaires, etc. (included in the HERO application) have also been approved as part of the protocol. As has previously been discussed with the study coordinator, Ms. Jumpsen, the application which was given 'approval in principle' last year can now be closed.

We have just a couple of editorial suggestions related to the information sheets. The phrase 'University Ethics Board' should be replaced with 'Research Ethics Board', and within the next weeks you may be required to update the reference to Calgary and Capital Health Regions in the Confidentiality clause. Finally, we are curious as to why the fathers are being asked if their family doctors can be advised that they are taking part in the trial since they are not receiving treatment. Perhaps it is just the standard template language, but it could be adjusted if you wish.

This approval will expire on February 11, 2010. A renewal report or closure notice must be submitted next year prior to the expiry of this approval. You will receive electronic reminders at 60, 30, 15 and 1 day(s) prior to the expiry date. If you do not renew on or before that date, you will have to submit a new ethics application.

For studies where investigators must obtain informed consent, signed copies of the consent form must be retained, as should all study related documents, so as to be available to the HREB on request. They should be kept for the duration of the project and for at least seven years following its completion.

Approval by the Health Research Ethics Board does not encompass authorization to access the patients, staff or resources of Capital Health or other local health care institutions for the purposes of research. Enquiries regarding Capital Health administrative approval, and operational approval for areas impacted by research, should be directed to the Capital Health Regional Research Administration office, #1800 College Plaza, phone 407-1372.

Sincerely,
J. Stephen Bamforth, MD
Associate Chair, Health Research Ethics Board (Biomedical Panel)
Note: This correspondence includes an electronic signature (validation and approval via an online system).

## APPENDIX E: Ethics Approval Form - March 2010

Date: March 11, 2010

Principal Investigator: Catherine Field

Study ID: MS8_Pro00002954

Study Title: Alberta Pregnancy Outcomes and Nutrition (APrON): the impact of Maternal nutrient status during pregnancy on maternal mental health and child development.

Study Investigator: Catherine Field

Sponsor/Funding Agency AHFMR - Alberta Heritage Foundation for Medical Research AHFMR

Date of Informed Consent:

| Approval Date | Approved Document |
|---|---|
| 3/11/2010 | Maternal Information Sheet Feb2010 |

Approval Expiry Date: February 10, 2011

Thank you for submitting the following documents to the Health Research Ethics Board (Biomedical Panel):

- maternal information sheet as referenced above, February 21, 2010;
- initial post paternal questionnaire;
- 3-month paternal questionnaire.

You have also updated the SmartForm to indicate collection of extra blood and urine samples, although the protocol itself has not been changed. The proposed changes are described in the amendment request.

All the changes and the documents referenced above are approved on behalf of the committee. Many thanks for keeping the committee informed.

Sincerely,
J. Stephen Bamforth, MD
Associate Chair, Health Research Ethics Board (Biomedical Panel)
Note: This correspondence includes an electronic signature (validation and approval via an online system).

**APPENDIX F: Anthropometric Assessment Protocol**

APrON Alberta Pregnancy Outcomes and Nutrition

Protocol for Anthropometric Assessment

Weight, Height, Skin Fold Thicknesses and Circumferences

Fatheema Begum and Dr. Rhonda Bell
Department of AFNS, University of Alberta.

Reference: Adapted from: Anthropometric Standardization Reference Manual. TG Lohman, AF Roche and R Martorell (Eds.) 1988; Human Kinetics Book, Champaign Il.

# An Overview

**Background:**

The health status of Canadian women of child bearing age has changed since past decades, today more women enter pregnancy at an older age and a significant proportion (over 20%) of them have high pre-pregnancy BMI considered as overweight or obese. Many also have underlying chronic conditions associated with high body weight before becoming pregnant. There is growing evidence that a higher pre-pregnancy BMI and higher GWG are associated with negative health consequences in infant and mother.

GWG has a significant effect on fetal growth but is modified by the mother's pre-pregnancy BMI. Current revised Health Canada guidelines for weight gain in pregnancy provide weekly weight gain recommendations for women with different pre-pregnancy BMI. Desirable weight gains in underweight women are recommended to be higher and overweight and obese women are recommended to make lower weight gain during pregnancy.

Monitoring weight before and during pregnancy is crucial and primary technique to understand a healthy pregnancy, however many individuals with same BMI have different composition of body fat and lean mass and differences in fat distribution. Hence longitudinal assessment of body composition along with monitoring weight during pregnancy is essential in understanding the effect of weight gain on maternal and infant health.

**What is the purpose of anthopometrics in APrON?**

1. Is to understand if pregnant women in Alberta are following current weight gain guidelines.

2. Identify similarities and differences in pre-pregnancy BMI, changes in weight gain and body composition during pregnancy and post partum weight retention patterns between women.

**What measurements are made?**

1. Height
2. Weight
3. Body Circumferences
    - Waist
    - Buttock (hips)
    - Arm
    - Thigh
4. Skinfold Thickness
    - Subscapula
    - Suprailiac
    - Triceps

- Biceps
- Thigh

**How will the measurements be used?**

- Percentage body fat and muscle mass will be computed from the sum of the skin fold thicknesses using pregnancy specific body composition equations
- Waist:hip ratio at ≤ 16 weeks gestation and at postpartum will be calculated.
- Mid upper arm muscle mass will be determined from the mid arm circumference and triceps skin fold using specific equations.
- Weekly GWG will be computed as a difference of the self reported pre pregnancy weight and highest weight gained in pregnancy, divided by the gestational age.

**Who is involved?**

**Dr. Rhonda Bell** is the investigator responsible for the anthropometric measurements.

**Fatheema Begum** is APrON's PhD student working in this area. She has been involved in the development of APrON's "Protocol for Anthropometric Assessment",the training of new staff, and the majority of APrON's data entry . She is very knowledgeable and is also a great person to answer any questions you may have.

Each study location (Edmonton and Calgary) has a designated research assistant or coordinator to oversee this area. Their duties include the training of new and current staff, ensuring measurers are following protocol and that the data collected is reliable. They are also here to answer any questions and help with any problems that may arise.
They are:
**Lubna Anis - Calgary**
**Sarah Loehr - Edmonton**

**APrON Research Assistants** – Both Calgary and Edmonton have a team of trained staff that are responsible for taking anthropometric measurements on all of the APrON participants. This group of skilled staff is diligent in ensuring that the data they collect is both accurate and reliable. As an APrON Research Assistant, you are now a part of this team. The data you help collect will be used to improve the health of future women and children in Alberta.

## Training Schedule

There are 6 steps to the training the process. During the practice sessions, steps 2, 3 and 5, both you and a trained RA will take 2 sets of measurements on each subject. This data will be used to calculate your inter- and intra-rater reliability. Once you have achieved an acceptable level of reliability, you will move on to the next step.

**Step 1: Introduction to Anthropometric Measurements**

You will be given the introductory information that you are currently reading through, as well as, the anthropometric training manual "Protocol for Anthropometric Assessment" and links to the NHANES III training videos (see Appendix A).

**Step 2: Practice Session #1**

During this session, you will practice on at least 2-3 other staff members and/or graduate students. You will work closely with your training RA to ensure that you have a good understanding of each measurement and the precision required to achieve reliable measurements.

**Step 3: Practice Session #2**

During this session, you will continue to practice taking measurements. You will be practicing on at least 2-3 non-pregnant volunteers. The focus of this session will be to continue to work on taking reliable measurements. As well, you will use this session to get comfortable at taking measurements on people you do not know, while also ensuring their comfort.

**Step 4: Observation and Recording**

You will watch a trained RA take measurements during a number of APrON clinics/visits. You will also record the measurements for the RA. This step will allow you to become familiar with the clinic/visit processes, and get comfortable with interacting with the participants as they get their measurements taken.

**Step 5: Practice Session #3**

You will now get an opportunity to practice on 3 pregnant volunteers and/or study participants. The measurements can be more difficult to take on pregnant women. This session will allow you get an understanding of these difficulties and allow you to work through them.

**Step 6: Measuring APrON Participants**

You will now start taking actual measurements on participants. A trained RA will record the measurements for you and will provide with assistance if required.

**Step 7: Ongoing Testing for Reliability**

To ensure reliability of data, there will be ongoing practice sessions where you will test your inter-rater reliability with other RAs. Every 50$^{th}$ participant will be measured twice by the same RA to ensure intra-rater reliability.

## Study Periods

Anthropometric assessments will be made during the following study periods on each participant:

1. First Trimester (1-13 wk Gestation)
2. Second Trimester (14-28 wks Gestation)
3. Third Trimester (29- 42 wks Gestation)
4. 3months Postpartum

***Anthropometric Assessments***

1. Height
2. Weight
3. Skin Folds( Biceps, Triceps, Sub scapular, Suprailiac, Thigh)
4. Circumferences (waist, mid upper arm and thigh)

## Measurement Overview

- All measurements will be performed at each time point with the exception of waist. The waist circumference will only be taken on participants if they are less than 16 weeks gestation and 12 weeks postpartum.
- Calibrate all the equipment (weighing scale, stadiometer and skinfold calipers) once every day before making measurements.
- Before getting started, explain to the participant what you will be doing and what they can expect from each measurement procedure. Continue to explain to the participant what you are doing while you are taking the measurements. A well-informed participant is more likely to feel at ease.
- Since measurements are not accurate if made over clothing, ask the participants to change into shorts. They can wear a t-shirt, blouse or shirt on top. Ask the participant to lift up their sleeve for the bicep/triceps measurements, their shirts for subscapula and waist/abdominal measurements, short leg for thigh measurements and lower their shorts for suprailiac. Hip circumference will be taken over their clothing.
- Each measurement will be performed 3 times.
- Measurements for skinfold thicknesses and circumference should be taken on the participant's right side. If the participant has a cast on her right arm, take the measurement on the left side and write an appropriate comment on your form.
- Be tactful. Try to avoid excessive body contact when arranging the measuring tape, finding sites and using the calipers.
- Keep all equipment clean. Wipe skinfold caliper heads and measuring tape with an alcohol wipe after each interview.
- Use gloves in the presence of obvious contamination with blood or secretions.
- If subject is too large or too muscular to get a measurement, make an appropriate note on the data collection form. For example, "exceeds caliper scale" can be indicated for very large measurements, or "measurement unreliable" can be indicated for difficult measurements.

> As part of the training process, you will watch a NHANES III training video. It is important to note that some of the methods and equipment used in the video differ from than used in APrON. Those differences will be outlined and explained throughout the manual in text boxes titled "Video Notes".

**Measuring Weight**

**Equipment required:** SECA 770 or Tanita HD-351 weighing scales.

**Setting the scales**

Place the scales on a hard flat surface. If carpet is the only floor covering in the measurement location, put a wooden board down on the carpet and place the scales on the board.

**Procedure: Edmonton (Electronic Scale)**

1. Make sure the participant is wearing a pair of shorts and appropriate top. Have them remove any coats, heavy sweaters, shoes, keys or heavy pocket contents.
2. Ask the participant to stand in the middle of the scale's platform with the body weight equally distributed on both feet, hands at their side, and looking straight ahead.
3. Weigh the participant in kilograms to the nearest 0.1 kg (100 grams).


**Procedures: Calgary (Balance Beam Scale) Healthometer Professional 752KL, Pelstar LLC, IL, USA**

1. Make sure the participant is wearing a pair of shorts and appropriate top. Have them remove any coats, heavy sweaters, shoes, keys or heavy pocket contents.
2. Ask the participant to stand in the middle of the scale's platform with the body weight equally distributed on both feet, hands at their side, and looking straight ahead.
3. Adjust the large weight to the nearest 10kg mark
4. Adjust the small weight to the nearest 0.1kg mark
5. Wait for the scale to balance and read weight to recorder
6. To measure second and third measure:
   a) Have the woman step off the scale and move the small weight to zero
   b) Ask the woman to step onto the scale again and re-adjust the small weight so the scale balances. Read the weight to the recorder.
   c) Repeat steps a and b for the third measurement

**Video Notes:**

- Edmonton will use an electronic scale similar to the one seen in the video. Calgary will use a manual balance beam scale.
- In the training video, weight is recorded to 2 decimal places. In APrON,

it is only required that weight is recorded to 1 decimal place.

## Measuring Height

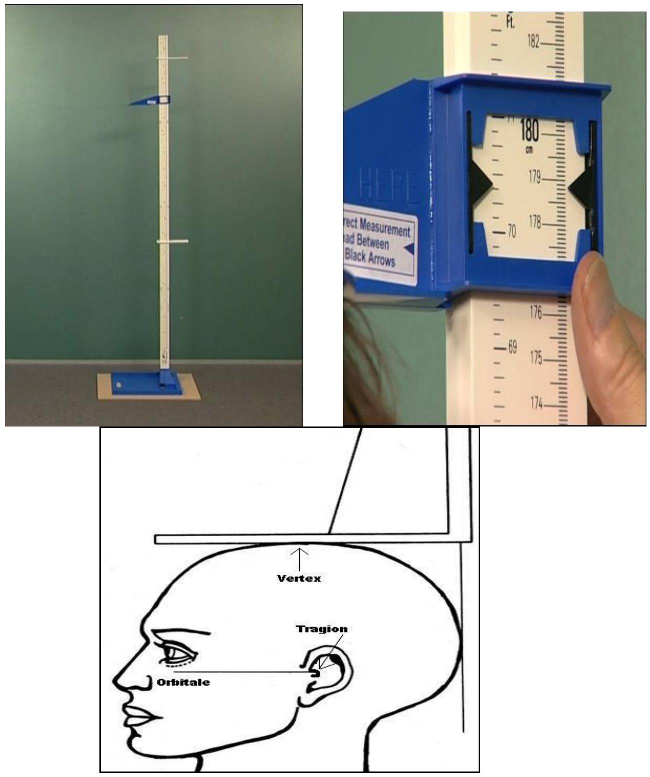
***Note: Height will be measured only at intake (first visit)***

**Equipment:** 235A Heightronic Digital Stadiometer, Quick Medical, USA

The measurement of stature requires a vertical board with an attached metric rule and a horizontal headboard that can be brought into contact with the most superior point on the head. The combination of these elements is called a Stadiometer.

## Procedure

1) Make sure the participant's shoes are removed.
2) Ask the participant to remove any hair dressings (hair clips, bands, elastics, etc.) that may interfere with an accurate measurement.
3) The participant should stand with heels together, arms at their sides, legs straight, and shoulders relaxed.
4) The participant's heels, buttocks, shoulder blades and head should be in contact with the vertical board. For a participant who cannot place all four body parts against the board, be sure that at least the buttocks and heels or buttocks and head are touching the board.
5) Position the participant's head so that eyes are looking straight forward, without lifting their chin.
6) The participant's head should be in the Frankfort plane. This is achieved when the lower edge of the eye socket (the Orbitale) is horizontal with the Tragion [see Figure 1]. The vertex will be the highest point on their head. If their head is not aligned properly, ask them to raise or lower their chin until it is in the Frankfort Plane.
7) Just before taking the measurement, ask the participant to take a deep breath and stand as tall as possible. Remind them to keep shoulders relaxed.
8) Lower the headboard to the highest point of the head. Make sure the hair is compressed. If participant has thick braids, make as accurate a measurement as possible and make a note on your data form.
9) Measure the height to the nearest 0.1 cm. Make sure your eyes are level with the headboard when recording the measurement. If necessary, stand on a foot stool to read the measure correctly.




Head in the Frankfort Plane

Source: Ministry of Health. 2008. *Protocol for Collecting Height, Weight and Waist Measurements in New Zealand Health Monitor (NZHM) Surveys*. Wellington: Ministry of Health.

**Video Notes:**

- In the training video, it states that participants should remove hair dressings from the top of their head. It is also important that participants also remove dressings from back of head because they can interfere with the participant properly placing their head against the backboard.
- In the training video, the technician straightens the subjects head. In APrON, the RA will ask the participant to straighten their head, for example, “Can you please lift your chin slightly?”

## Measuring Circumference

- Flexible, non-elastic tape measures should be used.
- Primary cause of poor reliability and validity is improper positioning of tape and differences between the tensions applied.
- To reduce improper positioning, mark the position where measurements are to be made.
- To reduce variability in tension applied while measuring, hold tape snugly around the body part but not tight enough to compress subcutaneous tissue.

**Equipment:** Lufkin W606PM anthropometric measuring tape.

**Waist Circumference:**

***Note: Waist Circumference will be measured at first visit (≤ 16 weeks gestation) and the postpartum visit***

1) Ask the participant to lift up their shirt. If the participant does not want to lift their shirt, make this measurement underneath the shirt, while lifting and resting it on your left arm.
2) The participant must stand erect with feet together, arms at their sides and abdomen relaxed.
3) Locate the narrowest part of the torso, the smallest horizontal circumference in the area below the lower costal ribs (10$^{th}$ rib) and above the iliac crest (hip bone).
4) Place the tape in a horizontal plane around the body.
5) The zero end of the tape should be held in the left hand above the remaining part of the tape held by the right hand.
6) Take the measurement after a normal expiration.
7) Record measurement to the nearest 0.1 cm.

> **Video Notes:**
>
> - In the training video, waist circumference is done using a method different than that used by APrON. APrON's body measurements follow the methodologies outlined in Anthropometric Standardization Reference Manual (Lohman, 1988).

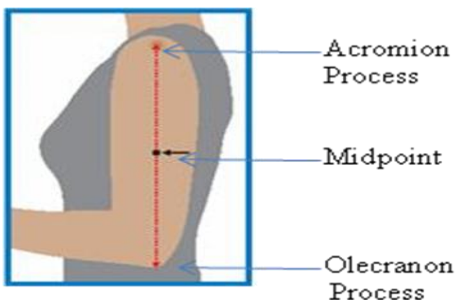
**Buttocks (Hip) Circumference:**

1) This measurement will be made over the participant's shorts.
2) The participant should stand erect with arms by their sides and feet together.
3) Squat or kneel down to the right side of the subject. Locate the level of maximum extension of the buttocks.
4) Place the tape around the buttocks in a horizontal plane. Pull slightly without compressing the skin.
5) The zero end of the tape should be held in the left hand below the remaining part of the tape held by the right hand
6) Record measurement to the nearest 0.1 cm.

> **Video Notes:**
>
> - In the training video, the assistant technician holds pants snugly to help determine the level of maximum extension. The APrON research assistant recording the measurements will only do this when the participant is wearing a baggy pair of short or skirt. This RA should always assist the measuring RA to achieve a horizontal plane around the buttocks with the measuring tape.

**Arm Circumference:**

1) Ask the participant to lift their sleeve exposing the shoulder area. The participant should stand erect with arms relaxed at their sides.
2) Locate the midpoint of the arm:
   a) Ask the participant to bend the right elbow to 90 degree with the palm facing up.
   b) Stand behind the participant and locate the tip of *acromion process of the scapula* (bump on the top of the shoulder). Make a small mark
   c) Locate the *olecranon process of the ulna* (pointy part of the elbow). Make a small mark.
   d) Measure the length between the two marks by running the tape down the back of arm.
   e) Mark (+) the midpoint with a pen or a marker. Wrap the tape horizontally to the front of the arm (bicep) and make another mark.
3) Place the tape horizontally around the arm at the marks, touching the skin without compressing it.
4) The zero end of the tape should be held in the left hand above the remaining part of the tape held by the right hand
**5)** Record the measurement to the nearest 0.1 cm.

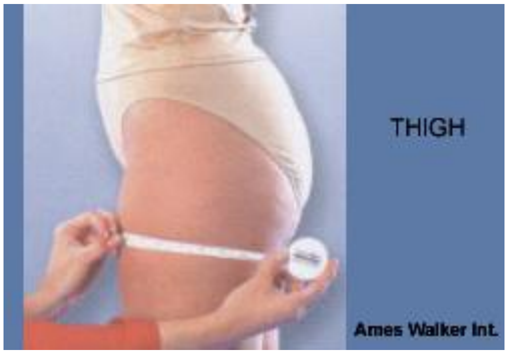



**Thigh Circumference:**

1) Ask the participant to pull up the leg of their shorts exposing their mid thigh.
2) Find the midpoint of the thigh:
   a) Have the participant sit on a chair with back straight and knee at a 90 $^{o}$ angle
   b) Mark a horizontal line just at the superior edge of the patella (knee cap).
   c) Ask the participant to hold the zero end of the measuring tape at the inguinal crease (crease between the torso and the thigh). Extend the tape measure to the mark made just proximal to the patella.
   d) Mark a (+) at the midpoint of the thigh.
3) Ask the participant to stand with her right leg just in front of the left leg, with all their weight on their left leg. Soles of both feet should be flat on the floor. Demonstrate this stance for the participant.
4) Squat down to the right of the participant. Place the measuring tape around the mid-thigh at the point that is marked (+). Make sure the tape is positioned

perpendicular to the long axis of the thigh, and not the floor.

5) The zero end of the tape should be held in the left hand above the remaining part of the tape held by the right hand.
6) Pull tape lightly and record measurement to the nearest 0.1 cm.




**Video Notes:**

- In the training video, they have the subject sit on a table to measure the midpoint of the thigh. In APrON, the participant will sit in a chair.
- In the training video, small sliding calipers are used to mark the superior edge of the patella. This instrument is not used in APrON. The research assistants will palpate the area with their fingers to find the superior edge of patella.
- In the training video, the technician places the tape in the inguinal crease. In APrON, tape will be handed to participant and the participant will be instructed as to where to place the tape.

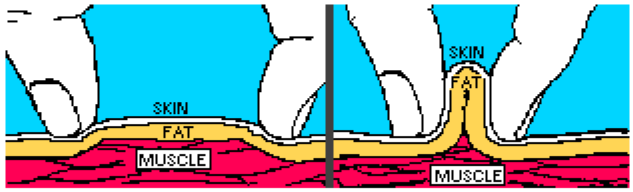
## Measuring Skin fold Thickness

- Skinfold thicknesses, also called "fatfold" thicknesses are the thicknesses of double folds of skin and subcutaneous adipose tissue at specific sites on the body.
- They provide a simple, non invasive method of estimation of fatness and also distribution of subcutaneous body fat.
- The position for skin folds measurements is important, small differences in position can make significant differences in measurement.
- Compressibility of both skin and adipose varies with individuals and should be dealt with care.

### General Guidelines

- Measurements should be taken on the right side of the body.
- Mark the sites where the measurements will be made.
- Grasp a double fold of skin and subcutaneous adipose tissue with your left thumb and index finger and pull it away from the body. The elevated skinfold should have parallel sides. You should grasp the skin above the marked site; for all the skinfold measurement (biceps, triceps, subscapula and thigh). The grasp is made on the marked site for the suprailiac measurement and caliper head is placed 1cm away from your fingers (check the video).
- The fold is raised perpendicular to the surface of the body at the measurement site.
- Hold the caliper in your right hand with the dial face up. Place the caliper heads on the skinfold at the marked site, approximately 1 cm away from your fingers holding the skinfold. This is important to prevent pressure from the fingers effecting pressure of the caliper heads. During each measurement maintain the pressure of the fingers.
- Take care not to place the caliper too far into the skinfold. The caliper heads should be placed on the skin fold where the sides are approximately parallel.
- Release the lever of the caliper and read the dial after approximately 4 seconds. Waiting longer than 4 seconds will result in inaccurate smaller readings.
- Record the measurement to the nearest 0.5 mm.
- Repeat the measurements twice. Make sure at least 15 seconds have passed before repeating the measurement at the same site so that the skinfold is allowed to "flatten" or return to normal between readings.
- If repeated measurements differ, additional measurements need to be taken until the readings are consistent. Be sure the outlier is clearly crossed off with your initials so that the 3 closest measurements are obvious for data entry.
- If the skinfold is above the measurable limits of the calipers (i.e., greater than 67 mm), then note "exceeds caliper" in the recording space for that skinfold.

**Equipment**: Lange Skinfold Calipers (Beta Technologies, Inc., Cambridge, MD)



Skinfold thickness Illustration

**Video Notes:**

- In the training video, the technician holds the skinfold **2 cm** from the mark. In APrON, the skinfold will be held **1 cm** away from the mark unless otherwise indicated.
- In the training video, it states that a measurement should be made after **3 seconds**. In APrON, the calipers will be placed on the skinfold and the measurement will be read after **4 seconds**.
- There is no video for the bicep skinfold measurement.
- In APrON we are holding the skinfold above the marked site for triceps, biceps, subscapula and thigh and on the marked site for suprailiac.

**Subscapula:**

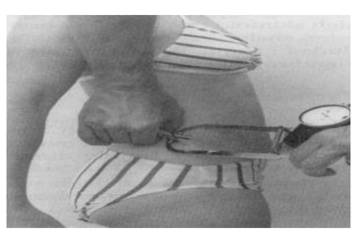
1) With the participant's back exposed, locate the participant's scapula. For some subjects, especially the obese, gentle placement of the subject's arm behind the back aids in identifying the scapula.
2) Palpate and mark (+) the inferior angle of the right scapula (the lower most tip of the triangular bone).
3) Place the left index finger above and medial to the mark. The skinfold should form a line extending diagonally 45º toward the elbow
4) Place the calipers directly on the mark at the inferior edge of the scapula.
5) Release the caliper and read the dial after approximately 4 seconds while the fingers continue to hold the skinfold.

Note: If the measurements differ by more than 2mm, a fourth measure must be made and the outlier clearly crossed out.

**Suprailiac:**

1) The participant should stand erect with feet together.
2) Have them hold their shirt so the hip area on the right side is exposed.
3) While standing to the right of the participant, palpate the hip area for the right iliac crest (hip bone). If the participant is very large, you may want to ask him/her to locate the top of right hip bone. Using thumbs, palpate iliac crest to midline.
4) Mark a horizontal line at the highest point of the iliac crest and then cross the line (+) to indicate the midaxillary line of the body (imaginary line drawn from apex of armpit)
5) The thumb is placed on the intersecting marks. The index finger is placed above and anterior to the marks. The skinfold slopes downward at an approximate angle of 45 º.
6) Place the calipers perpendicular to the length of the fold about 1 cm below the fingertips.
7) Release the caliper and read the dial after approximately 4 seconds while the fingers continue to hold the skinfold.

Note: If the measurements differ by more than 2mm, a fourth measure must be made and the outlier clearly crossed out.



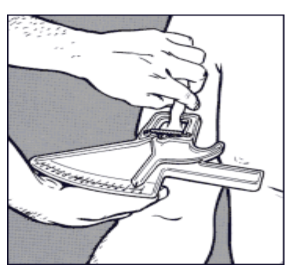
**Triceps Skinfold:**

1) Make sure the participant's right arm is hanging loosely at their side.
2) Stand behind the participant and pull a vertical skinfold about half an inch above the previously marked site, on the mid upper arm with the thumb and index finger pointing downward, centering the mark (+).
3) Place the calipers perpendicular to the length of the fold, centering the mark.
4) Release the caliper and read the dial after approximately 4 seconds while the fingers continue to hold the skinfold.

Note: If the measurements differ by more than 2mm, a fourth measure must be made and the outlier clearly crossed out.

**Biceps Skinfold:**

1) Make sure the participant's right arm is hanging loosely with palm facing anteriorly (palm facing the measurer).
2) Stand at the participant's right side facing the participant.
3) Skinfolds are measured on the anterior aspect of the arm over the biceps muscle. A skin fold is raised 1 cm above to the line marked for triceps measurement.
4) Place the calipers perpendicular to the length of the fold, centering the mark.
5) Release the caliper and read the dial after approximately 4 seconds while the fingers continue to hold the skinfold.
   Note: If the measurements differ by more than 1mm, a fourth measure must be made and the outlier clearly crossed out.



**Thigh:**

1) Ask the participant to stand with weight shifted back on the left leg and the right leg forward and knee slightly bent. The soles of both feet should be flat on the floor.
2) Grasp a fold about 1 cm above the previously marked site on the mid-thigh.
3) Place the calipers perpendicular to the length of the fold, centering the mark.
4) Release the caliper and read the dial after approximately 4 seconds while the fingers continue to hold the skin.

Note: If the measurements differ by more than 2mm, a fourth measure must be made and the outlier clearly crossed out.

**Baby's Body Weight**

- Baby's body weight will be measured at the postpartum visit (12 weeks)
- Ideally a pan scale is used to measure baby's body weight. In Apron an alternative technique will be used.
- Mother will be requested to remove any excessive clothing on the baby (sweater, hat etc)
- The baby can be measured with a diaper.
- Weigh the mother as described earlier (take three measurements - measuring weight- pg 7)
- Ask the mother to hold the baby and step on the scale and record the weight using the same procedure (measuring weight- pg 7)
- Repeat the measurements three times.
- Average of the three measurements will be recorded.
- The difference between mother's weight without the baby and weight with the baby will provide an estimate of the baby's weight.

## Links for Body Measurement Videos

The following are links to videos that were used for the NHANES III study. These videos are a value training resource, however, it is important to note that some of the techniques used in the videos differ slightly to the techniques used in APrON. These differences are pointed out throughout this manual. It is important to follow APrON's protocols for performing measurements.

**Weight:**
http://www.youtube.com/watch?v=9xYwUqUVKr8&NR=1

**Height:**
http://www.youtube.com/watch?v=0LNCuP24MSc&NR=1

**Thigh Length:**
http://www.youtube.com/watch?v=eqvb1OFX1ow&feature=related

**Upper Arm Length:**
http://www.youtube.com/watch?v=p9BWi4WbXj8&NR=1

**Upper Arm, Waist, Hip and Thigh Circumference:**
http://www.youtube.com/watch?v=KacU_TW50Zo&NR=1

**General Instruction, Thigh, Triceps Skinfold:**
http://www.youtube.com/watch?v=xmtJjIk6IXA&NR=1

**Subscapular and Suprailiac Skinfold Thickness:**
http://www.youtube.com/watch?v=SXFSvTCHPXo&feature=related

## APPENDIX G: Physical Activity Questionnaire

We are asking about your physical activity at work and outside of work. Most of the questions refer to your "current physical activity," defined as the past month. There are also 2 questions that ask about physical activity over the past year.

For some people your work will be your paid job; for others your work could be attending school and studying, or household activities. Consider your main daily activities to be your occupation.

1.a. What is your main occupation (i.e. your work)?________________________

Please be specific. For example: student, homemaker, farmer, high school teacher, legal secretary, self-employed accountant.

→ Is this work: _____ Full Time ______ Part Time

Please read the following examples carefully:

| |
|---|
| Examples of light activity: Desk work, driving, teaching, studying, housework.<br><br>Examples of moderate activity: Occupations requiring moderate effort and considerable use of arms, legs or occasional total body movements including cleaning services, waiting tables or institutional dishwashing, carpentry, plumbing, electrical work, dry wall, farming, assembly line work (tasks requiring movement of the entire body, arms, or legs with moderate effort), mail carriers, patient care (bathing, dressing, moving patients, physical therapy).<br><br>Examples of vigorous activity: Occupations requiring strenuous effort and extensive total body movement including sports, teaching an aerobics or physical activity class requiring active and strenuous participation, fire fighting, masonry, heavy construction work, coal mining, manually shovelling or digging ditches, most forestry work, moving items professionally.<br><br>Use these examples to answer the next question |

1.b. Most of the time would you rate your physical activity level of this main occupation as: _______ Light _______ Moderate ________ Vigorous

Please answer the following about your current activity (past month):

2. At “work” I sit…..
_____ Never _____Seldom _____Sometimes _____Often _____Always
3. At “work” I stand...
_____ Never _____Seldom _____Sometimes _____Often _____Always

4. At “work” I walk...
_____ Never _____Seldom _____Sometimes _____Often _____Always

5. At “work” I lift heavy loads...
_____ Never _____Seldom _____Sometimes _____Often _____Always

6. After “work” I am tired..
_____ Never _____Seldom _____Sometimes _____Often _____Always

7. At “work” I sweat..
_____ Never _____Seldom _____Sometimes _____Often _____Always

8. In comparison to others my own age, I think my “work” is physically…
_____Much lighter _____Lighter _____as heavy
_____Heavier _____Much heavier

The next questions refer to your leisure time activities (i.e., physical activity outside of work):

<u>Please read the following examples carefully:</u>

9. Do you participate in regular physical activity?
___Yes ____No (Go to Question 11)

If yes, which activity do you do most frequently?____________________

- How many hours a week?

_____<1 _____1-2 _____2-3 _____3-4 _____>4

- How many months a year?

_____<1 _____1-3 _____4-6 _____7-9 _____>9

Based on the definitions below, how would you rate your first leisure time activity in terms of physical activity?

______Light ________Moderate ______Vigorous

Light Physical Activity: Considered to be physical movement that is easy to sustain over a prolonged period of time and requires minimal effort (e.g. light walking).

Moderate Physical Activity: Considered to be a somewhat harder activity that may have you breathing faster and, while not exhausting, can only be sustained for a shorter period of time (e.g. brisk walking).

Vigorous Physical Activity: Considered to be activity that is hard, has you breathing heavily and sweating, and could only be sustained for very short periods of time (e.g. running).

10. Do you participate in a second regular physical activity?
Yes No (go to question 11)

If yes, which activity is it?_______________________________

- How many hours a week?
  _____<1 _____1-2 _____2-3 _____3-4 _____>4

- How many months a year?
  _____<1 _____1-3 _____4-6 _____7-9 _____>9

Based on the definitions of light, moderate, and vigorous physical activity above, how would you rate your second leisure time activity in terms of physical activity?

______Light ________Moderate ______Vigorous

11. In comparison with others my own age, I think my physical activity during leisure time is...
_____Much less _____Less _____The same_____More _____Much more

12. During leisure time I sweat...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

13. During leisure time I walk...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

14. During leisure time I cycle...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

15. During leisure time I do physical activities (other than walking or cycling)...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

16. During leisure time I watch television...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

17. How many minutes per day do you walk and/or cycle (rollerblade/run) to and from work, school and shopping?
_____<5 _____5-15 _____15-30 _____30-45 _____>45

18. During leisure time I do do-it-yourself activities...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

19. During leisure time in the spring/summer/fall I work in the garden...
_____ Never _____Seldom _____Sometimes _____Often _____Very often

20. How many hours per day do you sleep on average?
_____<5 _____6 _____7 _____8 _____>9