

2007-12-17

The Dose-Response of Maternal Exercise Volume on Newborn and Placental Outcomes

Melisa A. Mena

University of Miami, mmena524@hotmail.com

Follow this and additional works at: https://scholarlyrepository.miami.edu/oa_dissertations

Recommended Citation

Mena, Melisa A., "The Dose-Response of Maternal Exercise Volume on Newborn and Placental Outcomes" (2007). *Open Access Dissertations*. 9.

https://scholarlyrepository.miami.edu/oa_dissertations/9

This Open access is brought to you for free and open access by the Electronic Theses and Dissertations at Scholarly Repository. It has been accepted for inclusion in Open Access Dissertations by an authorized administrator of Scholarly Repository. For more information, please contact repository.library@miami.edu.

UNIVERSITY OF MIAMI

THE DOSE-RESPONSE OF MATERNAL EXERCISE VOLUME
ON NEWBORN AND PLACENTAL OUTCOMES

By

Melisa A. Mena

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

December 2007

UNIVERSITY OF MIAMI

A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

THE DOSE-RESPONSE OF MATERNAL EXERCISE VOLUME
ON NEWBORN AND PLACENTAL OUTCOMES

Melisa A. Mena

Approved:

Dr. Arlette C. Perry
Professor of Exercise Physiology
Committee Chairperson

Dr. Terri A. Scandura
Dean of the Graduate School

Dr. Craig Enders
Associate Professor of Psychology
Arizona State University

Dr. Arlette C. Perry
Chairperson, Department of
Exercise and Sports Sciences

Dr. Barbara Luke
Professor of Nursing, Obstetrics,
and Pediatrics

Dr. Samir Beydoun
Professor of Obstetrics and
Gynecology

MENA, MELISA A.
The Dose-Response of Maternal Exercise Volume
on Newborn and Placental Outcomes

(Ph.D., Exercise Science)
(December 2007)

Abstract of a dissertation at the University of Miami.

Dissertation supervised by Professor Arlette Perry, Ph.D.
No. of pages in text. (101)

Current ACOG guidelines recommend exercise during a low-risk pregnancy for 30 minutes on most, if not all days of the week. However, little is known about how the volume of exercise performed during pregnancy affects fetoplacental size. In addition, the confounding effects of maternal nutrient intake and weight gain, and how they interact with exercise volume to influence fetoplacental size have not been appropriately addressed. Therefore, the purpose of this study was to examine the effects of varying maternal exercise volumes on neonatal birthweight and placental volume, while addressing the influence of maternal nutrient intake and weight gain.

Subjects evaluated for this study included pregnant women who walked during gestation (n=26), performed non-walking aerobic exercise during gestation (n=30), or remained as sedentary controls (n=32). At 16, 20, 24, 28, 32, 36 weeks gestation, women recorded their nutrient intake for 3 consecutive days. Additionally, they kept monthly exercise logs indicating the type and duration of their exercise. Nutrient variables calculated included average daily Calorie intake, average daily carbohydrate intake, average daily protein intake, average daily fat intake, and average daily fiber intake. Exercise volume was calculated as the average number of minutes per week spent performing exercise. Latent growth modeling was the statistical procedure used to analyze how change in maternal exercise volume and nutrient intake throughout gestation affects neonatal outcomes. Neonatal outcomes measured were birthweight, corrected

birthweight for gestational age, sex, race, and socioeconomic status, and placental volume at delivery.

Maternal walking volume had no effect on newborn birthweight or corrected birthweight, while it was inversely related to placental size at birth. Maternal non-walking aerobic exercise volume was inversely related with newborn birthweight, while there was a trend toward an inverse relationship with corrected birthweight and placental volume. Controlling for Calorie intake strengthened the relationship between any form of exercise volume and infant birthweight. Calorie intake, carbohydrate intake, and protein intake were all positively related to infant birthweight. Fiber intake was significantly inversely related to placental volume. Finally, maternal exercise volume and nutrient intake were not related to maternal weight gain.

This data suggests that neonatal outcome will be affected by variations in exercise protocol. In addition, nutrient intake is a potentially confounding variable that should be examined when undertaking studies addressing the role of maternal exercise on neonatal outcome.

DEDICATION

Thank you to Carlos and Dulce for your unwavering support of me through this challenging time. I could not have done this without you.

ACKNOWLEDGMENTS

Thank you to Dr. Arlette Perry for giving me the opportunity to pursue this research.

Many thanks to Dr. Craig Enders for recognizing what I wished to accomplish with this study and for your ability to conceive of the statistics necessary to achieve this goal. Thank you also for your constant support and your assistance in helping me complete this manuscript.

Thank you to Dr. Randy Fink and Dr. Anthony Lai for convincing the obstetricians at Baptist and South Miami Hospitals that this was a worthwhile study and that they should allow that their patients be recruited for this study – without you I wouldn't have a study to talk about.

Thank you to Rich Kish and Martin Blue for agreeing to help with this study by taking your time from work to calculate the volumes of the placentas.

Thank you to the Baptist Health System and to the Labor and Delivery Departments of Baptist and South Miami Hospitals for allowing me to conduct this study and for your assistance in collecting the placentas.

Thank you to Melissa Marcus for helping me with the logistics of this study and the analysis of nutrient intake. Your reliability and organization were instrumental to this study's success.

Finally, thank you to all of the subjects who volunteered to do the time-consuming tasks of recording your exercise habits and nutrition intake throughout pregnancy. You spent a lot of your free time during a stressful period of your life in order for us to learn more about how exercise and nutrition affect the health of your baby and I can't thank you enough.

TABLE OF CONTENTS

LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
CHAPTER ONE: INTRODUCTION.....	1
Introduction.....	1
Significance.....	5
Research Hypotheses.....	6
Delimitations.....	7
Limitations.....	7
Definition of Terms.....	8
CHAPTER TWO: REVIEW OF LITERATURE.....	13
Introduction.....	13
Physiological Changes During Pregnancy.....	14
Physiological Effects of Exercise During Pregnancy.....	17
Maternal Health Benefits of Exercise During Pregnancy.....	20
Effect of Maternal Exercise on Birthweight.....	22
Effect of Maternal Exercise on Placental Size.....	27
Effect of Maternal Nutrient Intake on Fetoplacental Size.....	31
Summary of Review of Related Literature.....	33
CHAPTER THREE: METHODS AND PROCEDURES.....	36
Introduction.....	36
Research Sample.....	36
Procedures.....	37
Follow-up Data Collection.....	38
Statistical Procedures.....	41
CHAPTER FOUR: RESULTS.....	44
Introduction.....	44
Subject Characteristics.....	44
Walking Growth Curve Model.....	45
Non-walking Aerobic Exercise Growth Curve Model.....	54
Effect of Nutrient Intake on Birth Outcomes.....	60
Means Comparison of Dependent Variables Between Exercising and Non-exercising Gravidae.....	69
Summary.....	70
CHAPTER FIVE: DISCUSSION AND CONCLUSIONS.....	72
Introduction.....	72
Summary of Findings.....	73
Discussion and Applications.....	77
Conclusions.....	86
Recommendations for Future Research.....	87
REFERENCES.....	91

LIST OF TABLES

Table 1. Summary of Studies that Have Examined the Maternal Training Effect on Placental Size.....	29
Table 2. A Comparison of Maternal Demographics of Participants Using Multiple ANOVAs.....	45
Table 3. Regressions of Birthweight on Volume of Maternal Walking.....	48
Table 4. Regressions of Corrected Birthweight on Volume of Maternal Walking.....	50
Table 5. Regressions of Placental Volume on Volume of Maternal Walking.....	51
Table 6. Regressions of Maternal Weight Gain on Volume of Maternal Walking.....	53
Table 7. Regressions of Birthweight on Volume of Maternal Non-walking Aerobic Exercise.....	55
Table 8. Regressions of Corrected Birthweight on Volume of Maternal Non-walking Aerobic Exercise.....	57
Table 9. Regressions of Placental Volume on Volume of Maternal Non-walking Aerobic Exercise.....	58
Table 10. Regressions of Maternal Weight Gain on Volume of Maternal Non-walking Aerobic Exercise.....	59
Table 11. Nutrient Intake Means of Exercising Gravidae.....	61
Table 12. Regressions of Neonatal Outcomes on Maternal Caloric Intake.....	62
Table 13. Regressions of Neonatal Outcomes on Maternal Carbohydrate Intake.....	63
Table 14. Regressions of Neonatal Outcomes on Maternal Fiber Intake.....	66
Table 15. Regressions of Neonatal Outcomes on Maternal Fat Intake.....	67
Table 16. Regressions of Neonatal Outcomes on Maternal Protein Intake.....	68
Table 17. Means Comparison of Dependent Variables Between Exercising and Non-exercising Gravidae Using Multiple ANOVAs.....	69

LIST OF FIGURES

Figure 1. The Hypothesized Relationship Between Independent and Dependent Variables.....	12
Figure 2. Individual Walking Growth Patterns Throughout Gestation.....	46

CHAPTER 1: INTRODUCTION

Prior to the 1980's, pregnant patients (gravidae) were advised to avoid vigorous exercise by their obstetricians following conventional medical practice. This advice was based upon the understanding of the redistribution of blood flow to working muscles thereby reducing the available blood to the fetus, and the potential teratogenic effects on the fetus as a result of elevated maternal body temperature with exercise (Wolfe et al. 1994). However, by the 1980's, aerobic exercise emerged as a popular pastime for many women, particularly for those who were active prior to conception and wished to continue exercising during pregnancy. This led to the establishment of guidelines for exercise during pregnancy by the American College of Obstetricians and Gynecologists (ACOG) (American College of Sports Medicine [ACSM], 1986). Due to the lack of research, and initial studies involving maximal exercise bouts on untrained subjects, the ACOG set conservative guidelines limiting exercise intensity to a heart rate of 140 beats per minute, and exercise duration to 15 minutes (ACSM, 1986). In addition, they urged sedentary women to avoid starting a vigorous exercise program during pregnancy (ACSM, 1986). Further research demonstrated that both sedentary and active healthy women with low-risk pregnancies could perform moderate exercise without harm to the fetus (Lotgering et al., 1985; Brent and Beckman, 1990; Clapp, 1990). This resulted in a revision of prior guidelines by ACOG, removing exercising heart rate and duration restrictions (ACOG, 1994). Although the ACOG maintained caution regarding the potential teratogenic effects to the fetus, they also suggested non-weight bearing exercise as a better choice for gravidae than weight-bearing exercise (ACOG, 1994). In 2000, Riemann and Kanstrup

Hansen published a review on the effects of maternal exercise on the fetus, and demonstrated that no studies had shown any adverse effects due to increased maternal temperature during exercise. As a result, the ACOG updated its guidelines and currently recommend that, in the absence of complications, gravidae can adopt the Center for Disease Control/American College of Sports Medicine guidelines for nonpregnant individuals. These guidelines recommend that all individuals should perform weight-bearing or non-weight bearing exercise for 30 minutes on most if not all days of the week (ACOG, 2002). The ACSM recommendations have been reinforced by The Society of Obstetricians and Gynaecologists of Canada (SOGC) and the Canadian Society for Exercise Physiology (CSEP). The SOGC/CSEP have encouraged all women, sedentary or active, to participate in aerobic and strength-conditioning exercises as part of a healthy lifestyle (Davies et al., 2003). Nonetheless, the ACOG maintained a provision stipulating that previously sedentary women should be evaluated prior to initiating an exercise program.

Previous research has supported the fact that exercising gravidae can gain the same metabolic and cardiovascular benefits observed in exercising non-pregnant individuals. This has included protection against the development of type 2 diabetes and coronary heart disease, as well as the reduction of coronary heart disease risk factors including hypertension, plasma dyslipidemia, insulin resistance and obesity (Department of Health and Human Services, 1996). Furthermore, they may experience protection against pregnancy-specific disorders including gestational diabetes (Jovanovic-Peterson and Peterson, 1996; Bung and Artal, 1996) and pre-eclampsia (Marcoux et al., 1989; Sorensen et al., 2003). Other pregnancy-specific benefits of exercise have included the

prevention of excessive maternal weight gain, improved sleep, decreased low-back pain, improved posture, and increased likelihood of postpartum exercise (Ezmerli, 2000).

Although exercise at higher intensities is currently permitted in a maternal exercise program (ACOG, 2002), there has been minimal data regarding the effect of exercise volume (the product of weekly training frequency and duration of session) on pregnancy outcomes. Recent experiments have shown mixed results about how exercise volume affects birthweight. Bell et al. (1995) showed that pregnant women who exercised at least five times per week (high volume) produced offspring that were of significantly lower birthweight than women who exercised three times per week (moderate volume) or who did not exercise at all. Later, Clapp et al. (2000) showed no difference in birthweight between high volume (16-20 times per month) and moderate volume (12-14 times per month) exercisers. The only significant difference found between high and moderate volume exercisers was a reduction in the percentage of body fat in the offspring of high volume exercisers (Clapp et al., 2000). To add to the confusion, while some studies showed lower infant birthweights born to exercising gravidae (Clapp and Dickstein 1984; Clapp, 1990; Clapp and Capeless, 1990), others showed no differences (Rice and Fort, 1991; Sternfeld et al., 1995; Kardel and Kase, 1998), while still others showed even greater infant birthweights born to exercising gravidae (Hatch et al., 1993; Clapp et al. 2000). Thus, results have remained equivocal regarding the effects of exercise on birthweight.

One reason for the apparent discrepancy in results may be the confounding influence of nutrition. In studies by Bell et al. and Clapp et al., there were no differences in average daily Calorie intake between the exercise and non-exercise gravidae (Bell et

al. 1995, Clapp et al. 2000). Given the fact that energy expenditure of exercising gravidae is increased with exercise, the Calorie intake would also be expected to be greater. Thus, at similar Calorie intakes, as the literature suggests, exercising gravidae performing high volume exercise may be expected to give birth to lower birthweight infants.

Exercising gravidae are reported to make physiological adaptations to ensure the health and well-being of the fetus. This has included an increase in placental volume in response to exercise. In fact, it has been shown that placental volume increases as a result of consistent submaximal exercise training (Clapp and Risk, 1992; Kardel and Kase, 1998; Clapp et al., 2000). The placenta is the organ shared by the mother and fetus that supplies all nutritional, endocrinological, and immunological needs of the developing fetus (Newton, 1993). During exercise, blood flow is directed toward the working skeletal muscles and away from the internal organs, including the placenta. Clapp (2000) has theorized that the increased placental volume observed in exercising mothers is the result of a reduction in uterine blood flow and a larger blood volume found in regularly exercising pregnant women. However, there have been several cases in which placental weight has remained unchanged as a result of exercise during pregnancy (Collings et al. 1983; Clapp and Capeless, 1990; Jackson et al. 1995). The studies finding no relationship between exercise and placental size at term have all allowed for self-selection into each group, and for variation in exercise volume and nutrient intake throughout gestation.

The mechanisms explaining how maternal nutrient intake affects placental growth are not completely understood. The limited data available has suggested that total

number of Calories that gravidae consume throughout pregnancy may not affect placental size at term (Clapp, 1997). In fact, as fetoplacental growth is dependent on 24-hour blood glucose levels, it may be that rather than total Calories consumed, nutrient partitioning i.e. carbohydrate consumption affects maternal blood glucose concentration and ultimately placental size (Clapp, 2002). No study that has examined the relationship between exercise and fetoplacental size has directly addressed the influence of maternal nutrient intake in a single study.

Therefore, the purpose of this study is to examine the effects of varying maternal exercise volumes on birthweight, while addressing the influence of maternal nutrient intake and maternal weight gain. To determine whether maternal physiological adaptations have occurred as a result of an exercise regimen, placental volume at the time of birth will be measured. Differences in dependent variables will be examined in women who exercised prior to pregnancy and continued exercising throughout various stages of pregnancy compared to non-exercising controls.

Significance

Low birthweight is associated with a higher rate of infant and childhood disorders and infant mortality. Although some of the literature indicates exercise may result in lower birthweight, these findings remain equivocal. Some of the disparate findings may be related to variation in exercise mode, intensity, volume, and/or gestational age when exercise was performed. This may be confounded by the nutrient intake of gravidae as it impacts energy balance and maternal weight gain. The interaction of how exercise volume and nutrient intake may modulate placental size may be in fact, rooted in

one's understanding of birthweight. Given the importance of exercise in improving health, longevity, and reducing weight gain, many more women are inclined to exercise both before and during pregnancy. Many women may wish to adopt the CDC/ACSM guidelines that individuals should perform at least 30 minutes of exercise on most if not all days of the week. Thus, this study will help clarify how the interaction between exercise volume and nutrient intake may affect both birthweight and placental size.

Research Hypotheses

1. It is hypothesized that the volume of exercise performed will directly affect neonatal outcomes measured in this study (i.e. birthweight and placental volume) (Bell et al., 1995; Clapp et al., 2002). In addition, it is hypothesized that the volume of exercise performed will indirectly affect neonatal outcomes via their impact on maternal weight gain. The volume of exercise performed directly affects the amount of weight an expectant mother gains during her pregnancy (Clapp and Dickstein, 1984). Maternal weight gain is a mediator that in turn affects neonatal outcomes (See Figure 1).
2. It is hypothesized that the total amount of carbohydrates and fiber consumed during pregnancy will directly affect neonatal outcomes measured in this study. (Clapp, 1997; Clapp, 1998; Clapp, 2002). Additionally, total carbohydrates and fiber consumed during pregnancy are hypothesized to indirectly affect neonatal outcomes via their impact on maternal weight gain. Total carbohydrate intake and fiber intake exert a direct effect on the amount of weight a woman gains

during her pregnancy (Clapp, 2002). In turn, maternal weight gain acts as a mediator that directly affects placental volume and birthweight (See Figure 1).

Delimitations

This study will be delimited to the following:

1. Volunteers over the age of 18 who are apparently healthy and are experiencing low risk pregnancies.
2. Volunteers from Baptist and South Miami Hospitals located in Miami, FL.
3. Women who do not drink alcohol, smoke, or abuse substances.
4. Use of the volume displacement technique to calculate placental volume.
5. Use of a three day food log to assess nutrient intake.
6. Use of frequency and duration of aerobic exercise to determine total exercise volume.
7. Use of self-reported information to quantify exercise volume and nutrient intake information.
8. Use of the computer software program Diet Analysis Plus to evaluate nutrient intake information.

Limitations

The accuracy and reliability of these data will be limited by the following:

1. The ability and willingness of the subject to accurately record the frequency, and duration of her exercise program.
2. The fact that exercise intensity is not factored into the quantification of exercise.

3. The ability and willingness of the subject to accurately record the type and amount of food intake during the designated periods of dietary recall.
4. The accuracy of using a self-report to assess nutrient intake.
5. The accuracy and reliability of the computer software program Diet Analysis Plus to evaluate nutrient intake.
6. The accuracy of using a self-report to assess exercise volume.
7. The accuracy and reliability of the scales used to measure birthweight.
8. The accuracy and reliability of the volume displacement technique to measure placental volume.

Definition of Terms

For the purpose of this study, the following definitions were adopted:

BIRTHWEIGHT - the weight of the newborn. Normal weight of the newborn is between 5.5 lb (2.5 kg) and 10 lb (4.5 kg). Birthweight is an important index of maturation and chance for survival. Weight of less than 2.5 kg is associated with an increased chance of death in the perinatal period. Medical advances have increased the chance of survival of newborns of 2.0 kg or more (Thomas, 1997).

CESAREAN SECTION – delivery of the fetus by means of incision into the uterus (Thomas, 1997).

CORRECTED BIRTHWEIGHT - weight of the newborn taking into account factors known to affect fetal growth such as gestational age, sex, race, parity, maternal weight gain, and socioeconomic status (Campbell et al., 1993).

DIABETES MELLITUS – a chronic disorder of carbohydrate metabolism, marked by hyperglycemia and glycosuria and resulting from inadequate production or use of insulin (Thomas, 1997).

DURATION OF EXERCISE - the amount of time invested in performing the primary workout (Powers and Dodd, 1999).

EPIDURAL ANESTHESIA – anesthesia produced by injection of local anesthetic into the peridural space of the spinal cord beneath the ligamentum flavum (MedlinePlus).

EXERCISE VOLUME - product of weekly training frequency and duration of session (Brooks et al., 1996).

FREQUENCY OF EXERCISE - the number of times per week that one intends to exercise (Powers and Dodd, 1999).

GESTATION - in mammals, the length of time from conception to birth. In humans, the average length, as calculated from the first day of the last normal menstrual period, is 280 days, with a normal range of 259 days (37 weeks) to 287 days (41 weeks) (Thomas, 1997).

GESTATIONAL DIABETES MELLITUS – diabetes mellitus that manifests clinically during pregnancy as a result of hormonal changes. It usually subsides after delivery (Thomas, 1997).

GRAVIDA – a pregnant woman (Thomas, 1997).

INDUCTION – the process of causing or producing, as induction of labor with oxytocic drugs in cases of uterine dysfunction (Thomas, 1997).

MODE OF EXERCISE - the specific type of exercise to be performed (Powers and Dodd, 1999).

MULTIGRAVIDA – a woman who is experiencing her second pregnancy or who has been pregnant more than once (Thomas, 1997).

MORPHOMETRICS - the measurement of forms (Thomas, 1997).

NATURAL CHILDBIRTH – the delivery of a fetus without the use of analgesics, sedatives, or anesthesia (Thomas, 1997).

NULLIPAROUS - never having borne a child (Thomas, 1997).

PARENCHYMA - the essential parts of an organ that are concerned with its function in contradistinction to its framework (Thomas, 1997).

PERCEIVED EXERTION SCALE – a rating scale of relative fatigue. A high correlation exists between the perception of exhaustion and $VO_2 \text{ max}$ (Brooks et al., 1996).

PARITY - the condition of having carried a pregnancy to a point of viability (500 g birthweight or 20 weeks gestation), regardless of the outcome (Thomas, 1997).

PLACENTA - the oval or discoid spongy structure in the uterus of eutherian mammals from which the fetus derives its nourishment and oxygen (Thomas, 1997).

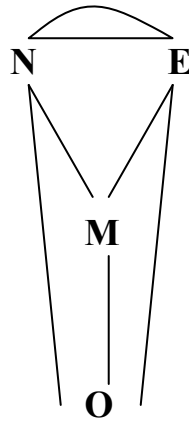
PLACENTAL VOLUME - the space occupied by the placenta, expressed in liters or milliliters (Thomas, 1997).

PRE-ECLAMPSIA – a complication of pregnancy characterized by increasing hypertension, proteinuria, and edema. The condition may progress rapidly from mild to severe and, if untreated, to eclampsia. It is the leading cause of fetal and maternal morbidity and death, especially in underdeveloped countries (Thomas, 1997).

PRIMIGRAVIDA – a woman during her first pregnancy (Thomas, 1997).

TERATOGENIC – causing abnormal development of the embryo (Thomas, 1997).

THREE-DAY FOOD LOG - a computerized data base that quantifies total Calories, fat, carbohydrates, and other nutrient components.



N = nutritional intake (calories, carbohydrates, fat, fiber)
E = exercise volume
M = maternal weight gain
O = neonatal outcomes (birthweight and placental volume)

***Figure 1.* The hypothesized relationship between independent and dependent variables.**

CHAPTER 2: REVIEW OF LITERATURE

During pregnancy, dramatic physiological changes occur in the gravid patient due to a rise in the production of the gestational hormones estrogen and progesterone. Increases in body weight and body fat are accompanied by alterations in cardiovascular, respiratory, and metabolic function (Lotgering et al., 1985; Artal et al., 1986; Boden, 1996; Kuhl, 1998; Ezmerli, 2000). Given the large physiological changes accompanying pregnancy, weight gain associated with pregnancy, and the physiological demands of delivery, more and more women are exercising during pregnancy to keep in good physical condition and be better prepared for delivery. While moderate-intensity aerobic exercise has been determined to be safe for low-risk gravidae, there are questions as to how maternal exercise affects fetoplacental size (Collings et al., 1983; Clapp and Rizk, 1992; Kardel and Kase, 1998; Clapp et al., 2000, Clapp et al., 2002). In addition, studies that have examined the relationship between maternal exercise and fetoplacental size have not addressed the potentially confounding role of maternal nutrient intake. Therefore, the purpose of this study was to examine the effects of maternal exercise volume on birthweight and placental volume, while addressing the influence of maternal nutrient intake and maternal weight gain. This review of related literature will be divided into the following sections:

- Physiological Changes During Pregnancy
- Physiological Effects of Exercise During Pregnancy
- Maternal Health Benefits of Exercise During Pregnancy
- Effect of Maternal Exercise on Birthweight

- Effect of Maternal Exercise on Placental Size
- Effect of Maternal Nutrient Intake on Fetoplacental Size

Physiological Changes During Pregnancy

During pregnancy, there is an increase in body weight that averages 13 kg. The increase in body weight is due to an enlargement of uterine mass, breast size, placental mass, amniotic fluid, blood volume, and the fetus, which averages 3.5 kg at term. Maternal body fat mass also increases by an average of 4.0 kg (Boden, 1996).

The enlargement of the uterus and breasts creates a progressive lordosis of the lumbar spine and a changing in the center of gravity (Artal et al., 1991). To compensate for the progressive lordosis, there is an increase in the anterior flexion of the cervical spine and an abduction of the shoulders (Artal, 1992).

A rise in hormones such as relaxin cause an increase in joint laxity, especially at the interspinous and sacroiliac joints, pubic symphysis, knees and ankles (Goodlin and Buckley, 1984). Increase in joint laxity theoretically should increase the probability of an increase in the number of sprains, however the only evidence of this is in the metacarpophalangeal joint (Calguneri, 1982).

Resting cardiac output increases progressively throughout gestation, with a total increase of up to 40% over non-pregnant values (Lotgering et al., 1985). The increase in cardiac output can be attributed to rises in resting heart rate, blood volume, and stroke volume (Ezmerli, 2000).

Resting heart rate increases by seven beats per minute (bpm) in early pregnancy, and gradually rises to increase by a total of 15 bpm over non-pregnant values by late

pregnancy (Hartmann and Bung, 1999). The rise in heart rate can be attributed to a reduced parasympathetic innervation, and possibly a slight increase in sympathetic innervation compared to a non-pregnant state (Avery et al., 2001).

Blood volume rises with advancing gestational age, reaching a peak of 40-50% above non-pregnant levels in late gestation (Longo, 1983; Pivarnik et al., 1994). Higher blood volume can be attributed to increases in both plasma volume and erythrocyte mass. Plasma volume increases by 30-60% (Scott, 1972), while erythrocyte mass increases by 20% (Lund and Donovan, 1967).

A higher preload, along with an increase in the internal diameter of the left ventricle, results in an increase in end-diastolic volume and an increase in stroke volume (Rubler et al., 1977; Katz et al., 1978; Larkin et al., 1980). A greater stroke volume enables the gravid patient to increase oxygen consumption to working tissues.

As a result of increased progesterone levels during pregnancy, an increase in respiratory sensitivity to carbon dioxide is observed (O'Toole, 2003). Increased ventilatory sensitivity to carbon dioxide, which occurs during the first trimester, causes a 50% increase in resting minute ventilation by the third trimester, due primarily to increased tidal volume (Hartmann and Bung, 1999; Artal et al., 1986; Prowse and Gaensler, 1965). Since increased sensitivity to carbon dioxide occurs in the first trimester only, increases in minute ventilation in the second and third trimesters may be attributed to changes in the dimensions of the thoracic cavity. The growing fetus pushes the diaphragm upwards, causing a lateral expansion of the rib cage. The larger chest circumference produces higher tidal volume and minute ventilation values, along with a

lower expiratory reserve volume and functional residual capacity (Artal and Wiswell, 1986).

During the first half of pregnancy, maternal core body temperature rises from 37°C by approximately 0.5°C to reach 37.5°C (Walker et al., 1969). Fetal temperature is approximately 0.5°C higher than maternal core temperature (Lotgering et al., 1985). Higher fetal temperature promotes oxygen consumption and facilitates heat loss from the fetus to the mother (Walker et al., 1969; Lotgering et al., 1985).

During the early stages of pregnancy, there is an increase in the secretion of insulin due to the increase in number of pancreatic beta cells. As insulin is an anabolic hormone, higher circulating insulin results in increased storage of fat (Kuhl, 1998; Homko et al., 2001). In the later stages of pregnancy, placental hormones create an environment of insulin resistance leading to a higher blood glucose concentration. Insulin resistance serves as a protective effect to ensure that the developing fetus has sufficient access to a glucose supply. If insulin resistance is too high, gestational diabetes will result (Kuhl, 1998; Homko et al., 2001). Gestational diabetes mellitus (GDM) can be harmful to both mother and fetus, causing fetal macrosomia (birthweight greater than two standard deviations above the mean), fetal and maternal birth trauma, and neonatal hypoglycemia (Jovanovic, 2001). Women who contract GDM have up to a 50% chance of recurrence in a future pregnancy (Gaudier et al., 1992; Moses, 1996), and up to a 60% chance of developing type 2 diabetes later in life (Henry and Beischer, 1991; O'Sullivan, 1991).

Physiological Effects of Exercise During Pregnancy

During submaximal exercise, maternal exercise heart rate appears to be slightly higher (Guzman and Caplan, 1970; Knuttgen and Emerson, 1974; Blackburn and Calloway, 1976) or not significantly different (Dahlstrom and Ihrman, 1960; Seitchik, 1967; Blackburn and Calloway, 1976) than non-exercising controls. However, if the rise in resting heart rate is taken into account, the slight increase in maternal exercise heart rate is similar to non-pregnant controls (Dahlstrom and Ihrman, 1960; Seitchik, 1967; Blackburn and Calloway, 1976). In contrast, at maximal workloads, heart rate is less than non-gravid controls most likely due to exercising gravidae reaching their maximum work capacity at lower work levels. (Guzman and Kaplan, 1970; Lotgering et al., 1991; Lotgering et al., 1992). Thus, exercising heart rates may no longer be a valid measure of exercise intensity, since heart rates at lower workloads may overestimate exercise intensity and heart rates at higher workloads may underestimate exercise intensity (Wolfe and Weissgerber, 2003).

Higher maternal cardiac output and absolute oxygen uptake values (L/min) are seen not only during rest, but also during both non-weight bearing (Guzman and Caplan, 1970; Ueland et al., 1973; Knuttgen and Emerson, 1974; Pivarnik et al., 1991), and weight-bearing exercise (Teruoka, 1933; Saltin et al., 1968; Artal et al. 1991). However, when taking into account gestational weight gain, VO_2 (mL/kg/min) actually declines (Artal et al., 1989). A similar pattern is found for maternal maximal oxygen uptake (VO_2 max). Maternal absolute VO_2 max either increases (Collings et al, 1983) or remains unchanged (Sady et al., 1990; Lotgering et al., 1991). Relative VO_2 max declines with progressive maternal weight gain (Lotgering et al., 1991).

During moderate exercise, core temperature of non-gravid women commonly rises above 38°C, and in hot/humid conditions may rise to above 40°C (Clapp, 1991). Hyperthermia occurring during the first trimester may cause neural tube defects in the developing fetus (Shioto, 1988). Even a slight rise in maternal core temperature (1.5°C-2.5°C) has been shown to cause death of an embryo in animal studies (Edwards, 1986; Warkany, 1986). Previous concerns were that maternal exercise would elicit an increase in core temperature as occurs in non-gravid exercisers, and reverse the transfer of heat from the mother to the fetus. However, gravidae experience enhanced thermoregulation mechanisms including improved peripheral vasodilation and a lower temperature threshold for sweating (Clapp, 1991). In fact, there have been no temperature increases over 38/39°C (O'Neill, 1996) and there have been no adverse effects reported as a result of elevated body temperature during exercise (Riemann and Kanstrup Hansen, 2000).

Exercise stimulates the sympathetic division of the autonomic nervous system and the release of the catecholamines epinephrine and norepinephrine. Part of the sympathetic response is the redistribution of blood flow away from the internal organs and toward the skin and skeletal muscles (Rowell and O'Leary, 1990). This response begins at low intensity levels of exercise and changes linearly with an increase in exercise intensity and duration (Rowell, 1974; Rowell, 1983). At moderate exercise intensity, visceral blood flow is approximately 50% below resting level, and during prolonged high-intensity exercise, exercise may fall to 70% below resting level (Clapp, 1993). Since the fetus is part of the organ systems temporarily deprived of blood flow, there is concern that the fetus is not receiving sufficient oxygen and glucose during exercise. Although there is some discrepancy as to how exercise affects fetal size, no study has

shown that exercise causes expecting mothers to give birth to clinically low birthweight babies (Lokey et al., 1991; Pivarnik, 1998). The fact that babies of exercising mothers are of clinically normal size indicates that while in utero, they are receiving a sufficient blood supply.

A secondary concern about catecholamine release during maternal exercise is that norepinephrine can increase the intensity and amplitude of uterine contractions and increase the risk of pre-term labor (Clapp, 1994). However, a 1991 meta-analysis of 18 studies that examined exercising gravidae indicates that exercise does not significantly affect gestational length (Lokey et al., 1991).

During submaximal maternal exercise, the most common fetal response is an increase in FHR of 5-25 bpm dependent on intensity, duration, and mode of maternal exercise, in addition to maternal fitness level (Wolfe et al., 1994). This is followed by a gradual return to baseline post-exercise (Wolfe et al., 1994). Fetal heart rate acceleration is accepted as a sign of well-being (Webb et al., 1994), while a decline in FHR below normal values (bradycardia) is more alarming, indicating insufficient oxygen (Brenner et al. 1999). Incidence of fetal bradycardia has been reported sporadically, although it has generally been found in untrained women exercising at maximal bouts (Pivarnik et al., 1991; Watson et al., 1991; Webb et al., 1994). Transient bradycardia may be expected to occur during recovery from exercise due to continued maternal vasodilation and decreased venous return. However, report of bradycardia may be inaccurate due to problems with FHR recording methods and failure to standardize the definition of clinical bradycardia (Webb et al., 1994). Furthermore, in those studies that did report

bradycardic response to exercise, all newborns were found to be healthy at term (Pivarnik et al., 1991; Watson et al., 1991; Webb et al., 1994).

Maternal Health Benefits of Exercise During Pregnancy

Regular aerobic exercise performed during pregnancy results in similar health benefits as exercise during non-pregnancy. This includes protection against the development of type 2 diabetes and coronary heart disease, and of coronary heart disease risk factors including hypertension, plasma dyslipdemia, insulin resistance and obesity (Department of Health and Human Services, 1996). Maternal exercise during pregnancy also results in pregnancy-specific benefits including improved sleep, decreased low-back pain, improved posture, and increased likelihood of postpartum exercise (Ezmerli, 2000). Psychological benefits of exercise during pregnancy include decreased anxiety and depression bouts, and improved self-esteem, mood, and body image (Bungum et al., 2000). Negative body image during pregnancy has been related to inadequate maternal weight gain, premature delivery, low birthweight, delayed child development, and possibly maternal and fetal death (Shearer, 1980; Franko and Walton, 1993).

Exercise during pregnancy also reduces the occurrence of GDM (Dye et al., 1997). Regular aerobic exercise lowers blood glucose levels in women with GDM not only by reducing maternal insulin resistance, but also by stimulating glucose uptake through insulin-independent pathways (Borghouts and Keizer, 2000). In its current position statement on exercise and pregnancy, the American College of Obstetricians and Gynecologists (ACOG) has recommended exercise for women with GDM as a way of helping regulate blood glucose levels (2002).

Maternal exercise may not only be used as therapy to protect against GDM, but also against preeclampsia. Preeclampsia is a medical condition diagnosed after 20 weeks gestation on the basis of continuing hypertension (blood pressure over 140/90) and proteinuria (24 hour urinary protein level of at least 0.3 g/d) (ACOG, 2002). Proteinuria indicates damage to the endothelial cells of the kidney, causing protein to leak out of the bloodstream and into the urine. Preeclampsia is a leading cause of maternal and perinatal morbidity and mortality worldwide, affecting 3%-4% of healthy gravidae (Sorensen et al., 2003). Research has shown that moderate leisure-time physical activity may reduce the risk of preeclampsia (Marcoux et al, 1989; Saftlas et al., 2004).

While there have been some reports that maternal exercise prevents excessive weight gain during pregnancy (Wolfe et al., 1994), Lokey's 1991 meta-analysis showed no difference in maternal weight gain between exercising and sedentary gravidae (Lokey et al., 1991). Since 1991, most other studies have confirmed findings by Lokey (Hatch et al., 1993; Bell et al., 1995; Brenner et al., 1999; Marquez-Sterling, et al., 2000, Magann et al., 2002). Furthermore, one recent study showed no difference in maternal weight gain between gravidae exercising at high versus medium volumes (Kardel, 2005). However, Clapp and his colleagues have shown that the time in gestation during which exercise is performed may dictate whether or not exercise effects maternal weight gain. Clapp and Dickstein (1984) showed that women who exercised beyond 28 weeks gestation gained an average of 4.6 kg less than those who voluntarily discontinued exercise before 28 weeks gestation. Furthermore, Clapp et al. (2002) conducted a study of gravidae who performed weight bearing exercise at 55-60% of their pre-pregnancy VO_2 max. They were randomly assigned to one of three groups: (a) those who performed

20 minutes of exercise 5 times/week through week 20 and gradually increased to 60 minutes 5 times/week by week 24 (lo-hi), (b) those who performed 40 minutes of exercise five times/week until delivery (mod-mod), (c) those who performed 60 minutes of exercise five times/week through week 20 and gradually decreased to 20 minutes five times/week by week 24 (hi-lo). They found that pregnancy weight gain was significantly reduced in the lo-hi group versus the mod-mod and hi-lo groups (Clapp et al., 2002). Thus, while most studies show that exercise does not significantly affect maternal weight gain, the distribution of exercise during gestation may be what actually affects maternal weight gain.

Effect of Maternal Exercise on Birthweight

Numerous studies have examined the effect of maternal training on birthweight. Maternal exercise has been shown to increase, decrease, or result in no change in birthweight. The variability in results may be related to factors such as sample size, exercise mode, exercise intensity, exercise volume, and time during gestation that exercise is performed.

Lokey's meta-analysis (1991) of the studies that examined the training effect of exercise during pregnancy prior to 1989 showed that maternal exercise has no effect on birthweight. Subsequently, studies by Rice and Fort (1991), Clapp and Risk (1992), Webb et al. (1994), Bell et al. (1995), Sternfeld et al. (1995), Brenner et al. (1999), and Marquez-Sterling et al. (2000) all found that maternal exercise does not affect birthweight. However, upon closer inspection, there are several inconsistencies among the studies reporting no training effect. In some cases, the number of subjects was very

small (Brenner et al., 1999; Marquez-Sterling et al., 2000). Exercise mode was often retrospective (Rice and Fort, 1991; Sternfeld et al., 1995), or self-selected (Clapp and Risk, 1992; Webb et al., 1994; Brenner et al., 1999). Modes varied among walking (Rice and Fort, 1991), non-weight bearing aerobic exercise (Webb et al., 1994; Brenner et al., 1999) or a combination of all types of aerobic exercise including walking and non-weight bearing modalities (Kulpa et al., 1987; Clapp and Rizk, 1992; Bell et al., 1995; Marquez-Sterling et al., 2000). Furthermore, differences in exercise volume were often unaccounted for (Kulpa et al., 1987; Rice and Fort, 1991; Clapp and Rizk, 1992).

Bell et al. (1995) found that previously active women who exercised five, six, or seven days per week had significantly smaller babies than previously active women who exercised three days per week, and significantly smaller babies than sedentary controls. These findings have been confirmed in the literature by Clapp and Dickstein (1984), Campbell and Motolla (2001), Clapp et al. (2002), and Magann et al. (2002).

Clapp and Dickstein (1984) interviewed women antepartum and between 28 and 36 weeks to determine exercise performance during pregnancy. They categorized women as exercisers if they increased their heart rate to greater than 50% of age-predicted maximum at least 30 minutes per session, at least 3 days per week. Exercise mode was running, aerobics, or cross-country skiing. They found that gravidae who continued to exercise into their third trimester delivered lighter infants than gravidae who either stopped exercise prior to 28 weeks gestation or who were sedentary throughout pregnancy. Women who were sedentary throughout pregnancy delivered infants of similar birthweights as women who stopped exercise prior to 28 weeks gestation.

Campbell and Motolla (2001) administered a questionnaire shortly after delivery to 529 women who gave birth to infants weighing less than the fifteenth percentile for gestational age. They found that women who participated in five or more exercise sessions per week were significantly more likely to give birth to low-birthweight infants than women who participated in three to four exercise sessions per week. They also found that women who exercised two or less times per week were significantly more likely to give birth to low-birthweight infants than women who exercised three to four times per week.

Magann et al. (2002) administered a questionnaire before, during and after pregnancy to 750 women who were on active-duty in the Navy. They found that after controlling for confounding factors, gravidae who performed voluntary exercise after 28 weeks gestation gave birth to significantly lighter babies than gravidae who did not exercise.

Clapp et al. (2002) enrolled 75 women prior to conception in a program of weight-bearing exercise five times per week as explained in detail in the previous discussion on the effect of exercise on maternal weight gain. They found that gravidae who performed a high volume of exercise in the third trimester delivered significantly smaller infants than gravidae who performed either a moderate or low volume of exercise in the third trimester. No difference was found between gravidae who performed a low volume and gravidae who performed a moderate volume of exercise in the third trimester.

In contrast, a few studies have found that high-volume exercisers gave birth to heavier babies (Hall and Kaufmann, 1987; Kardel and Kase, 1998; Bell and Palma, 2000). Hall and Kaufmann (1987) enrolled gravidae in an exercise protocol on the cycle

ergometer at an intensity that elicited an exercise heart rate of less than 140 beats per minute. They allowed gravidae to choose how many exercise sessions they would participate in throughout pregnancy. They found that gravidae who completed the highest number of sessions (60-99) during pregnancy tended to have heavier babies than gravidae who completed the lowest number of sessions (0-10) ($p=.06$). They concluded that the discrepancy between studies may be due to the less-vigorous, non-weight bearing exercise program chosen for their study.

Kardel and Kase (1998) enrolled athletes in a program of strength, interval, and endurance training during pregnancy. They allowed gravidae to select whether they would be a part of the high-volume or medium-volume training group which consisted of cycling, cross-country skiing, running, or brisk walking throughout pregnancy. Women who took breaks in training of up to 125 days were included in the data analysis. They found that gravidae who exercised at a higher volume throughout pregnancy tended to give birth to heavier infants than gravidae who exercised at a medium-volume.

Bell and Palma (2000) randomized gravidae intending to exercise vigorously throughout pregnancy to either exercising at least five times per week ($n=23$) or three times per week or less ($n=20$). Each group exercised at least 30 minutes per session at an intensity of greater than 50% age-predicted maximum heart rate. They found that gravidae who exercised at least five times per week into their third trimester tended to give birth to larger babies than gravidae who exercised three times per week or less.

Only one study reported that maternal exercise volume differences do not affect birthweight. Clapp et al. (2000) conducted a randomized study in which exercisers performed weight-bearing exercise throughout pregnancy at 55-60% of preconception

VO₂max for 20 minutes, three to five times per week. They found that while exercisers gave birth to significantly heavier infants than sedentary controls, there was no difference between those who exercised 16-20 times per month and those who exercised 12-14 times per month. They speculated that the discrepancy in their findings compared to others was due to the fact that subjects began their exercise protocol at 8 weeks gestation. Most other studies did not examine training data until the second trimester. They noted that the first trimester is a time for significant placental growth, and may prepare the placenta for improved function and fetal growth later in gestation.

The relationship between maternal exercise and birthweight is complex. Previous studies suggest that the type of exercise, the intensity and volume of exercise, and the length of time engaged in exercise during gestation modulate the relationship between exercise and birthweight. Most studies reporting that exercise has no significant effect on birthweight either used a small number of subjects, allowed walking or non-weight bearing exercise, or permitted changes in exercise volume throughout gestation (Collings et al., 1983; Kulpa et al., 1987; Rice and Fort, 1991; Webb et al., 1994; Sternfeld et al., 1995; Bell et al., 1995; Brenner et al., 1999; Marquez-Sterling et al., 2000). Studies have suggested that gravidae who continue a high volume of exercise into late pregnancy give birth to lighter infants (Clapp and Dickstein, 1984; Bell et al., 1995; Clapp et al., 2002; Magann et al., 2002). Since the majority of these studies were not randomized, investigators have theorized that an additional factor such as nutrient intake contributed to the difference in birthweight found between groups.

Effect of Maternal Exercise on Placental Size

The placenta is the organ of respiration and nutrition for the developing fetus (Aherne and Dunnill, 1966). Its function is to bring the fetal and maternal bloodstreams into close proximity so that gases, nutrients, and wastes may be exchanged (Aherne and Dunnill, 1966). Placental weight has been shown to have a direct relationship with birthweight (McKeown and Record, 1953; Thomson et al., 1969; Molteni et al., 1978), and this relationship transcends small, average, and large birthweight for gestational age groups (Molteni et al., 1978). Research on active gravidae supports this relationship. The majority of studies have reported no significant differences in placental size between exercising and sedentary gravidae, and no significant differences in birthweight between groups thereby supporting the placental size/infant birthweight relationship (Collings et al., 1983; Clapp and Rizk, 1992; Jackson et al., 1995; Kardel and Kase, 1998).

While the majority of studies have reported no significant differences in placental size between exercising and sedentary gravidae, it may be that the distribution of exercise throughout gestation modulates placental size. In fact, a few studies reported that gravidae who exercise at a high volume into their third trimester have smaller placentas than those who maintain or decrease their exercise volume (Clapp and Rizk, 1992; Clapp et al., 2002). These studies also reported a corresponding reduction in birthweight of infants born to gravidae exercising at a high volume into their third trimester.

One study found that gravidae who exercise throughout pregnancy have larger placentas than sedentary controls (Clapp et al., 2000). The larger placental size found in exercising gravidae corresponded to a greater birthweight. Furthermore, they found no

difference in placental size or birthweight between high-volume and moderate-volume exercisers.

Regardless of the dose-response controversy between maternal exercise and birthweight, there is consensus that a linear relationship between birthweight and placental size exists in active gravidae similar to that observed in sedentary gravidae (McKeown and Record, 1953; Thomson et al., 1969; Molteni et al., 1978). That is, the larger the placenta, the heavier the newborn. Similarly, the smaller the placenta, the lighter the newborn.

The question of how maternal exercise affects placental size remains complicated. During exercise, blood flow is diverted away from the viscera including the placenta, and toward the working skeletal muscles. Blood flow to the placenta may decrease by 50% or more during vigorous exercise (Clapp et al., 2000). Since most studies show that exercise during pregnancy results in no change in placental size, investigators have theorized that maternal exercise may increase placental blood flow at rest (Clapp, 2006). A summary of how maternal exercise affects placental weight is presented in Table 1.

Table 1. Summary of Studies that Have Examined the Maternal Training Effect on Placental Size

Authors	Study design	Sample size (exercise/control)	Exercise mode	Exercise intensity	Exercise volume	Duration of training protocol	Impact of exercise on placental size
Collings et al. 1983	5 self-selected 15 random assignment	12/8	cycle	65-70% 2 nd T VO ₂ max	25 min., 3x/wk	7-19 wks from mean of 22.5 wks	↔
Clapp and Capeless 1990	self-selected	77/55	running or aerobic dance	>50% maximum capacity	25-30 minute 3-11x/wk	throughout pregnancy ave # sessions declined	↔
Clapp and Rizk 1992	self-selected	18/16	aerobic dance, swimming, running	>50% maximum capacity	≥20 min/session ≥3 x/wk	throughout pregnancy ave # sessions declined	↔
Jackson et al. 1995	self-selected	20 control 20 early 20 continued	running, aerobics, cross-country skiing	>50% VO ₂ max	>30 min/session >3x/wk	early: stopped at 20 wks gest. continued: throughout pregnancy	↔



Table 1. Summary of Studies that Have Examined the Maternal Training Effect on Placental Size (Continued)

Authors	Study design	Sample size (exercise/control)	Exercise mode	Exercise intensity	Exercise volume	Duration of training protocol	Impact of exercise on placental size
Kardel and Kase 1998	self-selected	17 high-volume (I), 16 med-volume (II)	cycle, ski, run, brisk walk	interval: 170-180 bpm endurance: 120-140 bpm	I: 2.5 hrs endurance 2x/wk 35 min interval 2x/wk II: 1.5 hrs endurance 2x/wk 25 min interval 2x/wk	through pregnancy (breaks allowed)	Non sig in high-volume group
Clapp et al. 2000	random selection	22/24	running, step aerobics, stair stepper	55-60% pre- conception VO ₂ max	20 min/session 3-5 x/wk	throughout pregnancy	↑ control 16-20x/mth ↔ 12-14x
Clapp et al. 2002	random selection	26 lo-hi/24 mod-mod/ 25 hi-lo	running, step aerobics, stair stepper	55-60% pre- conception VO ₂ max	all groups 5x/wk lo-hi: 20 min through wk 20, to 60 min by wk 24 until delivery mod-mod: 40 min wk 8 through delivery hi-lo: 60 min through wk 20, to 20 min by wk 24 until delivery		↑ mod-mod hi-lo ↑ lo-hi

Effect of Maternal Nutrient Intake on Fetoplacental Size

Basal metabolism is defined as the amount of energy needed for maintenance of life when the subject is at digestive, physical, and emotional rest (Thomas, 1997). During pregnancy, basal metabolism increases due to the increased mass of fetal, placental, and maternal tissue; the increased cost of cardiorespiratory work; and the increased cost of tissue synthesis (van Raaij, 1995). Based on Hytten and Leitch's (1971) theoretical calculations of increased maternal energy expenditure, the World Health Organization (1985) recommends that pregnant women consume an additional 285 kcal/day. However, energy expenditure is not only dependent on basal metabolism, but also dependent on daily physical activity, which typically comprises between 20 and 35 percent of total energy expenditure (van Raaij, 1995). As gravidae progress through gestation, they tend to decrease their level of physical activity, replacing high-intensity with low to moderate-intensity activities, and reducing the number of exercise sessions (Clapp, 1990; Clapp and Capeless, 1990; Hatch et al., 1993; Sternfeld et al., 1995). Gravidae who continue an exercise program of moderate to high-intensity, weight-bearing exercise throughout gestation may require extra calories in excess of the 285 kcal/day as recommended by the WHO. The balance between maternal nutrient intake and maternal physical activity and its effect on fetoplacental size has not been well studied. Most studies that have examined how maternal exercise affects fetoplacental size did not account for maternal nutrient intake (Collings et al., 1983; Clapp and Dickstein, 1984; Kulpa et al., 1987; Hall and Kaufmann, 1987; Clapp, 1990; Rice and Fort, 1991; Hatch et al., 1993; Webb et al., 1994; Kardel and Kase, 1998; Brenner et al., 1999; Bell and Palma, 2000; Campbell and Mottola, 2001; Magann et al., 2002). Other

studies implied that diet was adequate but did not present nutrient data (Clapp and Capeless, 1990; Clapp and Rizk, 1992; Sternfeld et al., 1995; Jackson et al., 1995). Interestingly, in those studies that examined the impact of maternal exercise on newborn and placental size and accounted for nutrient intake, Calorie intake was found to be similar between groups (Bell et al., 1995; Clapp et al., 2000; Clapp et al., 2002). This is in agreement with Ning et al.'s (2003) epidemiological study showing no relationship between maternal total Calorie intake and physical activity status. There is evidence that maternal exercise into late pregnancy may result in lower birthweight (Clapp and Dickstein, 1984; Clapp et al., 2002; Magann et al., 2002). The third trimester is the period of the largest physical growth of the developing fetus. Since Calorie intake has been shown to be similar between exercising and sedentary groups, it is possible that Calorie intake may be insufficient to meet metabolic needs of the fetus, resulting in lighter-weight infants born to exercising gravidae.

In addition to total Calorie intake, other nutrient variables may be related to fetoplacental growth. These include carbohydrate, fat, and fiber intake. Sufficient carbohydrate intake is important for the expectant mother who continues to exercise because during exercise, blood glucose is diverted away from the fetus to the working skeletal muscles. This results in a temporary reduction in glucose delivery to the fetus. Blood glucose levels correlate directly with fetal growth rate and size at birth, thus if glucose delivery is reduced, fetal growth rate may also be compromised (Clapp, 1997). Matsuno et al. (1999) showed that in rats fed isocaloric diets with varying levels of glucose, there was no change in mean birthweight of individual pups. There was however, a significant difference observed in the total litter weight. Total litter weight

was higher in dams fed a 60% glucose diet when compared to dams fed a 20% glucose diet.

Not only may the amount of carbohydrate affect birthweight, but the type of carbohydrate may also be important. In exercising gravidae fed an isocaloric, high carbohydrate diet, Clapp (1997) showed that those who ate higher glycemic index foods; i.e., processed grains, root vegetables, and simple sugars, experienced larger placental size, increased birthweight, and had greater maternal weight gain than those who consumed a similar diet, but with lower glycemic index carbohydrates; i.e., whole grains, fruits, vegetables, beans, and dairy products.

Calorie requirements are tremendously increased during pregnancy due to the growth of the developing fetus. They are also increased among non-gravidae who exercise and are increased even further in gravidae who choose to exercise throughout gestation. The effect of nutrient intake on fetoplacental size in exercising gravidae is an area that warrants further investigation. Gravidae who continue to exercise into late pregnancy may not be consuming sufficient calories to compensate for their metabolic needs. Furthermore, the amount and type of carbohydrates consumed may be a more critical factor in the examination of how nutrient intake affects fetoplacental growth.

Summary of Review of Related Literature

During pregnancy, numerous physiological changes occur including cardiovascular, respiratory, physical, and metabolic constituents. Women who plan to exercise throughout gestation should consider these changes. Theoretical concerns include a shift in blood flow away from the fetus toward contracting skeletal muscles,

resulting in impaired nutrient delivery to the fetus; an increase in maternal core temperature resulting in impaired heat transfer from the fetus to the mother; an increase in fetal heart rate and adverse fetal outcomes. However, the above theoretical concerns may not be clinically significant as there are no differences shown in miscarriage rate or fetal abnormalities between exercising gravidae and sedentary controls.

In fact, exercise may be helpful during pregnancy in a manner similar to its positive effect on non-pregnant controls. Exercise helps reduce the risk of heart disease and associated co-morbidities. Furthermore, there is evidence that it may help reduce the rate of pregnancy-specific disorders such as gestational diabetes and pre-eclampsia. In contrast, maternal exercise appears to have little impact on labor and delivery outcomes.

The effect of maternal exercise on birthweight is much more controversial. Conflicting results may be due to exercise mode, intensity, volume, and time in gestation performed. The majority of studies suggest that gravidae who exercise at high volumes into late pregnancy deliver lighter weight babies. Late pregnancy is a key period for fat deposition in the developing fetus. Given the fact that there is no difference in self-reported caloric intake between exercising and sedentary gravidae, and since late pregnancy results in extensive fat deposition to the fetus, it is possible that exercising gravidae may not be consuming sufficient calories to meet their metabolic needs. This may result in lower birthweight infants compared to non-exercisers or those who discontinue exercise late in pregnancy. On the contrary, a small number of studies have reported that continuing exercise throughout pregnancy or maintaining an exercise protocol at higher exercise volume results in greater birthweight. Analysis of results is

difficult since there is large variation in exercise protocols between studies, and nutrient intake is not accounted for.

In contrast to the numerous studies examining the relationship between maternal exercise and birthweight, fewer studies have examined the relationship between maternal exercise and placental size. The majority of research conducted has shown that maternal exercise results in no change in placental size. Since exercise during pregnancy results in a redistribution of blood flow away from the placenta toward the active skeletal muscles, the most likely explanation may be an increased blood flow toward the placenta during periods of rest. Regardless of the relationship between maternal exercise and placental size, a linear association between placental size and birthweight persists.

The present study will examine the relationship between maternal exercise, birthweight and placental size, with nutrient intake and maternal weight gain as possible modifiers of these relationships. The purpose of the study is to clarify the relationship between maternal exercise and newborn outcomes by accounting for changes in exercise volume, nutrient intake, and maternal weight gain.

CHAPTER 3: METHODS AND PROCEDURES

The purpose of this study was to address the interaction of maternal exercise volume and nutrient intake on birthweight, placental size, and maternal weight gain. Differences in dependent variables were examined between women who exercised at various stages throughout gestation. Additional analyses were performed between women who continued exercising throughout various stages of pregnancy and non-exercising controls.

Research Sample

A total of 137 pregnant women were recruited from the offices of obstetricians who are affiliated with Baptist Hospital and South Miami Hospital in Miami, FL between October 2003 and May 2005. Among exercising gravidae, 32 were Caucasian, 22 were Hispanic, 2 were African-American, and 2 were of Middle-Eastern descent. Among non-exercising gravidae, 13 were Caucasian, 32 were Hispanic, 6 were African-American, and 1 was of mixed descent. A total of 23 subjects withdrew voluntarily prior to any data collection. An additional five subjects were excluded from the study due to miscarriage ($n=2$) or high-risk symptoms ($n=3$). Therefore, 109 subjects provided data for the final analysis. Inclusion criteria included subjects: (a) who were over the age of 18, (b) whose fetus was less than 20 weeks gestation, (c) who were apparently healthy and experiencing a low-risk pregnancy, (d) who obtained the consent of their obstetricians to participate in a regular exercise program, and (e) who had a sonogram verifying that the fetus was healthy confirming its' gestational age. Exclusion criteria included: (a) women carrying

multiple fetuses, (b) smokers, (c) substance abusers, and (d) high-risk pregnancies. Complications included prior miscarriage, hypertension, gestational diabetes, and metabolic disorders. Each subject completed an informed consent form that was approved by the University of Miami Subcommittee for the use of Patients or Human Subjects prior to participation.

Procedures

This study was approved by the Internal Review Board (IRB) at the University of Miami (UM), and at Baptist Health System. Recruitment occurred through Baptist Health System at a physicians meeting. Interested physicians received informative flyers sent to their offices to recruit new OB patients. Physicians interested in the study were also encouraged to talk with their colleagues to increase physician interest and participation. A total of 20 offices agreed to allow UM to pass out their recruitment letter. Interested patients completed personal information on the flyer, which was given to the front desk staff. Flyers were picked up monthly from each office, and all prospective subjects were followed up and provided with more detailed information regarding the study. This was followed by a personal meeting in which more information was provided including consent forms, demographic data forms, the Four Factor Index of Social Status, and diet and exercise logs

. The Four Factor Index of Social Status is a questionnaire that ranked each participant from 8 to 66 based on academic rank and profession (Hollingshead, 1975). It is used as a measure of socioeconomic status. Baseline maternal weight was established as the subject's weight at the time of confirmation of pregnancy by her obstetrician.

Follow-up Data Collection

The investigator methodically reviewed with each participant how to fill out her diet and exercise logs. Subjects were asked to provide 3-day food logs at 16, 20, 24, 28, 32, and 36 weeks gestation. Each food log was analyzed with the ESHA Food Processor computer software for average daily caloric intake, average daily fat intake, average daily protein intake, average daily carbohydrate intake, and average daily fiber intake. Subjects who turned in a minimum of one log were included in the data analysis.

From 16 weeks gestation until term, subjects were asked to keep a record of their exercise regimen. Information recorded included the date, mode, and duration of each exercise session. Weekly exercise volume was calculated by the investigator as the product of weekly exercise frequency and duration of each exercise session. Exercise mode was required to be sustained aerobic exercise, although the mode was self-selected by each subject. Separate data analyses were performed on walkers and higher-intensity exercisers. If at least 25% of an exercise log was completed, the log was included in the data analysis. Subjects who turned in a minimum of one log were included in the data analysis.

Self-reported information on maternal weight gain, nutrient intake, and exercise habits was mailed back to the investigator by each subject in pre-paid envelopes provided by the University of Miami at 16, 20, 24, 28, 32 and 36 weeks of gestation. Subjects were called monthly in order to thank them for their participation, and to remind them it was time to record their nutrient intake and send their food and exercise logs.

At the time of delivery, subjects were responsible for notifying their admitting nurse that they were part of the University of Miami study. Each subject provided her

admitting nurse with her subject number. A list of all subjects, along with their subject numbers and due dates, was provided to the Labor and Delivery Departments of Baptist and South Miami Hospitals by the investigator and periodically updated. After delivery, the protocol varied slightly between Baptist and South Miami Hospitals.

At Baptist Hospital, the nurses or technicians in the Labor and Delivery Department were responsible for bagging and labeling the placentas. A colored label containing the subject number (and not the subject's name) was marked to the attention of the pathology assistant. If it was during normal business hours, a volunteer took the placenta to the Pathology Department. If it was off-hours, the placenta was stored on the Labor and Delivery floor in a refrigerator that UM provided. A volunteer then took the placenta to the Pathology Department the next business day. Bags, biohazard stickers, and labels were provided by UM to the nurse manager prior to Baptist involvement in the study.

The pathology assistant for Baptist Hospital was responsible for receiving placentas sent from the Labor and Delivery Department and for performing volume analysis of each placenta. Volumes were recorded in a log provided by UM, and the investigator was responsible for periodically contacting the pathology assistant to obtain the recorded data.

At South Miami Hospital, the nurses or technicians in the Labor and Delivery Department were responsible for placing the placentas in a bucket with appropriate labeling and putting them in a refrigerator used regularly to store placentas. The pathology technician was responsible for picking up placentas marked for the research study during usual rounds to the Labor and Delivery Department. South Miami provided

their own labels and buckets for placenta collection and storage. The pathology technician also performed volume analysis of the placentas. Volumes were recorded in a log provided by UM, and the investigator was responsible for periodically contacting the pathology technician to obtain the recorded data.

Of the 109 subjects providing data for analysis, 43 placentas were collected and analyzed for volume. After investigation into the missing placentas, it appeared that the Labor and Delivery Department and/or the pathology technician at South Miami Hospital failed to collect the placentas from subjects enrolled in the study.

Placentas were refrigerated in each Pathology Department for calculation of volume within 48 hours of delivery. Placental volume must be calculated shortly after expulsion to minimize the effect that clotting has on the volume measurement. Placental volumes were calculated in the same manner at Baptist and South Miami Hospitals by fluid displacement according to the methods of Jackson et al. (1995). One pathology assistant was in charge of placental volume analysis at each hospital. A specially calibrated three liter beaker was filled with one liter of water. A graduated cylinder was used for all water measurements. Each placenta was trimmed of cord and membranes, blotted, and submerged in the water. Water was added to the beaker to total two liters of water. Placental volume was calculated as the difference between two liters and the total amount of water added to the beaker.

Subjects were called shortly after delivery to collect birthweight and total maternal weight gain. To allow for disparities due to gestational age, sex, race, maternal weight gain, and socioeconomic status, corrected birthweight was also calculated

according to the regression equation established by Campbell et al. (1993). Birthweight was collected from 77 of the 109 subjects included in the study.

Statistical Procedures

Latent growth modeling was used to analyze how change in maternal exercise volume over time affects neonatal outcomes. A growth model is a more flexible way to analyze repeated measures data and model change over time. The impact of change in maternal exercise volume over time on neonatal outcomes has not been investigated in previous studies, so a growth model provides a unique perspective on how the amount of exercise performed affects outcome variables.

The latent growth model has two main parameters: 1. intercept and 2. slope parameter. The intercept is the average value of the initial time point. For this study, the intercept is the average maternal exercise volume at 16 weeks gestation. The variance around the intercept will allow an assessment of how much individual difference exists between gravidae in terms of how much exercise they perform. The slope parameter refers to the change that occurs longitudinally. In this study, the slope parameter allows one to quantify the shape of the growth trajectory across gestation. Some women may steadily decrease their exercise volume as they progress through their pregnancy - this is considered a linear growth pattern. Other women may continue exercising through their pregnancy at a constant volume and then suddenly reduce the amount of exercise they perform - this is considered a non-linear growth pattern. If maternal exercise volume is plotted across time, the value of the slope parameter reveals the shape of the growth trajectory and the amount of change in maternal exercise volume across gestation. The

variability of the slope parameter quantifies the individual differences in women's growth patterns across time.

The components of the growth model (intercept and slope) serve two purposes. The first purpose is descriptive: they provide a more complete understanding of how exercise volume changes across the duration of pregnancy. More importantly, the second purpose is to serve as a predictor of neonatal outcomes. The intercept can determine whether the amount of exercise performed at 16 weeks gestation is predictive of fetoplacental growth. This is accomplished by using the value of the intercept as a predictor of the dependent variables. The slope can determine whether the change in exercise across the duration of gestation is predictive of fetoplacental growth. This is accomplished by using the slope factor as the predictor for the dependent variables.

Latent growth modeling is an advantageous statistical method when compared to more traditional techniques used to analyze longitudinal data. Previously, a static point would have to be chosen to measure how maternal exercise volume affects neonatal outcomes. With latent growth modeling, one is allowed to recognize that exercise volume is not a static variable, but a dynamic one that changes as gestation progresses. Rather than answer the question if maternal exercise volume at a static point predicts neonatal outcomes, we are able to view exercise volume as a changing process and answer the question how changes in maternal exercise volume affect neonatal outcomes.

In summary, latent growth modeling allows one to quantify maternal exercise volume in terms of two components: slope (initial maternal exercise volume) and intercept (how maternal exercise volume changes over time). These components provide a more complete picture and serve as predictors of neonatal outcome. They allow one to

examine not only if the initial maternal exercise volume affects neonatal outcome, but also if the change in maternal exercise volume over gestation is important in determining outcome variables.

To provide a comparison between this study and previous experiments, multiple ANOVAs were performed to determine if there are significant differences in neonatal outcomes between women who exercise during pregnancy and women who were sedentary prior to their pregnancy and continued an inactive lifestyle during their pregnancy.

CHAPTER 4: RESULTS

Introduction

The purpose of this study was to examine how the interaction between maternal exercise volume and nutrient intake throughout pregnancy affect birthweight, corrected birthweight, placental volume at birth, and total maternal weight gain. Subjects were asked to record all modes of exercise they voluntarily performed. Two longitudinal analyses were conducted on the effect of maternal exercise volume on delivery outcomes: 1) how maternal walking volume affected delivery outcomes, and 2) how maternal non-walking aerobic exercise affected delivery outcomes. Non-walking aerobic exercise included running, spinning, and aerobic dance classes. Additionally, the effect of maternal daily nutrient intake throughout pregnancy on delivery outcomes was examined. Finally, a comparison of dependent variable means was calculated between exercising and non-exercising gravidae. Exercisers were classified as having performed any mode of exercise at least once a week on a regular basis at 16 weeks gestation. Non-exercisers were classified as not performing exercise on a regular basis at 16 weeks gestation or any other time throughout their pregnancies.

Subject Characteristics

As shown in Table 2 are the maternal demographics of participants in the study. There were no significant differences in initial maternal BMI levels and the number of prior children between exercisers and non-exercisers. Exercisers were

significantly older ($p = .03$) and scored significantly higher on the Hollingshead SES scale ($p < .01$),

Table 2. A Comparison of Maternal Demographics of Participants

Using Multiple ANOVAs

Demographic	Exercisers	Non-exercisers	p-value
Maternal BMI (kg/m ²)	23.12 ± 3.3	24.28 ± 4.0	NS
Number of children	1.54 ± 0.7	1.75 ± 0.9	NS
Maternal age (years)	30.96 ± 4.1	29.13 ± 4.6	$p = .03$
Maternal SES	56.9 ± 7.4	49.4 ± 11.0	$p < .01$

SES: socioeconomic status using Hollingshead SES scale

indicating higher socio-economic status. No adjustments for multiple comparisons have been made and results at $p < .05$ should be interpreted with caution.

Walking Growth Curve Model

A random sample of individual growth curves is presented in Figure 2. Each person's observed data points, which may not be a linear curve, are represented by a straight line. This straight line signifies an "idealized" growth trajectory. The line has two components: an initial status (intercept) and a slope (growth per month). The

intercepts and slopes are treated as variables that can be correlated with other variables (e.g., birthweight, placental volume, etc.). The growth model summarizes the collection of individual trajectories using an average intercept and slope, and also yields an estimate of the variation (e.g., standard deviation) of the intercepts and slopes.

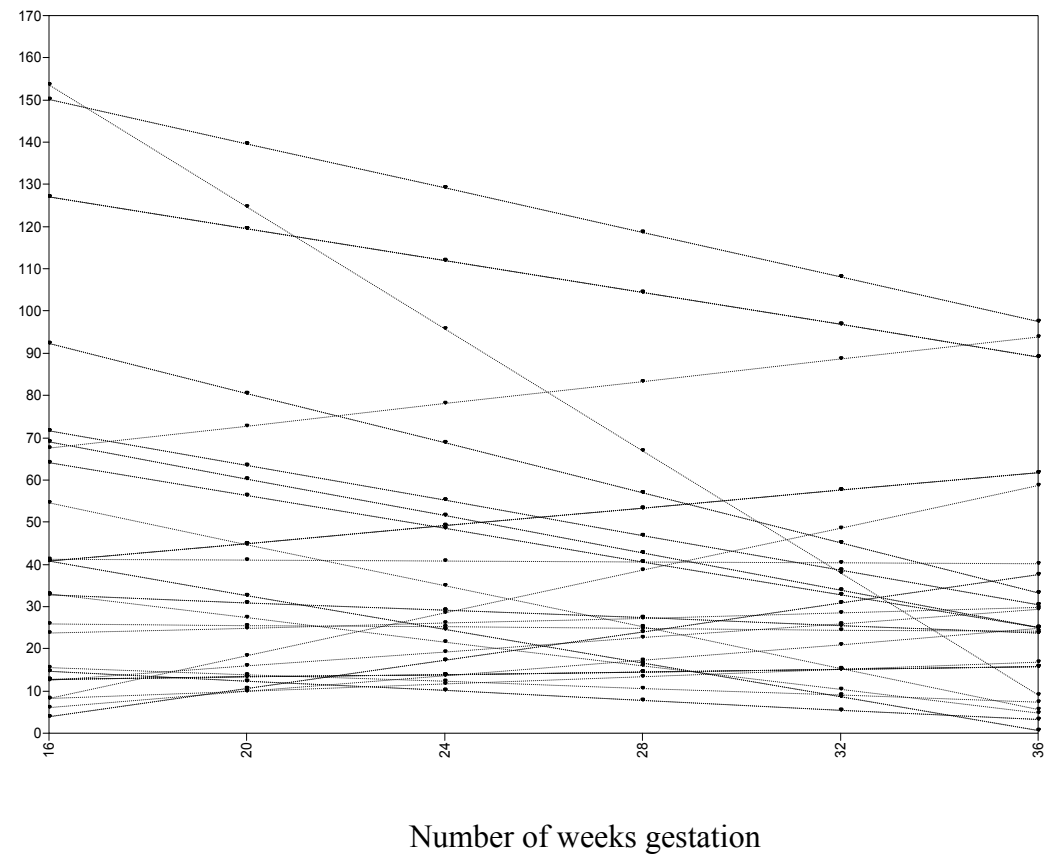


Figure 2. Individual walking growth patterns throughout gestation

A total of 26 gravidae walked regularly throughout their pregnancies. The average amount of time spent walking at 16 weeks gestation, the initial point of data

collection, was 54.93 ± 55.5 minutes per week. The amount of walking performed each month declined significantly over time ($z = -1.98, p < .05$). The z score represents the number of standard deviations that a given value is above or below the mean. Walkers exercised an average of 5.15 ± 12.5 minutes less per month. There was a high correlation ($z = -2.69, p < .01$) between the initial amount of time spent walking and the rate of change in walking time over through pregnancy. The larger amount of time spent walking at 16 weeks gestation, the more rapidly the decline in walking time. If little time was spent dedicated to walking at the beginning of pregnancy, there was little change walking habits throughout gestation.

Hypothesis 1. It is hypothesized that the volume of exercise performed directly affects neonatal outcomes measured in this study (i.e. birthweight and placental volume) (Bell et al., 1995; Clapp et al., 2002). In addition, it is hypothesized that the volume of exercise performed indirectly affects neonatal outcomes via their impact on maternal weight gain. The volume of exercise performed directly affects the amount of weight an expectant mother gains during her pregnancy (Clapp and Dickstein, 1984). Maternal weight gain is a mediator that in turn affects neonatal outcomes.

Relationship With Birthweight. Regression coefficients are reported in table 3. There was no relationship between the amount of time spent walking at the initial data point collected (16 weeks gestation) and birthweight ($B = -0.861, z = -0.191, p > .05$). The beta weight represents the change in the dependent variable for a 1-point increase in the predictor variable. Furthermore, there was no relationship between the rate of change in walking throughout gestation and birthweight ($B = 11.679, z =$

0.473, $p > .05$). The combination of the amount of time spent walking at 16 weeks gestation and the rate of change in walking time through pregnancy explained 9.6% of the variation in birthweight. When average total daily Calorie intake was added as an additional predictor of birthweight, the initial amount of time spent walking and the rate of change in walking time explained 20.2% of the variation in birthweight. When walking time was kept constant, there was a trend toward a positive relationship between amount of Calories consumed per day and birthweight ($B = 6.315$, $z = 1.763$, $p = .08$). The more Calories consumed by the expecting mother, the heavier the newborn. Also the fewer Calories consumed, the lighter the newborn.

Table 3. Regressions of Birthweight on Volume of Maternal Walking

Independent Variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Walking volume intercept	-0.861	4.497	-0.191
Walking volume slope	11.679	24.709	0.473
Walking volume intercept with average daily caloric intake	1.128	4.388	0.257
Walking volume slope with average daily caloric intake	15.672	23.486	0.667

(table continues)

Table 3. (cont.)

Independent Variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Average daily caloric intake	6.315	3.582	1.763

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

Relationship With Corrected Birthweight. As seen in table 4, there was no relationship between initial amount of time spent walking and corrected birthweight ($B = -0.770, z = -0.233, p > .05$). Also, there continued to be no relationship between the rate of change in walking time throughout gestation and corrected birthweight ($B = 13.272, z = 0.762, p > .05$). When maternal weight, gestational age, sex, and parity are controlled, the amount of explained variance in corrected birthweight by initial walking time and rate of change in walking time increased from 9.6% to 16.6%. When the average daily caloric intake was taken into account, initial maternal walking time and rate of change in maternal walking time explained 28% of the variation in corrected birthweight. When walking time was kept constant, there was no relationship between total Calorie intake and corrected birthweight ($B = 5.307, z = 1.451, p > .05$).

Table 4. Regressions of Corrected Birthweight on Volume of Maternal Walking

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Walking volume intercept	-0.770	3.300	-0.233
Walking volume slope	13.272	17.422	0.76
Walking volume intercept with average daily caloric intake	0.613	3.357	0.183
Walking volume slope with average daily caloric intake	16.537	17.323	0.955
Average daily caloric intake	5.307	3.657	1.451

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

Relationship With Placental Volume. As reported in table 5, the initial amount of maternal walking time was negatively correlated with placental volume at

birth ($B = -0.919, z = -2.532, p < .05$). The greater the amount of walking performed at 16 weeks gestation, the smaller the placental volume. Also, the less walking performed at 16 weeks gestation, the larger the placental volume. The rate of change in maternal

Table 5. Regressions of Placental Volume on Volume of Maternal Walking

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Walking volume intercept	-0.919	0.363	-2.532
Walking volume slope	-6.963	1.954	-3.564
Walking volume intercept with average daily caloric intake	-1.248	0.385	-3.243
Walking volume slope with average daily caloric intake	-8.041	1.898	-4.237
Average daily caloric intake	-1.054	0.506	-2.083

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

walking time throughout gestation was negatively related to placental volume at birth ($B = -6.963, z = -3.564, p < .01$). The steeper the decline in walking time through pregnancy, the larger the placental volume. The smaller the variation in maternal walking time throughout pregnancy, the smaller the placental volume. Together, the amount of walking performed at 16 weeks gestation and the change in walking volume throughout pregnancy explained 41.8% of the variation in placental volume at birth. When the average daily caloric intake was accounted for, initial amount of walking and rate of change in amount of walking explained 60.1% of the variance in placental volume. When walking volume was held constant, the amount of Calories consumed daily was inversely proportional to placental volume ($B = -1.054, z = -2.083, p < .05$). As the amount of Calories consumed during pregnancy increased, placental volume decreased. Similarly, as the amount of Calories consumed during pregnancy decreased, placental volume increased.

Relationship With Maternal Weight Gain. Research hypothesis #1 states that the volume of maternal exercise performed will indirectly affect neonatal outcomes via the impact on maternal weight gain. This analysis addresses the question as to whether maternal weight gain acts as a mediator between exercise volume and neonatal outcomes. If there is no significant relationship between walking volume and maternal weight gain, the mediation hypothesis is rejected (Barron and Kenny, 1986). Regression coefficients are reported in table 6. There was no relationship between either the amount of walking performed at 16 weeks gestation and maternal weight gain ($B = 0.004, z = 0.062, p > .05$) or the change in walking volume over

pregnancy and maternal weight gain ($B = -0.010$, $z = -0.029$, $p > .05$). Furthermore, when initial maternal walking volume and change in

Table 6. Regressions of Maternal Weight Gain on Volume of Maternal Walking

Independent Variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Walking volume intercept	0.004	0.062	0.062
Walking volume slope	-0.010	0.326	-0.029
Walking volume intercept with average daily caloric intake	0.038	0.067	0.570
Walking volume slope with average daily caloric intake	0.081	0.334	0.241
Average daily caloric intake	0.079	0.058	1.363

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

maternal walking volume are combined, they explained virtually no variation in maternal weight gain ($R^2 = .001$). When the amount of Calories consumed daily was held constant, there continued to be no relationship between either the initial amount of walking performed ($B = 0.038, z = 0.570, p > .05$), or the rate of change in walking volume over time and maternal weight gain ($B = 0.081, z = 0.241, p > .05$). When the amount of walking was held constant, there was no relationship between number of Calories consumed and maternal weight gain ($B = 0.079, z = 1.363, p > .05$). When the number of Calories was held constant, the amount of variance explained by initial walking volume and rate of change in walking volume increased from 0 to 7.5%.

Non-walking aerobic exercise growth curve model

30 women performed some form of non-walking aerobic exercise during their pregnancies. Exercise modes included running, spinning, and aerobic dance classes. The average amount of time spent performing non-walking aerobic exercise at the initial time point of 16 weeks gestation was 38.21 ± 43.9 minutes. The volume of non-walking aerobic exercise performed throughout pregnancy did not change. In other words, the average slope coefficient was not significantly different from zero. Since non-walking aerobic exercise volume remained constant over time, the amount of non-walking aerobic exercise performed at 16 weeks gestation represents the amount of non-walking aerobic exercise at any time point throughout gestation.

Relationship With Birthweight. Regression coefficients are presented in table 7. There was a large negative relationship between the amount of non-walking aerobic exercise performed during pregnancy and birthweight ($B = -6.036$, $z = -2.679$, $p < .01$).

Table 7. Regressions of Birthweight on Volume of Maternal Non-walking Aerobic Exercise

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Volume of maternal non-walking aerobic exercise	-6.036	2.253	-2.679
Volume of maternal non-walking aerobic exercise with average daily caloric intake	-5.168	2.233	-2.314
Average daily caloric intake	5.095	3.095	1.646

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

The larger the volume of non-walking aerobic exercise performed during pregnancy, the lighter the birthweight. In a similar manner, the smaller the volume of non-walking aerobic exercise performed during pregnancy, the greater the birthweight.

The individual differences in the amount of non-walking aerobic exercise performed during pregnancy explained 19.5% of the variance in birthweight. When average daily caloric intake was accounted for, 27.4% of the variance in birthweight was explained by individual differences in non-walking aerobic exercise volume. When exercise volume was held constant, there was a trend toward a positive relationship between average daily caloric intake and birthweight ($B = 5.095$, $z = 1.646$, $p = .10$). The greater the amount of Calories consumed by gravidae, the larger the newborn tends to be. Similarly, the smaller the amount of Calories consumed by gravidae, the smaller the newborn. When caloric intake was kept constant, the negative relationship between non-walking aerobic exercise volume and birthweight was still present.

Relationship With Corrected Birthweight. Results are presented in table 8. When maternal weight, gestational age at birth, sex, and parity were controlled for, the inverse relationship between exercise volume and birthweight became non-significant ($B = -1.839$, $z = -0.693$, $p > .05$). Also, while previously 19.5% of the variance was explained by the amount of exercise volume performed, after accounting for maternal and newborn variables, only 2.6% of corrected birthweight was explained. However, when the amount of Calories consumed was accounted for, individual level differences in non-walking aerobic exercise volume explained 15.1% of the variance in corrected birthweight.

Table 8. Regressions of Corrected Birthweight on Volume of Maternal Non-walking Aerobic Exercise

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Volume of maternal non-walking aerobic exercise	-1.839	2.652	-0.693
Volume of maternal non-walking aerobic exercise with average daily caloric intake	-0.783	2.637	-0.297
Average daily caloric intake	5.464	3.469	1.575

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

When caloric intake was held constant, the relationship between exercise volume and corrected birthweight continued to be weak ($B = -0.783, z = -0.297, p > .05$). When exercise volume was held constant, there was no relationship between maternal caloric intake and corrected birthweight ($B = 5.464, z = 1.575, p > .05$).

Relationship With Placental Volume. Regression coefficients are presented in table 9. There was an inverse relationship between amount of non-walking aerobic

**Table 9. Regressions of Placental Volume on Volume of Maternal
Non-walking Aerobic Exercise**

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Volume of maternal			
non-walking aerobic exercise	-0.790	0.424	-1.863
Volume of maternal			
non-walking aerobic exercise			
with average daily caloric intake	-0.813	0.422	-1.926
Average daily caloric intake	-0.475	0.554	-0.858

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

exercise performed throughout pregnancy and placental volume at birth ($B = -0.79$, $z = -1.86$, $p = .06$). As the amount of aerobic exercise performed during pregnancy increased, placental volume at birth decreased. In the same way, as the amount of aerobic exercise performed during pregnancy decreased, placental volume at birth increased. Individual differences in the amount of non-walking aerobic exercise performed during pregnancy explained 14.1% of the variation in placental volume.

When the number of Calories consumed by gravidae was accounted for, the explained variance in placental volume by level differences in exercise volume increased from 14.1% to 15.4%.

When the number of Calories consumed was kept constant, the inverse relationship between exercise volume and placental volume at birth persisted ($B = -0.813, z = -1.926, p > .05$). When the amount of exercise performed during pregnancy was held constant, there was little relationship between Calories consumed and placental volume ($B = -0.475, z = -0.858, p > .05$).

Relationship With Maternal Weight Gain. As shown in table 10, there was no relationship between the amount of exercise performed during pregnancy and maternal weight gain ($B = -0.017, z = -0.345, p > .05$). Individual differences in exercise volume throughout gestation do not explain any variance in maternal weight gain ($R^2 = .007$).

Table 10. Regressions of Maternal Weight Gain on Volume of Maternal Non-walking Aerobic Exercise

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Volume of maternal non-walking aerobic exercise	-0.017	0.048	-0.345

(table continues)

Table 10. (cont.)

Independent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Volume of maternal non-walking aerobic exercise with average daily caloric intake	-0.007	0.048	-0.139
Average daily caloric intake	0.058	0.051	1.129

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$.

When the number of Calories consumed throughout pregnancy was accounted for, individual differences in exercise volume throughout gestation explained 5.2% of the variation in maternal weight gain. When caloric intake was held constant, there continued to be no relationship between exercise volume and maternal weight gain ($B = -0.007, z = -0.139, p > .05$). Also, when exercise volume was held constant, there was no relation between caloric intake and maternal weight gain ($B = 0.058, z = 1.129, p > .05$).

Effect of Nutrient Intake on Birth Outcomes

Hypothesis 2. It is hypothesized that the total amount of carbohydrates and fiber consumed during pregnancy directly affects neonatal outcomes measured in this study

(Clapp, 1997; Clapp, 1998; Clapp, 2002). Additionally, total carbohydrates and fiber consumed during pregnancy are hypothesized to indirectly affect neonatal outcomes via their impact on maternal weight gain. Total carbohydrate intake and fiber intake exert a direct effect on the amount of weight a woman gains during her pregnancy (Clapp, 2002). In turn, maternal weight gain acts as a mediator that directly affects placental volume and birthweight.

Effect of Caloric Intake on Birth Outcomes. Nutrient intake means are shown in table 11. Among exercising gravidae, the average Caloric intake at 16 weeks gestation was 2083.79 ± 339.3 . Average Caloric intake did not change throughout pregnancy so the average Caloric intake at 16 weeks gestation represents the average Caloric intake at all data points collected (20, 24, 28, 32, 36 weeks gestation).

Table 11. Nutrient Intake Means of Exercising Gravidae

Nutrient variable	Mean	Standard deviation
Caloric intake (kcal/day)	2083.79	339.3
Carbohydrate intake (g/day)	270.58	53.1
Fiber intake (g/day)	21.74	6.3
Protein intake (g/day)	95.05	16.2
Fat intake (g/day)	74.26	13.9

As viewed in table 12, there was a significant positive relationship between the average daily number of Calories consumed throughout pregnancy and

birthweight ($B = 6.55, z = 2.901, p < .01$). The more Calories consumed by expecting mother, the higher the birthweight. Individual differences in daily caloric intake explained 13.8% of the variance in birthweight.

Table 12. Regressions of Neonatal Outcomes on Maternal Caloric Intake

Dependent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Birthweight	6.555	2.260	2.901
Corrected birthweight	5.780	3.342	1.730
Placental volume	-0.465	0.829	-0.561
Maternal weight gain	0.059	0.050	1.174

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$.

The relationship between maternal caloric intake and corrected birthweight, while positive, is not significant ($B = 5.780, z = 1.730, p = .08$). However, when maternal weight, newborn sex, gestational age at birth, and parity are taken into consideration, individual differences in caloric intake explain 15.2% of the variance in corrected birthweight.

There was no relationship between maternal caloric intake and placental volume at birth ($B = -0.465, z = -0.561, p > .05$). Individual differences in caloric intake explained only 3.0% of the variance in placental volume.

Additionally, there was no relationship between maternal caloric intake and total maternal weight gain ($B = 0.059, z = 1.174, p > .05$). Individual differences in caloric intake explain only 5.0% of the variance in maternal weight gain.

Effect of Carbohydrate Intake on Birth Outcomes. Among exercising gravidae, the average daily carbohydrate intake at 16 weeks gestation was 270.58 ± 53.1 g. Carbohydrate intake did not vary significantly throughout gestation so the average daily carbohydrate intake at 16 weeks gestation is representative of the average daily carbohydrate intake throughout pregnancy. On average, carbohydrate intake accounted for 51.9% of total Calories consumed. As seen in table 13, there was a significant positive relationship between the number of carbohydrate grams consumed throughout gestation and birthweight ($B = 4.170, z = 2.851, p < .01$). Individual differences in carbohydrate consumption accounted for 13.6% of the variation in birthweight.

Table 13. Regressions of Neonatal Outcomes on Maternal

Carbohydrate Intake

Dependent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Birthweight	4.170	1.463	2.851

(table continues)

Table 13. (cont.)

Dependent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Corrected birthweight	3.229	1.924	1.678
Placental volume	-0.465	0.829	-0.561
Maternal weight gain	0.032	0.032	0.995

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$.

As was seen in the comparison between maternal daily caloric intake and corrected birthweight, there was a positive but non-significant relationship between maternal daily carbohydrate intake and corrected birthweight ($B = 3.229$, $z = 1.678$, $p = .09$). Individual differences in daily carbohydrate consumption accounted for 11.9% of the variation in birthweight.

There was no relationship found between maternal daily carbohydrate intake and placental volume at birth ($B = -0.465$, $z = -0.561$, $p > .05$). Individual differences in carbohydrate intake accounted for only 4.5% of the variation in placental volume.

Furthermore, there was no relationship found between maternal daily carbohydrate intake and total maternal weight gain ($B = 0.032$, $z = 0.995$, $p > .05$). Individual differences in carbohydrate intake accounted for 3.7% of total maternal weight gain. Research hypothesis #2 states that total carbohydrates consumed during pregnancy

indirectly affect neonatal outcomes via their impact on maternal weight gain. This analysis addresses the question as to whether maternal weight gain acts as a mediator between total carbohydrate intake and neonatal outcomes. If there is no relationship between carbohydrate intake and neonatal outcomes, the mediation hypothesis is rejected (Barron and Kenny, 1986)

Effect of Fiber Intake on Birth Outcomes. The average amount of fiber consumed per day at 16 weeks gestation was 21.74 ± 6.3 g. Fiber intake did not change significantly throughout gestation, so for the data analysis, the amount of fiber consumed at 16 weeks was fixed for the entire pregnancy. As presented in table 14, fiber intake throughout pregnancy had no measurable effect on birthweight ($B = 4.770, z = 0.388, p > .05$), corrected birthweight ($B = 1.358, z = 0.094, p > .05$), or maternal weight gain ($B = -0.185, z = -0.729, p > .05$). Research hypothesis #2 states that total fiber consumed during pregnancy indirectly affect neonatal outcomes via its impact on maternal weight gain. This analysis addresses the question as to whether maternal weight gain acts as a mediator between total fiber intake and neonatal outcomes. If there is not relationship between maternal fiber intake and maternal weight gain, the mediation hypothesis must be rejected (Barron and Kenny, 1986). There was a large negative relationship between fiber intake and placental volume at birth ($B = -12.421, z = -2.213, p < .05$). The more fiber consumed throughout pregnancy, the smaller the placenta at birth. Individual differences in fiber consumption accounted for 55.0% of the variance in placental volume.

Table 14. Regressions of Neonatal Outcomes on Maternal Fiber Intake

Dependent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Birthweight	4.770	12.296	0.388
Corrected birthweight	1.358	14.460	0.094
Placental volume	-12.421	5.612	-2.213
Maternal weight gain	-0.185	0.254	-0.729

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$

Effect of Fat Intake on Birth Outcomes. The average maternal daily fat intake at 16 weeks gestation was 74.26 ± 13.9 g. This accounted for 32.1% of total caloric intake. Since there was no change in fat intake throughout pregnancy, fat intake at 16 weeks was fixed as the assigned value for each data point. As shown in table 15, there was no relationship between maternal fat intake and any measured birth outcome.

Table 15. Regressions of Neonatal Outcomes on Maternal Fat Intake

Dependent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Birthweight	8.100	6.342	1.277
Corrected birthweight	4.224	10.157	0.416
Placental volume	-0.564	1.788	-0.315
Maternal weight gain	0.155	0.130	1.191

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$

^aZ-statistics greater than +/- 2.575 are significant at $p < .01$.

Effect of Maternal Protein Intake on Birth Outcomes. Among exercising gravidae, average daily protein intake at 16 weeks gestation was 95.05 ± 16.2 g. Since there was no measurable change in protein intake throughout gestation, daily protein intake at 16 weeks gestation was fixed to represent daily protein intake during the entire pregnancy. As presented in table 16, there was a significant positive relationship between maternal protein intake and birthweight ($B = 14.187$, $z = 2.869$, $p < .01$). The more protein consumed by the expectant mother during pregnancy, the larger the newborn at birth. Individual differences in protein intake accounted for 14.7% of the variance in neonatal weight at birth. The significant relationship

between maternal protein intake and birthweight persisted when maternal weight, newborn sex, newborn

Table 16. Regressions of Neonatal Outcomes on Maternal Protein

Intake

Dependent variable	Regression coefficient	Standard error	Z-statistic ^{ab}
Birthweight	14.187	4.945	2.869
Corrected birthweight	12.184	6.099	1.998
Placental volume	-0.687	2.451	-0.280
Maternal weight gain	0.074	0.112	0.665

^aZ-statistics greater than +/- 1.96 are significant at $p < .05$.

^bZ-statistics greater than +/- 2.575 are significant at $p < .01$.

gestational age at birth, and parity were accounted for ($B = 12.184$, $z = 1.998$, $p < .05$). Individual differences in protein intake through pregnancy accounted for 15.9% of the variance in corrected birthweight.

There was no relationship between maternal protein intake and placental volume at birth, ($B = -0.687$, $z = -0.280$, $p > .05$), nor between maternal protein intake and total weight gain throughout pregnancy ($B = 0.074$, $z = 0.665$, $p > .05$).

Means Comparison of Dependent Variables Between Exercising and Non-exercising Gravidae

Multiple ANOVAs were performed to compare the means of the dependent variables between exercising and non-exercising gravidae. A summary of the results is presented in table 17. There was no difference between groups in either the total amount of weight gained during pregnancy or placental volume at birth. While there was a trend that exercising gravidae had lighter newborns than non-exercising gravidae, the effect of exercise on birthweight was not significant. This trend continued when birthweight was corrected to account for maternal weight, newborn sex, newborn gestational age, and parity.

Table 17. Means Comparison of Dependent Variables Between Exercising and Non-exercising Gravidae using Multiple ANOVAs

Variable	Exercising gravidae (n = 44)	Non-exercising gravidae (n = 32)	p-value
Birthweight (g)	3334.93 ± 571.8	3550.8 ± 475.3	.086
Corrected birthweight (g)	3288.29 ± 488.6	3485.59 ± 511.3	.105
Placental volume (mL)	467.55 ± 98.3	450.73 ± 87.0	.562
Maternal weight gain (lb)	34.34 ± 9.9	34.33 ± 13.1	.997

Summary

Maternal walking performance differed from the performance of gravidae who performed non-walking aerobic exercise during pregnancy. Walkers who began exercising at a high volume tended to significantly drop off in the amount of exercise performed during pregnancy, while walkers who began at a low exercise volume maintained their volume throughout pregnancy. Non-walking aerobic exercisers tended to maintain their level of exercise throughout pregnancy, regardless of the exercise volume.

The amount of walking performed throughout pregnancy had no effect on birthweight or corrected birthweight. Non-walking aerobic exercise volume throughout pregnancy was negatively related to birthweight. However, when birthweight was corrected for maternal weight, newborn sex, parity, and gestational age at birth, the negative relationship between high-intensity exercise volume and birthweight was not significant. Controlling for caloric intake strengthened the relationship between any form of exercise volume and birthweight. Caloric intake tended to be positively related to birthweight, with the more Calories consumed by the expectant mother, the heavier the newborn.

The larger the amount of walking performed at 16 weeks gestation, and the steeper the decline in walking volume throughout pregnancy, the lower the placental volume at birth. Similarly, a higher level of non-walking exercise maintained throughout pregnancy also resulted in a smaller placenta. For both modes of exercise, controlling for the amount of Calories consumed throughout pregnancy strengthened the negative relationship between exercise volume and placental size. There was no

relationship between the amount of exercise of any mode and total maternal weight gain.

Nutrient intake remained constant throughout pregnancy. Maternal Caloric intake had a significant positive relationship with birthweight, and a non-significant positive relationship with corrected birthweight. Maternal carbohydrate intake throughout pregnancy also had a significant positive relationship with birthweight, and a non-significant positive relationship with corrected birthweight. Furthermore, maternal protein intake had a significant positive relationship with both birthweight and corrected birthweight. There was no relationship between maternal Caloric intake, maternal carbohydrate intake, or maternal protein intake and placental volume at birth, nor maternal weight gain.

Fiber intake through pregnancy had a large inverse relationship with placental volume at birth, but was not related to birthweight, corrected birthweight, or maternal weight gain. Fat intake was not related to any birth outcome.

CHAPTER FIVE: DISCUSSION AND CONCLUSIONS

Introduction

The current study examined the influence of maternal exercise volume on maternal and birth outcomes, while addressing the influence of maternal nutrient intake. Dependent variables examined were birthweight and placental volume at the time of birth. Placental volume was measured to examine maternal physiological adaptations that may occur as a result of exercise. Maternal weight gain, which may act as a mediator between exercise volume and nutrient intake and subsequently neonatal outcomes, was also examined.

A sample of 109 pregnant women who completed a minimum of one food log and one exercise log were included in the data analysis. Two data analyses of how maternal exercise volume and nutrient intake affects dependent variables were completed: (a) the effect of initial maternal walking volume and walking volume performed throughout gestation on dependent variables, and (b) the effect of initial maternal non-walking aerobic exercise volume and aforementioned exercise throughout gestation on dependent variables. Non-walking exercise modes included running, spinning, and aerobic exercise classes. Additionally, a longitudinal analysis was conducted to examine the effect of maternal nutrient intake on neonatal outcomes. Nutrient variables measured included average daily Calorie intake, average daily carbohydrate intake, average daily fiber intake, average daily protein intake, and average daily fat intake. Finally, ANOVAs were used to compare neonatal outcomes between exercising and non-exercising gravidae.

This chapter will consist of (a) Summary of Findings, (b) Discussion and Applications, (c) Conclusions and their Significance, and (d) Recommendations for Future Research.

Summary of Findings

1. *Maternal walking.* The amount of maternal walking at 16 weeks gestation was inversely related to the rate of change in walking time throughout gestation. The greater the amount of time spent walking at 16 weeks gestation, the steeper the decline in walking time throughout pregnancy. The walking growth curve model shows the following relationships between maternal walking volume and the dependent variables examined:
 - a) Birthweight. There was no relationship between maternal walking volume at 16 weeks gestation and birthweight, nor between the rate of change in walking volume throughout gestation and birthweight. When the amount of Calories consumed was controlled for, initial walking volume and the change in walking volume explained twice as much variation in birthweight compared to the regression of walking volume on birthweight without controlling for Calories.
 - b) Corrected birthweight. There was no relationship between maternal walking volume at 16 weeks gestation and birthweight corrected for maternal weight and weight gain, parity, newborn sex, and gestational age, nor between the rate of change in walking volume throughout gestation and corrected birthweight. When the amount of Calories consumed was controlled for,

initial walking volume and change in walking volume explained almost twice as much variation in corrected birthweight compared to the regression of walking volume on corrected birthweight without controlling for Calories.

- c) Placental volume. The amount of time spent walking at 16 weeks gestation was inversely related to placental volume at birth, i.e. a greater amount of time spent walking at 16 weeks gestation resulted in a smaller placenta. The rate of change in time spent walking throughout gestation was inversely related to placental volume at birth. A steeper decline in walking time resulted in a larger placenta. When average daily Calorie intake was accounted for, initial time spent walking and rate of change in walking time explained 50% more variation in placental size compared to the regression of walking volume on placental size without controlling for Calories.
 - d) Maternal weight gain. There was no relationship between walking time at 16 weeks gestation, or rate of change in walking time throughout gestation, and maternal weight gain. When the amount of Calories consumed daily was held constant, there continued to be no relationship between initial walking time, rate of change in walking time throughout gestation and maternal weight gain.
2. *Maternal non-walking aerobic exercise.* The amount of time per week a pregnant woman spent performing non-walking aerobic exercise did not change throughout gestation. In other words, the amount of time per week spent performing non-walking aerobic exercise at 16 weeks gestation represented the amount of time per week spent performing non-walking aerobic exercise throughout pregnancy. Furthermore, the type and rate of perceived exertion of exercise remained

unchanged. The non-walking aerobic exercise growth curve model shows the following relationships between maternal non-walking aerobic exercise volume and the following dependent variables:

- a) Birthweight. Maternal aerobic exercise volume was negatively related to birthweight. The more time spent performing non-walking aerobic exercise throughout pregnancy, the lighter the newborn. When average daily Calorie intake was accounted for, a larger percentage of variation in birthweight was explained compared to the regression of non-walking aerobic exercise volume on birthweight without controlling for Calories.
- b) Corrected birthweight. There was a non-significant inverse relationship between maternal exercise volume and corrected birthweight. More time spent performing non-walking aerobic exercise throughout pregnancy tended to result in a lighter newborn. When average daily Calorie intake was accounted for, a larger percentage of variation in corrected birthweight was explained compared to the regression of non-walking aerobic exercise volume on corrected birthweight without controlling for Calories.
- c) Placental volume. There was a non-significant inverse relationship between maternal exercise volume and placental volume at birth. More time spent performing non-walking aerobic exercise throughout pregnancy tended to result in a smaller placenta. When average daily Calorie intake was accounted for, a slightly larger percentage of variation in placental volume was explained compared to the regression of non-walking aerobic exercise volume on placental volume.

- d) Maternal weight gain. There was no relationship between the amount of non-walking aerobic exercise performed during pregnancy and maternal weight gain. When the number of Calories consumed daily was controlled for, non-walking aerobic exercise explained a slightly larger amount of the variation in maternal weight gain compared to the regression of non-walking aerobic exercise volume on maternal weight gain.
3. *Maternal nutrient intake.* Maternal nutrient intake did not change throughout gestation. In other words, maternal nutrient intake at 16 weeks gestation represented maternal nutrient intake throughout pregnancy. The maternal nutrient intake growth curve model shows the following relationships between maternal nutrient intake and the following dependent variables:
- a) Birthweight. There was a significant positive relationship between average daily Calorie intake, average daily carbohydrate intake, average daily protein intake, and birthweight. The more Calories, carbohydrates, or protein that gravidae consumed during pregnancy, the larger the newborn. On the other hand, average daily fiber intake and average daily fat intake did not affect birthweight.
- b) Corrected birthweight. After correcting for maternal weight and weight gain, parity, newborn sex, and gestational age, the positive relationship between Calorie intake, carbohydrate intake, and corrected birthweight became non-significant. Only the relationship between protein intake and corrected birthweight remained significant. There was no relationship between fiber intake nor fat intake, and corrected birthweight.

- c) Placental volume. There was a significant inverse relationship between the amount of fiber consumed by gravidae, and the size of the placenta at birth. The greater the amount of fiber consumed during pregnancy, the smaller the placenta. There was no relationship between any other nutrient variable and placental volume at birth.
 - d) Maternal weight gain. There was no relationship between any nutrient variable and total maternal weight gain.
4. *Maternal exercise vs. sedentary control.* A comparison of means between women performing any type of exercise throughout pregnancy and non-exercising controls indicated no significant differences in any dependent variable. Exercisers tended to have lower birthweight infants than non-exercising controls. This trend continued after correcting for confounding factors including maternal weight and weight gain, newborn sex, parity, and gestational age. However, the trend failed to reach significance.

Discussion and Application

Our study highlighted the differences between different types of exercise engaged in during pregnancy. For example, our walkers who engaged in a high volume of exercise at the beginning of pregnancy showed a reduction in exercise volume in the latter stage of pregnancy. Those that did not perform a large volume of walking at the beginning of pregnancy tended to sustain that pattern throughout gestation. In contrast, non-walkers maintained their exercise volume independent of their initial volume of

exercise. To our knowledge, this is the first study that systematically analyzed the pattern of exercise throughout gestation and observed a difference by exercise mode.

Our findings showed several differences according to exercise mode. Among walkers, there was no relationship between walking volume and birthweight. Among non-walking gravidae, however, there was a significant inverse relationship between the volume of non-walking exercise performed throughout pregnancy and birthweight. The larger the amount of non-walking aerobic exercise performed by exercising gravidae, the lighter the newborn. In a similar manner, the lower the amount of non-walking aerobic exercise performed, the heavier the newborn. One reason for the differences between walkers and non-walkers in birthweight may be related to the intensity of exercise. Walking gravidae recorded lower rates of perceived exertion as compared to the non-walking exercisers. Since walking constitutes a reduced intensity of exercise, it may not significantly alter maternal blood glucose levels and fetal nutrient supply. On the other hand, non-walking aerobic exercise, being of higher intensity, may alter maternal blood glucose levels and fetal nutrient supply, resulting in lower birthweight. In accordance with our findings, the majority of studies that included walking in their exercise program found no relationship between maternal exercise and birthweight (Kulpa et al., 1987; Rice and Fort, 1991; Sternfeld et al., 1995; Marquez-Sterling et al., 2000; Duncombe et al. 2006). Furthermore, the majority of studies conducted in women who performed non-walking aerobic exercise found an inverse relationship between maternal exercise and birthweight (Clapp, 1990; Clapp and Capeless, 1990; Bell et al., 1995; Jackson et al., 1995).

When examining studies of active gravidae with respect to exercise volume and birthweight, only one other study confirmed our significant inverse relationship between exercise volume and birthweight among non-walking exercisers. In support of our findings, Bell et al. (1995) also reported a significant inverse relationship between women who exercised five or more times per week in comparison to women who exercised three times per week. In addition, Duncombe et al. (2006) reported a trend toward an inverse relationship between gravidae who performed exercise five or more times per week as compared to gravidae who performed exercise three to four, or one to two sessions per week. However, Duncombe's study also included walkers in their exercise groups, which may why these investigators did not find statistical significance. However, Bell et al. (1995), Duncombe et al. (2006), and Clapp et al. (2000) did not find a significant relationship between exercise volume and birthweight in gravidae exercising less than five sessions per week regardless of modality. Thus, while the current study showed that the amount of non-walking aerobic exercise performed throughout pregnancy significantly affects birthweight, other studies reveal that exercise volume may be a factor in determining birthweight only when five or more sessions are performed each week.

Interestingly, when we examined corrected birthweight values, there was no longer a significant relationship between either exercise modality and corrected birthweight. These results are not surprising since corrected birthweight includes factors such as maternal weight and weight gain, parity, newborn sex, and gestational age, which are known to affect birthweight (Campbell et al., 1993).

The most common leisure activity for pregnant women appears to be walking (Evenson, 2004). In instances where low birthweight infants or premature infants represent a potential risk factor for exercising gravidae, our results may help to alleviate such concerns for those at risk, should they choose to exercise during pregnancy.

Lower placental weight may also be a cause for concern since the placenta provides oxygen and nutrients to the growing fetus. Small placentas may explain perinatal morbidity and mortality associated with low birthweight. In the present study, only one exerciser had a placenta falling below 300 g, and values in that range are not necessarily associated with perinatal problems (Thomson et al., 1969). On the other hand, too high a placental weight may be associated with higher blood pressure in adulthood (Barker, 1995). Thus, the lower placental weight of gravidae who perform a greater exercise volume by may not necessarily be disadvantageous to perinatal health and may actually confer some protective benefit to adult health.

Both walking and non-walking exercisers showed an inverse relationship between the amount of exercise performed and placental volume. Regardless of modality, our findings indicated that the more a woman exercises throughout gestation, the smaller the placenta will be. Exercise redirects blood glucose toward the skeletal muscles and away from the internal organs and the placenta, thus we may conclude that the more regularly the placenta is deprived of its nutrient supply, the smaller the placental volume at birth. Although few studies have examined the relationship between exercise volume and placental size, our results differed from other studies performed. Clapp (2000) reported no difference in placental size between gravidae performing different amounts of exercise, while Kardel and Kase (1998) reported that high-volume exercisers tended to

have larger placentas than medium-volume exercisers. Gravidae in both Clapp's and Kardel and Kase's studies were instructed to follow carefully designed exercise programs, while this study allowed gravidae to exercise ad libitum. In addition, Kardel and Kase's participants were well-trained athletes who participated in both aerobic and anaerobic exercise training components, and who were allowed breaks in training totaling up to 125 days while still meeting the inclusion criteria to be in an exercise group. This study examined the aerobic exercise volume of recreational athletes, and accounted for the natural change in exercise patterns throughout gestation. The difference in methods used between studies may account for the discrepancy in the relationship found between exercise volume and placental size.

This study also attempted to establish whether or not maternal weight gain acts as a mediator between maternal exercise volume and neonatal outcomes. In order for maternal weight gain to be considered a mediator between the variables, maternal exercise volume should directly affect maternal weight gain, and maternal weight gain should directly affect neonatal outcomes. While most previous research suggests no difference in maternal weight gain between exercising gravidae and non-exercising controls (Lokey et al.; Hatch et al., 1993; Bell et al., 1995; Brenner et al., 1999; Marquez-Sterling, et al., 2000, Magann et al., 2002; Kardel, 2005), Clapp and Dickstein (1984) found that gravidae who continue to exercise in their third trimester gained less weight than gravidae who discontinued exercise by the end of their second trimester. In agreement with the majority of the studies conducted, this study found no relationship between maternal exercise volume and maternal weight gain.

Many women who continue to exercise throughout pregnancy hope to control their weight gain. While exercise may be beneficial to the health of a pregnant mother as previously discussed, our findings indicated that exercise will not control excessive maternal weight gain. Since regular exercise has been found to be instrumental in controlling weight during the non-pregnant state, it appears that other factors may dictate weight gain during pregnancy. The consensus in the literature is that weight gain and maternal weight at delivery is related to fetoplacental size (Pomerance et al., 1974; Gormican et al., 1980; Hatch et al. 1993; Rice and Fort, 1991; Wynn et al. 1994; Godfrey et al., 1996; Alderman et al., 1998). Our study, however, showed that maternal weight gain does not act as a mediator between exercise and fetoplacental size. High maternal weight gain, prepregnancy weight, and large placental size are risk factors for the later development of type II diabetes (O'Sullivan, 1991; Taricco et al., 2003; King, 2006; Fiala et al., 2006). Thus, more research is needed to understand what factors mediate weight gain and maternal weight at delivery.

Another relevant factor requiring further study is the relationship between nutrient intake and fetoplacental size in active women. Active women are increasing their number of Calories expended during their pregnancies. It stands to reason that they may eat more to compensate for their added energy expenditure. Surprisingly, the active women did not consume a significantly higher amount of Calories than sedentary controls. Furthermore, they fell below the nutrition recommendations by the World Health Organization's for sedentary gravidae. Active women enrolled in our study consumed a mean of 2084 Calories. The Food and Drug Administration recommends that non-pregnant women performing a moderate amount of activity consume 2,200

Calories for individuals aged 19-51. The World Health Organization recommends the consumption of 285 additional Calories daily, thus women aged 19-51 should consume approximately 2485 Calories. The women enrolled in our study consumed fewer Calories than recommended, implying that active women were not eating enough to meet their metabolic needs. This may result in smaller placental size and newborn infants. Not only was an insufficient number of Calories consumed at the beginning of pregnancy, but Caloric intake remained unchanged throughout gestation. Given the growing fetus, it would be expected that metabolic needs would increase with exercise performed throughout gestation.

When Calorie intake was controlled for among exercising gravidae, there was significantly more variation explained in birthweight, corrected birthweight, and placental volume. As a result, we may conclude that Calorie intake positively impacts birthweight and placental volume independently of other variables. Most previous studies that have examined the relationship between maternal exercise and fetoplacental size have either not accounted for nutrient intake or have stated that maternal diet was either adequate or equivalent between groups. However, our results differ from the two previous studies examining the relationship between Calorie intake and birthweight in active women. Sternfeld et al. (1995) administered a food frequency questionnaire each trimester and noted that dietary factors showed little association with birthweight. Bell et al. (1995) had subjects keep a 7-day food diary at 25 and 35 weeks gestation, and reported that energy intake at 25 weeks was not related to birthweight. However, in the aforementioned studies, the statistical analysis used was not stated and the data was not presented. The present study used a linear regression model and presented data showing

a positive relationship between nutrient intake and newborn outcomes. This analysis may be a more powerful tool for examining the impact of nutrient intake during gestation on birthweight, since it allows investigators to follow women throughout pregnancy, thus providing more data points. Furthermore, linear regression analysis allows the examination of how initial maternal nutrient intake affects dependent variables, and how the change in nutrient intake throughout pregnancy affects dependent variables. No previous studies have analyzed the relationship between maternal nutrient intake and neonatal outcomes in active women in this manner.

Similar to the significant relationship found between maternal Calorie intake and fetoplacental size in active gravidae, there was also a positive relationship between maternal carbohydrate intake and birthweight, and between maternal protein intake and birthweight. Since carbohydrate and protein intake among gravidae account for a significant amount of total Calories ingested, it is not surprising that carbohydrate and protein intake mirrored the findings observed for total Calories. Surprisingly, no relationship was found between maternal fat intake and birthweight, nor maternal fiber intake and birthweight. Other than one study examining the relationship between glycemic index and birthweight (Clapp, 1997), there were no other studies that had explored the relationship between nutrient intake and birthweight in exercising women.

The relationship between nutrient intake and placental size is also a topic that warrants further investigation. Maternal fiber intake was the only nutrient significantly and inversely related to placental volume. Clapp (1998) suggested that high-fiber, low-glycemic index carbohydrates lower maternal blood glucose levels, reduce the amount of glucose available to the placenta, and result in a smaller placental size. This is relevant

since placental growth is an indicator of fetal size at birth (McKeown and Record, 1953; Thomson et al., 1969; Molteni et al., 1978). Thus, gravidae consuming higher amounts of fiber concomitant with exercise may be expected to show smaller placental growth along with reduced birthweight. Our study was the first to explore the relationship between nutrient variables and placental size in exercising gravidae.

The study also examined whether maternal weight gain acts as a mediator between maternal nutrient intake and neonatal outcomes. In order for maternal weight gain to be considered a mediator between the variables, a relationship must exist between maternal nutrient intake and weight gain, and between weight gain and neonatal outcomes. This study found no relationship between any nutrient variable and maternal weight gain, thus weight gain may not be considered a mediator between exercise and neonatal outcomes. These results are in agreement with previous findings showing no relationship between energy intake in healthy, active women and maternal weight gain (Picone et al., 1982; Langhoff-Roos, et al. 1987). They do however, conflict with the findings that the type of carbohydrates ingested affect the amount of weight gained during pregnancy (Clapp, 1997). The relationships between other nutrient variables including fat and protein intake and fetoplacental size have not been previously reported.

Women are typically advised to consume a diet low in fat and rich in nutrients during pregnancy. While this may be beneficial in contributing to the overall health of the expectant mother and her fetus, it appears that maternal nutrient intake does not contribute to her overall weight gain. Thus, a typical program of diet and exercise recommended to control weight gain in the non-pregnant state may not necessarily work in the same manner during pregnancy.

Conclusions

On the basis of this study, the following conclusions can be drawn:

1. Gravidae who performed high walking volumes at 16 weeks gestation declined steeply in their walking volumes throughout pregnancy. Gravidae who performed low walking volumes at 16 weeks gestation maintained their walking volumes throughout pregnancy.
2. Gravidae who performed non-walking aerobic exercise maintained their exercise volume throughout pregnancy, regardless of initial volume.
3. Gravidae who performed high volumes of walking at 16 weeks gestation and declined to low volumes of walking by 36 weeks gestation had significantly larger placentas than gravidae who maintained low volumes of walking throughout gestation.
4. The amount of time that gravidae spent performing non-walking aerobic exercise was inversely related to fetoplacental size. Gravidae who performed greater exercise volumes had significantly lower birthweight newborns, and tended to have newborns with lower corrected birthweights and placental volumes.
5. Maternal nutrient intake remained consistent in active women throughout pregnancy.
6. Average daily Calorie intake, average daily carbohydrate intake, and average daily protein intake were significantly and positively related to birthweight. Average daily protein intake was significantly and positively related to corrected birthweight, while average daily Calorie intake and average daily carbohydrate intake showed a trend toward a positive relationship to corrected birthweight.

7. Gravidae who consumed a larger amount of fiber throughout pregnancy had significantly smaller placentas.

Based upon the conclusions of this investigation:

1. Hypothesis #1 (walking) is accepted one time out of a possible four.
There was one significant correlation between walking volume throughout pregnancy and maternal and fetal outcomes.
2. Hypothesis #1 (non-walking aerobic exercise) is accepted one time out of a possible four.
There was one significant correlation between non-walking aerobic exercise volume throughout pregnancy and maternal and fetal outcomes.
3. Hypothesis #2 (average daily carbohydrate intake) is accepted one time out of a possible four.
There was one significant correlation between average daily carbohydrate intake and maternal and fetal outcomes.
4. Hypothesis #2 (average daily fiber intake) is accepted one time out of a possible four.
There was one significant correlation between average daily fiber intake and maternal and fetal outcomes.

Recommendations for Future Research

As a result of this study, the following recommendations for future research can be made:

1. Repeat the study enrolling a larger number of subjects.

2. Expand the study to examine the impact of maternal socioeconomic status on the relationship between exercise volume and neonatal outcomes i.e., placental size and birthweight.
3. Expand the study to examine the impact of maternal race on the relationship between exercise volume and neonatal outcomes i.e., placental size and birthweight.
4. Conduct a longitudinal study of gravidae who perform controlled amounts of walking at a pre-determined intensity and examine the impact of different walking volumes on neonatal outcomes i.e., placental size and birthweight.
5. Conduct a longitudinal study of gravidae who perform controlled amounts of walking at a pre-determined intensity and examine the impact of changing walking volume through pregnancy on neonatal outcomes i.e., placental size and birthweight.
6. Conduct a longitudinal study of gravidae who perform controlled amounts of weight-bearing aerobic exercise at a pre-determined intensity and examine the impact of different exercise volumes on neonatal outcomes i.e., placental size and birthweight.
7. Conduct a longitudinal study of gravidae who perform controlled amounts of weight-bearing aerobic exercise at a pre-determined intensity and examine the impact of changing exercise volume through pregnancy on neonatal outcomes i.e., placental size and birthweight.
8. Conduct a longitudinal study of gravidae who perform controlled amounts of non-weight bearing aerobic exercise at a determined intensity and examine the impact

of different exercise volumes on neonatal outcomes i.e., placental size and birthweight.

9. Conduct a longitudinal study of gravidae who perform controlled amounts of non-weight bearing aerobic exercise at a determined intensity and examine the impact of changing exercise volume through pregnancy on neonatal outcomes i.e., placental size and birthweight.
10. Examine the effect of fiber intake in active gravidae on neonatal outcomes by feeding gravidae performing the same type of exercise through pregnancy an isocaloric diet with equivalent percentages of macronutrients, but varying the amount of fiber in each diet.
11. Examine the effect of Calorie intake in active gravidae on neonatal outcomes by feeding gravidae performing the same type of exercise through pregnancy a diet with equivalent percentages of macronutrients, but varying the amount of fiber in each diet.
12. Examine placental tissue for histological changes and for the level of expression of critical genes in the analysis of neonatal outcome to determine if placental changes occur in parenchymal or non-parenchymal tissue.
13. Measure newborn body fat percentage in the analysis of neonatal outcomes to determine if changes in birthweight stem from changes in body fat or changes in lean body mass.
14. Study the role of exercise on fetal outcomes in women with high risk pregnancy, e.g. obesity, hypertension, type 2 diabetes.

15. Examine the growth and health of children of exercising mothers to determine whether maternal behaviors favorably impact on the physical health of their offspring.

REFERENCES

- ACOG Committee opinion. Number 267, January 2002: exercise during pregnancy and the postpartum period (2002). *Obstetrics and Gynecology*, 99(1), 171-173.
- Abrams, B. (1994). Weight gain and energy intake during pregnancy. *Clinical Obstetrics and Gynecology*, 37(3), 515-527.
- Aherne, W., & Dunnill, M.S. (1966). Quantitative aspects of placental structure. *Journal of Pathology and Bacteriology*, 91, 123-139.
- Alderman, B.W., Zhao, H., Holt, V.L., Watts, D.H., & Beresford, S.A.A. (1998). Maternal physical activity in pregnancy and infant size for gestational age. *Annals of Epidemiology*, 8, 513-519.
- American College of Sports Medicine: Guidelines for exercise testing and prescription* (3rd ed) (1986). Philadelphia, PA: Lea & Febiger.
- Amini, L.B., Catalano, P.M., Hirsch, V., & Mann, L.I. (1994). An analysis of birth weight by gestational age using a computerized perinatal data base, 1975-1992. *Obstetrics and Gynecology*, 83, 342-352.
- Artal, R., Masaki, D.I., Khodiguian, N., Romem, Y., Rutherford, S.E., & Wiswell, R.A. (1989). Exercise prescription in pregnancy: weight-bearing exercise versus non-weight-bearing exercise. *American Journal of Obstetrics and Gynecology*, 161(6 Pt 1), 1464-1469.
- Artal, R., Wiswell, R., Romem, Y., Dorey, F. (1986). Pulmonary responses to exercise in pregnancy. *American Journal of Obstetrics and Gynecology*, 154, 378-383.
- Artal Mittelmark, R., Wiswell, R.A., Drinkwater, B.L. (Eds.). (1991). *Exercise in pregnancy* (2nd ed). Baltimore: Williams and Wilkins.
- Artal, R. (1992). Exercise and pregnancy. *Clinics in Sports Medicine*, 11, 363-377.
- Avery, N.D., Wolfe, L.A., Amara, C.E., Davies, G.A.L., McGrath, M.J. (2001). Effects of human pregnancy on autonomic function above and below the ventilatory threshold. *Journal of Applied Physiology*, 90, 321-328.
- Barker, D.J.P. (1995). Fetal origins of coronary heart disease. *British Medical Journal*, 311, 171-174.
- Bell, R. & Palma, S. (2000). Antenatal exercise and birthweight. *Australia and New Zealand Journal of Obstetrics and Gynecology*, 40(1), 70-73.

- Bell, R.J., Palma, S.M., & Lumley, J.M. (1995). *Australia and New Zealand Journal of Obstetrics and Gynecology*, 35, 1, 46-51.
- Blackburn, M.W. & Calloway, D.H. (1976). Basal metabolic rate and work energy expenditure of mature, pregnant women. *Journal of the American Dietetic Association*, 69, 24-28.
- Boden, G. (1996). Fuel metabolism in pregnancy and in gestational diabetes. *Obstetrics and Gynecology Clinics of North America*, 23, 1-10.
- Borghouts, L.B., & Keizer, H.A. (2000). Exercise and insulin sensitivity: a review. *International Journal of Sports Medicine*, 21(1), 1-12.
- Brenner, I.K.M., Wolfe, L.A., Monga, M., & McGrath, M.J. (1999). Physical conditioning effects on fetal heart rate responses to graded maternal exercise. *Medicine and Science in Sports and Exercise*, 31(6), 792-799.
- Brent, R.L. & Beckman, T.A. (1990). Environmental teratogens. *Bulletin of the New York Academy of Medicine*, 66(2), 122-163.
- Brooks, G.A., Fahey, T.D., & White, T.P. (1996). *Exercise physiology: Human bioenergetics and its applications* (2nd ed.). Mountain View, CA: Allyn and Bacon.
- Bung, P. & Artal, R. (1996). Gestational diabetes and exercise: a survey. *Seminars in Perinatology*, 20(4), 328-333.
- Bungum, T.J., Peaslee, D.L., Jackson, A.W., & Perez, M.A. (2000). Exercise during pregnancy and type of delivery in nulliparae. *Journal of Obstetrics and Gynecology in Neonatal Nursing*, 29(3), 258-264.
- Calguneri, M., Bird, H.A., & Wright, V. (1982). Changes in joint laxity occurring during pregnancy. *Annals of the Rheumatic Diseases*, 41, 126-128.
- Campbell, D., Lemon, J., & Pritchard, C. (1993). Clinical birthweight standards for a total population in the 1980s. *British Journal of Obstetrics and Gynaecology*, 100, 436-445.
- Campbell, M.K. & Mottola, M.F. (2000). Recreational exercise and occupational activity during pregnancy and birth weight: a case-control study. *American Journal of Obstetrics and Gynecology*, 184, 403-408.
- Clapp, J.F. (1990). The course of labor after endurance exercise during pregnancy. *American Journal of Obstetrics and Gynecology*, 163, 1799-1805.

- Clapp, J.F. (1991). The changing thermal response to endurance exercise during pregnancy. *American Journal of Obstetrics and Gynecology*, 165, 1684-1689.
- Clapp, J.F. (1993). Exercise in pregnancy: good, bad, or indifferent? *Current Obstetric Medicine*, 2, 25-49.
- Clapp, J.F. (1994). A clinical approach to exercise during pregnancy. *Clinics in Sports Medicine*, 13(2), 443-458.
- Clapp, J.F. (1997). Diet, exercise, and feto-placental growth. *Archives of Gynecology and Obstetrics*, 260, 101-107.
- Clapp, J.F. (1998). Effect of dietary carbohydrate on the glucose and insulin response to mixed caloric intake and exercise in both nonpregnant and pregnant women. *Diabetes Care*, 21(S2), B107-112.
- Clapp, J.F. (2002). Maternal carbohydrate and pregnancy outcome. *Proceedings of the Nutritional Society*, 61(1), 45-50.
- Clapp, J.F. (2006). Influence of endurance exercise and diet on human placental development and fetal growth. *Placenta*, 27, 527-534.
- Clapp, J.F., & Capeless, E.L. (1990). Neonatal morphometrics after endurance exercise during pregnancy. *American Journal of Obstetrics and Gynecology*, 163, 1805-1811.
- Clapp, J.F., & Dickstein, S. (1984). Endurance exercise and pregnancy outcome. *Medicine and Science in Sports and Exercise*, 16(6), 556-562.
- Clapp, J.F., Kim, H., Burciu, B., & Lopez, B. (2000). Beginning regular exercise in early pregnancy: Effect on fetoplacental growth. *American Journal of Obstetrics and Gynecology*, 183, 1484-1488.
- Clapp, J.F., Kim, H., Burciu, B., Schmidt, S., Petry, K., & Lopez, B. (2002). Continuing regular exercise during pregnancy: Effect of exercise volume on fetoplacental growth. *American Journal of Obstetrics and Gynecology*, 186(1), 142-147.
- Clapp, J.F., & Rizk, K.H. (1992). Effect of recreational exercise on midtrimester placental growth. *American Journal of Obstetrics and Gynecology*, 167, 1518-1521.
- Clapp, J.F., Stepanchak, W., Tomaselli, J., Kortan, M., & Faneslow, S. (2000). *American Journal of Obstetrics and Gynecology*, 183, 167-172.
- Coleman, E. (2002). Nutrition and Pregnancy. *Sports Medicine Digest*, 24(5), 55-56.

- Collings, C.A., Curet, L.B., & Mullin, J.P. (1983). Maternal and fetal responses to a maternal aerobic exercise program. *American Journal of Obstetrics and Gynecology*, *145*, 702-707.
- Dahlstrom, H. & Ihrman. (1960). A clinical and physiological study of pregnancy in a material from Northern Sweden. I. Observations with special regard to the cardiopulmonary function during the first trimester of pregnancy. *Acta Societatis Medicorum Upsaliensis*, *65*, 117-136.
- Davies, G.A.L., Wolfe, L.A., Mottola, M.F., MacKinnon, C., Society of Obstetricians and Gynecologists of Canada, & SOGC Clinical Practice Committee (2003). Joint SOGC/CSEP clinical practice guidelines: exercise in pregnancy and the postpartum period. *Canadian Journal of Applied Physiology*, *28*(3), 330-341.
- Duncombe, D., Skouteris, H., Wertheim, E.H., Kelly, L., Fraser, V., & Paxton, S.J. (2006). Vigorous exercise and birth outcomes in an sample of recreational exercisers: a prospective study across pregnancy. *Australian and New Zealand Journal of Obstetrics and Gynaecology*, *46*, 288-292.
- Dye, T.D., Knox, K.L., Artal, R., Aubry, R.H., Wojtowycz, M.A. (1997). Physical activity, obesity, and diabetes in pregnancy. *American Journal of Epidemiology*, *146*, 961-965.
- Edwards, M.J. (1986). Hyperthermia as a teratogen. *Teratogenesis, Carcinogenesis, and Mutagenesis*, *6*, 563-582.
- Evenson, K.R., Savitz, D.A., Huston, S.L. (2004). Leisure-time physical activity among pregnant women in the US. *Paediatric and Perinatal Epidemiology*, *18*, 400-407.
- Exercise during pregnancy and the postpartum period (1994). *International Journal of Gynecology and Obstetrics*, *45*, 65-70.
- Ezmerli, N.M. (2000). Exercise in pregnancy. *Primary Care Update for Ob/Gyns*, *7*, 260-265.
- FAO/WHO/UNU (1985). *Energy and protein requirements*. Report of a joint FAO/WHO/UNU expert consultation. WHO Technical Report Series; No. 724. WHO: Geneva.
- Fiala, J.E., Egan, J.F., & Lashgan, M. (2006). The influence of body mass index on pregnancy outcomes. *Connecticut Medicine*, *70*(1), 21-23.
- Franko, D.J., Walton, B.E. (1993). Pregnancy and eating disorders: a review and clinical implications. *International Journal of Eating Disorders*, *13*, 41-47.

- Gaudier, F.L., Hauth, J.C., Poist, M., Corbett, D., Cliver, S.P. (1992). Recurrence of gestational diabetes mellitus. *Obstetrics and Gynecology*, 80, 755-758.
- Godfrey, K., Robinson, S., Barker, D.J.P., Osmond, C., & Cox, V. (1996). Maternal nutrition in early and late pregnancy in relation to placental and fetal growth. *British Medical Journal*, 312, 410.
- Goodlin, R.C. & Buckley, K.K. (1984). Maternal exercise. *Clinics in Sports Medicine*, 3, 881-894.
- Gormican, A., Valentine, J., & Satter, E. (1980). Relationships of maternal weight gain, prepregnancy weight, and infant birthweight. *Journal of the American Dietetic Association*, 77, 662-667.
- Guzman, C.A. & Kaplan, R. (1970). Cardiorespiratory response to exercise during pregnancy. *American Journal of Obstetrics and Gynaecology*, 108, 600-605.
- Hartmann, S., & Bung, P. (1999). Physical exercise during pregnancy – physiological considerations and recommendations. *Journal of Perinatal Medicine*, 27(3), 204-215.
- Hatch, M.C., Shu, X.-O., McLean, D.E., Levin, B., Begg, M., Reuss, L, et al. (1993). Maternal exercise during pregnancy, physical fitness, and fetal growth. *American Journal of Epidemiology*, 137, 1105-1114.
- Hall, D.C., & Kaufmann, D.A. (1987). Effects of aerobic and strength conditioning on pregnancy outcomes. *American Journal of Obstetrics and Gynecology*, 157, 1199-1203.
- Henry, O.A., & Beischer, R.A. (1991). Long-term implications of gestational diabetes for the mother. *Bailliere's Clinical Obstetrics and Gynaecology*, 5(2), 461-483.
- Hollingshead, A.de B. (1975). *Four factor index of social status*. Unpublished manuscript, Yale University.
- Homko, C., Sivan, E., Chan, X., Reece, E.A., & Boden, G. (2001). Insulin secretion during and after pregnancy in patients with gestational diabetes mellitus. *Journal of Clinical Endocrinology and Metabolism*, 86(2), 568-573.
- Hytten, F.E., & Leitch, I. (1971). *The physiology of human pregnancy* (2nd ed). Oxford: Blackwell.
- Jackson, M.R., Gott, P., Lye, S.J., Ritchie, J.W.K., & Clapp, J.F. (1995). The effects of maternal exercise on human placental development: placental volumetric composition and surface areas. *Placenta*, 16, 179-191.

- Jovanovic, L. (2001). What's so bad about a big baby? *Diabetes Care*, 24, 317-318.
- Jovanovic-Peterson, L., & Peterson, C.M. (1996). Review of gestational diabetes mellitus and low-calorie diet and physical exercise as therapy. *Diabetes/Metabolism Reviews*, 12(4), 287-308.
- Kardel, K.R. (2005). Effects of intense training during and after pregnancy in top-level athletes. *Scandinavian Journal of Medicine and Science in Sports*, 15, 79-86.
- Kardel, K.R., & Kase, T. (1998). Training in pregnant women: Effects on fetal development and birth. *American Journal of Obstetrics and Gynecology*, 178, 280-286.
- Katz, R., Karliner, J.S., & Resnik, R. (1978). Effects of a natural volume overload state (pregnancy) on left ventricular performance in normal human subjects. *Circulation*, 58(3 Pt 1), 434-441.
- King, J.C. (2006). Maternal obesity, metabolism, and pregnancy outcomes. *Annual Review of Nutrition*, 26, 271-291.
- Knuttgen, H.G. & Emerson, K. (1974). Physiological response to pregnancy at rest and during exercise. *Journal of Applied Physiology*, 36, 549-553.
- Kuhl, C. (1998). Etiology and pathogenesis of gestational diabetes. *Diabetes Care*. 21 (S2), B19-26.
- Kulpa, P.J., White, B.M., & Visscher, R. (1987). Aerobic exercise in pregnancy. *American Journal of Obstetrics and Gynecology*, 156, 1395-1403.
- Langhoff-Roos, J., Lindmark, G., Kylberg, E., & Gebre-Medhin, M. (1987). Energy intake and physical activity during pregnancy in relation to maternal fat accretion and infant birthweight. *British Journal of Obstetrics and Gynaecology*, 94, 1178-1185.
- Larkin, H., Gallery, E.D., Hunyor, S.N., Gyory, A.Z., & Boyce, E.S. (1980). Haemodynamics of hypertension in pregnancy assessed by M-mode echocardiography. *Clinical and Experimental Pharmacology and Physiology*, 7(5), 463-468.
- Lokey, E.A., Tran, Z.V., Wells, C.L., Myers, B.C., & Tran, A.C. (1991). Effects of physical exercise on pregnancy outcomes: a meta-analytic review. *Medicine and Science in Sports and Exercise*, 23(11), 1234-1239.
- Longo, L.D. (1983). Maternal blood volume and cardiac output during pregnancy; a hypothesis of endocrinologic control. *American Journal of Physiology*, 245, R720-729.

- Lotgering, F.K., Gilbert, R.D., & Longo, L.D. (1985). Maternal and fetal responses to exercise during pregnancy. *Physiological Reviews*, 65(1), 1-36.
- Lotgering, F.K., Van Doorn, M.B., Struijk, P.C., Pool, J., & Wallenburg, H.C.S. (1991). Maximal aerobic exercise in pregnant women: heart rate, O₂ consumption, CO₂ production and ventilation. *Journal of Applied Physiology*, 70, 1016-1023.
- Lotgering, F.K., Struijk, P.C., van Doorne, M.B., & Wallenberg, H.C.S. (1992). Errors in predicting maximal oxygen consumption in pregnant women. *Journal of Applied Physiology*, 72, 562-567.
- Lund, C.J., & Donovan, J.C. (1967). Blood volume during pregnancy. Significance of plasma and red cell volumes. *American Journal of Obstetrics and Gynecology*, 98(3), 394-403.
- Magann, E.F., Evans, S.F., Weitz, B. & Newnham, J. (2002). Antepartum, intrapartum, and neonatal significance of exercise on healthy low-risk pregnant working women. *Obstetrics and Gynecology*, 99, 466-472.
- Marcoux, S., Brisson, J. & Fabia, J. (1989). The effect of leisure time activity on the risk of pre-eclampsia and gestational hypertension. *Journal of Epidemiology and Community Health*, 43(2), 147-152.
- Marquez-Sterling, S., Perry, A.C., Kaplan, T.A., Halberstein, & Signorile, J.F. (2000). Physical and psychological changes with vigorous exercise in sedentary primigravidae. *Medicine and Science in Sports and Exercise*, 32(1), 58-62.
- Matsuno, A.Y., Esrey, K.L., Perrault, H., & Koski, K.G. (1999). Low intensity exercise and varying proportions of dietary glucose and fat modify milk and mammary gland compositions and pup growth. *Journal of Nutrition*, 129, 1167-1175.
- McKeown, T., & Record, R.G. (1953). The influence of placental size on foetal growth according to sex and order of birth. *Journal of Endocrinology*, 10(1), 73-81.
- MedlinePlus. Retrieved October 1, 2005 from <http://www2.merriam-webster.com/cgi-bin/mwmednlm>
- Molteni, R.A., Stys, S.J., & Battaglia, F.C. (1978). Relationship of fetal and placental weight in human beings: fetal/placental weight ratios at various gestational ages and birth weight distributions. *The Journal of Reproductive Medicine*, 21(5), 327-334.
- Moses, R.G. (1996). The recurrence rate of gestational diabetes in subsequent pregnancies. *Diabetes Care*, 19, 1349-1350.
- Newton, C. (1993). Weighing the placenta. *Nursing Times*, 89(17), 52-54.

- Ning, Y., Williams, M.A., Dempsey, J.C., Sorensen, T.K., Frederick, I.O., & Luthy, D.A. (2003). Correlates of recreational physical activity in early pregnancy. *The Journal of Maternal-Fetal & Neonatal Medicine*, 13(6), 385-393.
- O'Neill, M.E. (1996). Maternal rectal temperature and fetal heart rate responses to upright cycling in late pregnancy. *British Journal of Sports Medicine*, 30, 32-35.
- O'Sullivan, J.B. (1991). Diabetes mellitus after GDM. *Diabetes*, 40(S2), 131-135.
- O'Toole, M.L. (2003). Physiologic aspects of exercise in pregnancy. *Clinics in Obstetrics and Gynecology*, 46(2), 379-389.
- Picone, T.A., Allen, L.H., Olsen, P.N., & Ferris, M.E. (1982). Pregnancy outcome in North American women. II. Effects of diet, cigarette smoking, stress, and weight gain on placentas, and on neonatal physical and behavioral characteristics. *American Journal of Clinical Nutrition*, 36 (6), 1214-1224.
- Pivarnik, J.M. (1998). Potential effects of maternal physical activity on birth weight: brief review. *Medicine and Science in Sports and Exercise*, 30(3), 400-406.
- Pivarnik, J.M., Lee, W., & Miller, J.F. (1991). Physiological and perceptual responses to cycle and treadmill exercise during pregnancy. *Medicine and Science in Sports and Exercise*, 23(4), 470-475.
- Pivarnik, J.M., Mauer, M.B., Ayers, N.A., Kirshon, B., Dildy, G.A., Cotton, D.B. (1994). Effect of chronic exercise on blood volume expansion and hematologic indices during pregnancy. *Obstetrics and Gynecology*, 83, 265-269.
- Pomerance, J.J., Gluck, L., & Lynch, V.A. (1974). Physical fitness in pregnancy: its effect on pregnancy outcome. *American Journal of Obstetrics and Gynecology*, 119(7), 867-876.
- Powers, S.K., & Dodd, S.L. (1999). *Total fitness: Exercise, nutrition, and wellness (2nd ed.)*. Boston, MA: Allyn and Bacon.
- Prowse, C.M., & Gaensler, E.A. (1965). Respiratory and acid-base changes during pregnancy. *Anesthesiology*, 26, 381-392.
- Rice, P.L., & Fort, I.L. (1991). The relationship of maternal exercise on labor, delivery and health of the newborn. *The Journal of Sports Medicine and Physical Fitness*, 31, 9599.
- Riemann, M.K., & Kanstrup Hansen, I.-L. (2000). Effects on the foetus of exercise in pregnancy. *Scandinavian Journal of Medicine and Science in Sports*, 10, 12-19.

- Rowell, L.B. (1974). Human cardiovascular adjustments to exercise and thermal stress. *Physiological Reviews*, 54, 75-159.
- Rowell, L.B. (1983). Cardiovascular aspects of human thermoregulation. *Circulation Research*, 52, 367-379.
- Rowell, L.B., & O'Leary, D.S. (1990). Reflex control of the circulation during exercise: chemoreflexes and mechanoreflexes. *Journal of Applied Physiology*, 69, 407-418.
- Rubler, S., Damani, P.M., & Pinto, E.R. (1977). Cardiac size and performance during pregnancy estimated with echocardiography. *American Journal of Cardiology*, 40(4), 534-540.
- Sady, M.A., Haydon, B.B., Sady, S.P., Carpenter, M.W., Thompson, P.D., & Coustan, D.R. (1990). Cardiovascular response to maximal cycle exercise during pregnancy and at two and seven months post partum. *American Journal of Obstetrics and Gynecology*, 162(5), 1181-1185.
- Saftlas, A.F., Logsden-Sackett, N., Wang, W., Woolson, R., & Bracken, M.B. (2004). Work, leisure-time physical activity, and risk of preeclampsia and gestational hypertension. *American Journal of Epidemiology*, 160(8), 758-765.
- Saltin, B., Blomqvist, G., Mitchell, J.H., Johnson, R.L., Wildenthal, K., Chapman, C.B. (1968). Response to exercise after bed rest and after training. *Circulation*, 38 (S7), 1-78.
- Scott, D.E. (1972). Anemia in pregnancy. *Obstetrics and Gynecology Annual*, 1, 219-244.
- Seitchik, J. (1967). Body composition and energy expenditure during rest and work in pregnancy. *American Journal of Obstetrics and Gynecology*, 97, 701-713.
- Shearer, M.H. (1980). Malnutrition in middle class pregnant women. *Birth and the Family Journal*, 7, 27-35.
- Shioto, K. (1988). Induction of neural tube defects and skeletal malformations in mice following brief hyperthermia in utero. *Biology of the Neonate*, 53, 86-97.
- Sorensen, T.K., Williams, M.A., Lee, I.M., Dashow, E.E., Thompson, M.L., & Luthy, D.A. (2003). Recreational physical activity and risk of preeclampsia. *Hypertension*, 41(6), 1273-1280.
- Sternfeld, B., Quesenberry, C.P., Eskenazi, B., & Newman L.A. (1995). Exercise during pregnancy and pregnancy outcome. *Medicine and Science in Sports and Exercise*. 27(5), 634-640.

- Taricco, E., Radaeli, T., Nobile de Santis, M.S., & Cetin, I. (2003). Foetal and placental weights in relation to maternal characteristics in gestational diabetes. *Placenta*, 24(4), 343-347.
- Teruoka, G. (1933). Labour physiological studies on the pregnant women. *Arbeitsphysiologie*, 7, 259-279.
- Thomas, C.L. (Ed.). (1997). *Taber's Cyclopedic Medical Dictionary*. Philadelphia, PA: F.A. Davis Company.
- Thomson, A.M., Billewicz, W.Z., & Hytten, F.E. (1969). The weight of the placenta in relation to birthweight. *Journal of Obstetrics and Gynecology of the British Commonwealth*, 76(10), 865-872.
- U.S. Department of Health and Human Services (1996). *Physical activity and health: a report of the Surgeon General, executive summary*. Retrieved November 25, 2005 from <http://www.cdc.gov/nccdphp/sgr/pdf/execsumm.pdf>
- Ueland, K., Novy, M.J., Metcalfe, J. (1973). Cardiorespiratory responses to pregnancy and exercise in normal women and patients with heart disease. *American Journal of Obstetrics and Gynecology*, 115, 4-10.
- van Raaij, J.M.A. (1995). Energy requirements of pregnancy for healthy Dutch women. *European Journal of Obstetrics and Gynecology and Reproductive Biology*, 61, 7-13.
- Walker, D., Walker, A., Wood, C. (1969). Temperature of the human fetus. *Journal of Obstetrics and Gynecology of the British Commonwealth*, 76, 503-511.
- Warkany, J. (1986). Teratogen update: hyperthermia. *Teratology*, 33, 365-371.
- Watson, W.J., Katz, V.L., Hackney, A.C., Gall, M.M., & McMurray, R.G. (1991). Fetal responses to maximal swimming and cycling exercise during pregnancy. *Obstetrics and Gynecology*, 77, 382-386.
- Webb, K.A., Wolfe, L.A., & McGrath, M.J. (1994). Effects of acute and chronic maternal exercise on fetal heart rate. *Journal of Applied Physiology*, 77(5), 2207-2213.
- Wolfe, L.A., Brenner, I.K.M., & Mottola, M.F. (1994). Maternal exercise, fetal well-being and pregnancy outcome. *Exercise and Sport Science Reviews*, 22, 145-94.
- Wolfe, L.A., & Weissgerber, T.A. (2003). Clinical physiology of exercise in pregnancy: a literature review. *Journal of Obstetrics and Gynecology Canada*, 25(6), 473-483.

Wynn, S.W., Wynn, A.H.A., Doyle, W., & Crawford, M.A. (1994). The association of maternal social class with maternal diet and the dimensions of babies in a population of London women. *Nutrition and Health, 9*, 303-315.