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The Impact of Maternal Diabetes on Fetal and Infant Outcomes: A Secondary Analysis of Peridata.net® from 2013 to 2017

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THE IMPACT OF MATERNAL DIABETES ON FETAL AND INFANT OUTCOMES: A SECONDARY ANALYSIS OF PERIDATA.NET® FROM 2013 TO 2017

by

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ABSTRACT

THE IMPACT OF MATERNAL DIABETES ON FETAL AND INFANT OUTCOMES: A SECONDARY ANALYSIS OF PERIDATA.NET® FROM 2013 TO 2017

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Under the Supervision of Professor Teresa S. Johnson

Background: Diabetes is a leading cause of morbidity and mortality for most of the developed world and is known to contribute to adverse maternal, fetal, and infant outcomes. The purpose of this study was to examine the relationship of maternal diabetes to fetal and infant outcomes for infants born in a small heterogeneous urban community with significant disparities in infant mortality using data in the PeriData.Net® database.

Methods: Women with diabetes were case matched to women without diabetes by pre-pregnancy BMI and race to mitigate obesity effects on outcomes in this secondary analysis of PeriData.Net®.

Results (p<0.05= *,p -<0.01 = **, p<0.001 = *):** Compared to Caucasian and Hispanic women with diabetes, African-American women with diabetes had less gestational/more preexisting diabetes (65.3%, CI 56.5-73.9% vs 86.8%, CI 83.7-89.9%***), more pre-pregnancy hypertension (15.7%, CI 9.0-22.3% vs. 7.2%, CI 4.9-9.6%**) and more prematurity (37.4%, CI 28.5-46.2% vs. 23.6%, CI 19.8-27.5%**), and more infant mortality (4.3%, CI 0.6-8.1% vs. 0.9%,CI 0.0-1.7%**). Women of all races with diabetes had higher C-section (44.8%, CI 41.1-48.6% vs. 30.6%, CI 28.1-33.1%***) and hypertension (22.4%, CI

19.2%-25.6% vs.13.8%, CI 11.9%-15.6%***), while diabetes exposed infants experienced more prematurity (25.3%, CI 22.0-28.6% vs. 12.9%, CI 11.1-14.7%,***), NICU admission (18.2%, CI 15.1-21.0% vs. 10.4%, CI 8.6-11.9%***), respiratory distress (9.5%, CI 7.2-11.6% vs. 4.7%, CI 3.5-5.8%,***), hypoglycemia (7.7%, CI 5.6-9.6% vs. 2.3%, CI 1.5-3.1%***), hyperbilirubinemia (8.6%, CI 6.5-10.8% vs. 3.9% CI 2.9-5.0%***), LGA (18.2%, CI 15.2-21.1% vs. 11.6%, CI 9.9-13.4%***) and risk of SGA (OR 1.51, CI 1.04-2.19*). Women with diabetes gained less weight and had heavier infants when adjusted for gestational age.

Conclusions: Diabetes increased cesarean sections and hypertension prevalence for all women. Maternal diabetes increased LGA, SGA, prematurity, hypoglycemia, hyperbilirubinemia and respiratory distress which also increases risk for infant morbidity and mortality. A higher prevalence of preexisting diabetes and prematurity contributes to an increased risk of mortality for African-American infants.

To

my parents,

who made as many sacrifices as I did to complete this degree,

and my mentor, Dr. Teresa S. Johnson,

encourager, brilliant educator/scientist, and coach

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LIST OF ABBREVIATIONS

ACOG	American College of Obstetrics and Gynecologists
ADA	American Diabetes Association
ANOVA	analysis of variance
BMI	body mass index
DHA	docosahexaenoic acid
DOHaD	developmental origins of health and disease
HELLP	hemolysis, elevlated liver enzymes, low platelets
IADPSG	International Association of Diabetes and Pregnancy Study Groups
IOM	Institute of Medicine
IRB	institutional review board
IUGR	intrauterine growth restriction
LGA	large for gestational age
NICU	neonatal intensive care unit
RDS	respiratory distress syndrome
SGA	small for gestational age
SIDS	sudden infant death syndrome
WDHS	Wisconsin Department of Health Services
WHO	World Health Organization

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CHAPTER 1: INTRODUCTION

Diabetes, a chronic disease that has become epidemic worldwide, alongside obesity and sedentary lifestyle, has serious consequences for individual health and community well-being. The term *diabesity* combines the diabetes and obesity public health epidemics to acknowledge the relationship between diabetes and obesity and the disturbances in metabolic regulation found in both (Catalano et al., 2012; Centers for Disease Control and Prevention [CDC], 2014b; D. W. Lam & LeRoth, 2012; Schmidt & Duncan, 2003; World Health Organization [WHO], 2016). It is estimated that diabetes affects 8.5% of people worldwide and impacts approximately 10% of pregnancies each year. With obesity reaching epidemic proportions and worldwide prevalence of diabetes rising 1% in just 2 years, diabetes-related comorbid conditions and costs are expected to skyrocket. There is debate as to whether the diabetes epidemic can be controlled in the United States.

Diabetes during pregnancy causes economic, psychologic, and physiologic strains to affect the woman, infant, family, and community, as management of both diabetes and pregnancy can be complex. Exploring the impact of diabetes on maternal, fetal, and infant outcomes is vital as the diabesity epidemic affects more pregnancies (Anderson, Freeland, Clouse, & Lustman, 2001; Handisurya, 2011; Owens et al., 2010; Reece, 2008; Tomedi, Simhan, Chang, McTigue, & Bodnar, 2014). The addition of maternal weight gain to obesity and diabetes further increases the risks for complications for women and their infants (Catalano et al., 2012; CDC, 2014b; D. W. Lam & LeRoth, 2012; Parellada, Asbjornsdottir, Ringholm, Damm, & Mathiesen, 2014; Schmidt & Duncan, 2003; WHO, 2016). A possible explanation for adverse fetal and infant outcomes may be found in the increasing numbers of women of childbearing age

beginning pregnancy with diabetes, prediabetes, or obesity (CDC, 2014a, 2014b; D. W. Lam & LeRoth, 2012; Marshall, Guild, Cheng, Caughey, & Halloran; 2014a; Schmidt & Duncan, 2003; WHO, 2016).

Problem

The intersection between diabetes and pregnancy needs to be explored so that nurses and other health care professionals can positively impact women, their infants, and their communities in the short and long term. Pregnancy brings many changes physically and emotionally for the woman and her family, but the addition of diabetes during pregnancy creates a special perinatal challenge. The risk of fetal and infant compromise, whether by congenital anomalies, birth trauma, or other insults, adds to perinatal stress. Women are encouraged to avoid pregnancy-related complications by keeping their blood sugar low, but not so low that they experience complications from hypoglycemia. This balancing act must continue through the pregnancy so that fetal, infant, and maternal outcomes can be optimized. Through diet, exercise, and medical management, women work to keep their blood sugar under control so that their infants do not experience serious fetal and infant compromise.

A study is needed to explore the ways in which maternal diabetes contributes to adverse fetal and infant outcomes in a community with high infant mortality. Current work around infant mortality and morbidity by a community group called Life Course Initiative for Healthy Families can be augmented with more information about diabetes within the community. Of interest for the study are variables that offer insight into subgroups that may be experiencing more stress or have less coping reserves. These characteristics will be used in future studies to further explore maternal, fetal, and infant outcomes and interventions that may improve outcomes. As diabetes does contribute to adverse fetal and infant outcomes, it will be important to understand which

outcomes are the most affected and which maternal–fetal dyads have the highest risk before developing interventions that are efficacious and targeted. Maternal, fetal, and infant outcomes can be affected by obesity due to increased insulin resistance and stress found in obese individuals, and in the context of diabetes, there is increased risk of complications; therefore this must be considered in this study.

Theoretical Framework

For this study, the developmental origins of health and disease (DOHaD) theory was used to conceptualize health-related variables and logically organize data. Maternal diabetes adds stress to the developing fetus, resulting in increased adverse fetal and infant outcomes in offspring born to women with diabetes. With this theory, relationships between variables and aspects of health or human behavior can be explained or predicted. To further the science of diabetes and pregnancy and answer these proposed questions, theories that focus on maternal health and infant outcomes and theories that are related to diabetes outcomes must be a part of any planned research.

Scope of the Problem and Gaps in Knowledge

Diabetes Prevalence: United States and the World

As obesity, sedentary lifestyle, poor diet, and epigenetic influences increase, diabetes rates are rising worldwide. The World Health Organization (WHO) has classified diabetes as a noncommunicable epidemic. The total number of people with diabetes worldwide is estimated to rise from 171 million in 2000 to 366 million by 2030 (WHO, 2016). From 2000 to 2030, the number of people with diabetes is projected to rise worldwide: in China, from 20.76 million to 42.32 million people; in India, from 31.7 million to 79.4 million people; in France, from 1.7

million to 2.6 million people; in the United Kingdom, from 1.76 to 2.67 million; and in Canada, from 2 million to 3.5 million people (WHO, 2016).

Rates for preexisting diabetes (Type 1 [T1DM] and Type 2 [T2DM]), prediabetes, and gestational diabetes (GDM) have risen in the United States. From 1980 to 2012, the number of those diagnosed with diabetes quadrupled from 5.5 million to 21.3 million people (CDC, 2015). The prevalence of diabetes increased 1% from 2010 to 2012 in the United States (Boyle, Thompson, Gregg, Barker, & Williamson, 2010; CDC, 2014b). In 2012, diabetes cost Americans $245 billion: $176 billion was in direct costs from medical care, and $69 billion was from lost productivity (American Diabetes Association [ADA], 2013). This amount increased by 41% from the 2007 estimate of $174 billion (ADA, 2013). Wisconsin diabetes diagnoses increased 76% from 1989 to 2008 such that at least 10% of Wisconsin adults have diabetes (Robbins et al., 2014). The number of people with diabetes in the United States is expected to increase from 17.7 million in 2000 to 30.3 million by 2030 (CDC, 2014b; WHO, 2016).

Additionally, millions of people are unaware they have prediabetes, with glucose levels just above normal, and are therefore not working to reduce future risk of diabetes development (CDC, 2014a, 2014b; Disparities National Coordinating Center [DNCC], 2013). If the current trend of 1.7 million new diabetes cases each year continues, by 2050, 1 out of every 3 adults in the United States will have diabetes (Boyle et al., 2010; CDC, 2014b, 2015). Currently one out of every three adults has prediabetes, which raises the risk of developing Type 2 diabetes, having a stroke, or developing heart disease (CDC, 2015). Diabetes was the seventh leading cause of death in the United States in 2013 (CDC, 2015; Kochanek, Murphy, Xu, & Tejada-Vera, 2016; Wisconsin Department of Health Services [WDHS], 2016a).

Rising rates of diabetes are a great concern in Wisconsin and have become a significant burden to the state and contributor to morbidity and mortality. Within the state, diabetes prevalence has increased from 4.2% in 1989 to 7.4% in 2008—an increase of 76% (WDHS, 2010). It is estimated that 40% of Wisconsin adults will develop Type 2 diabetes in their lifetimes (Gregg et al., 2014). Recent data for Wisconsin have shown that 37% of adults have prediabetes, 8% of adults have diabetes, and 28% of adults have undiagnosed diabetes (BRFSS, 2014; CDC, 2014a; WDHS, 2016a). Self-reported prevalence of diabetes in Wisconsin was 365,000 adults, with another 22,000 cases of new diabetes annually (CDC, 2016, 2017). This is a rise in diagnosed diabetes from 2014, when it was estimated 356,000 adults in Wisconsin had been diagnosed with diabetes and an additional 138,000 had undiagnosed diabetes (BRFSS, 2014; National Center for Health Statistics [NCHS], 2012; WDHS, 2016a, 2016b; WISH, 2014). Diabetes prevalence in Wisconsin (per 1,000) from 2013 was 7.3 overall, with 7.7 for males and 7.1 for females (CDC, 2017). Data by sex were suppressed for those of childbearing age due to issues with data reliability, but overall prevalence for 18- to 44-year-olds was reported as 1.9 (CI 1.0–2.8) (CDC, 2017).

Diabetes rates in some groups in the US continue to rise; Hispanics, African Americans, and those without high school diplomas struggle with rising diabetes (CDC, 2015). Half of Hispanic women and men and half of African American women are likely to develop diabetes in their lifetimes (CDC, 2015). Higher rates of diabetes are found in Native Americans, African Americans, and Hispanics than in Asians and Caucasians of any age (CDC, 2014). The main concern for youths under the age of 20 years remains T1DM; however, there are rising rates of T2DM among minority youth as childhood obesity has risen (CDC, 2014, 2015; Dixon, Pena, & Taveras, 2012).

In women of childbearing age, diabetes rates are also rising (CDC, 2014; WHO, 2016). In America, 4.2 million women of childbearing age or 4.1% of the childbearing population, have preexisting T1DM or T2DM diabetes (CDC, 2014; Robbins et al., 2014). The risk of developing diabetes increases with increased weight. Maternal obesity affects 18.5%–38.3% of pregnancies (Reece, 2008; Salihu, Weldeselasse, Rao, Marty, & Whiteman, 2011). The percentage of overweight women without diabetes has roughly doubled from 1960 to 2000 in the United States; by 2012, 36% of women over the age of 20 years were obese, increasing their risk of diabetes development (CDC, 2014; Harper et al., 2014; Okosun et al., 2004; Thompson, Ananth, Jaddoe, Miller, & Williams, 2014). In Wisconsin, 50% of childbearing aged women were found to be overweight or obese (Robbins et al., 2014; WDHS, 2010). Two-thirds of women of childbearing age were overweight or obese in one study, putting more women at risk during pregnancy than before (Fiegel, Carroll, Kit, & Ogden, 2012).

Most diabetes during pregnancy develops as GDM; however, increasingly, women with T1DM and T2DM are becoming pregnant. High glucose is very damaging to organs over time (DeFronzo, 2009; Selvin et al., 2011). The effects of preexisting diabetes on the woman and her infant during pregnancy are more severe due to a longer exposure to a hyperglycemic state (Colstrup, Mathiesen, Damm, Jensen, & Ringholm, 2013; Coustan, 2013; Starikov et al., 2014). Women with T1DM had poor glycemic control and up to 5 times increased risk of adverse pregnancy outcomes compared to women without diabetes particularly cesarean section (Colstrup et al., 2013; Jovanovic et al., 2015; Starikov et al., 2014).

The incidence of pregnancy-related diabetes can be more difficult to assess. GDM complicates at least 3%–7% of pregnancies, with some more recent studies finding GDM using the 75 g 2-hour oral glucose tolerance test (oGTT) in closer to 12% of pregnancies; up to 25% of

women in specific high-risk populations had GDM (Alwan, Tuffnell, & West, 2009; Baker & Haeri, 2012; CDC, 2014; Coustan, 2013; Edu et al., 2016; HAPO Study Cooperative Research Group [HAPO], 2008; Hersh, 2014; Kim et al., 2013). Gestational diabetes has been rising steadily; One 2009 study showed that 5.6% of hospital deliveries were affected by GDM in the U.S. and in another U.S. study 7.86% of pregnant women had diabetes (0.13% T1DM, 1.21% T2DM and 6.52% GDM) (Alwan et al., 2009; CDC, 2015; Jovanovic et al., 2015).

Morbidity and Mortality Rates

As the diabesity epidemic has risen, the United States has also struggled with maternal, fetal, and infant morbidity and mortality, which are significant measures of public health. Increases in body mass index (BMI) are associated with a rise in neonatal mortality (MacDorman & Mathews, 2009), while women who had infants born at the extremes of birthweight have been found to have a higher risk of diabetes related mortality later in life (C. Li et al., 2011). U.S. infant mortality rates have improved from a rank of 30th in the world in 2005 to 26th in 2010 with focused effort; however, U.S. infant mortality rates were still twice those of the best performing nations (MacDorman & Mathews, 2009; MacDorman, Mathews, Mohangoo, & Zeitlin, 2014). This higher than expected mortality, despite advances and access to health care technology, is partly from higher preterm birthrates and assistive reproductive technology in addition to stress, diabetes, infection, and obesity (Billionnet et al., 2017; Fine, Kotelchuck, Adess, & Pies, 2009; Jovanovic et al., 2015; MacDorman & Mathews, 2009; MacDorman et al., 2014; Sen et al., 2016; Yang, Cummings, O'connell, & Jangaard, 2006). Preterm delivery is of great concern, as morbidity and mortality increase with earlier gestational age. The U.S. rate of infant mortality is similar to the rates of other nations for premature infants but is significantly higher for full-term infants (MacDorman et al., 2014). The neonatal mortality rate per 1,000 live

births for Wisconsin varies by maternal BMI for the first 30 days of life; women with a low or high BMI had higher infant mortality rates than normal-weight women (MacDorman et al., 2014).

Disparities in fetal and infant outcomes clearly exist for Wisconsin infants. Disparities in infant outcomes reflect community and individual stresses and are often related to comorbid conditions, such as diabetes (Fine et al., 2009). Particularly affected by these disparities are African American infants, as African American women have an increased prevalence of diabetes, obesity, and high maternal weight gain that contribute to infant mortality (Cabacungan, Ngui, & McGinley, 2012; Catov, Abatemarco, Althouse, Davis, & Hubel, 2015; Fine et al., 2009 Marshall, Guild, Cheng, Caughey, & Halloran, 2014b). Shoulder dystocia has been found to be higher in African American deliveries (Cheng, Norwitz, & Caughey, 2006). African American infants accounted for 24% of infant deaths but only 10% of Wisconsin births in 2010; if there was no disparity, then 60 of the 95 deaths in 2010 would have been prevented (WDHS, 2013). In the small urban city of this study, the infant mortality rate rose from 5.1 deaths per 1,000 live births for normal-BMI women to 9.4 deaths per 1,000 births for obese women and is impacted by race, with an African American infant mortality rate of 18 for every 1,000 births versus 2 per 1,000 births for Caucasians (WDHS, 2014b, 2015).

Reports of adequate social and emotional support during pregnancy for all women in Wisconsin varied by age and race, with younger women having more support and African American women and Hispanic women reporting a less supportive environment (Robbins et al., 2014). Adequate emotional and social support reported by women with diabetes varied by race but not age; African American women reported the least support and Caucasian women the most support (Robbins et al., 2014).

Diabetes and Obesity during pregnancy

Gestational diabetes, along with pregestational, Type 1, and Type 2 diabetes, can negatively affect maternal, fetal, and infant outcomes. Diabetes comprises a wide range of disorders that lead to hyperglycemic states. Hyperglycemia and insulin resistance from obesity raises concerns for pregnancy management, alters fetal adaptation to the intrauterine environment, and affects fetal and infant outcomes, discussed further in Chapter 2, in the short and long term (Catalano et al., 2012; Coustan, 2013; Marshall et al., 2014a). The degree of the effect can be predicted somewhat by hemoglobin A1C (HgA1C), weight gain during pregnancy, stress levels, activity level and lifestyle choices, and prepregnancy BMI (Starikov et al., 2014). Researchers have demonstrated that, more often than not, the better the diabetic control, the better the outcomes are for the woman, fetus, and infant (Catov, Abatemarco, Althouse, Davis, & Hubel, 2015; Coustan, 2013; Galindo, Burguillo, Azriel, & De La Fuente, 2006; Hawdon, 2008; Most & Langer, 2012). Type 2 diabetes, which is linked with the epidemic of obesity, continues to rise in populations with traditionally low rates of chronic illness, such as women of childbearing age and children (Coustan, 2013; Magriples et al., 2015; Ryan, 2009; Stuber, 2015; Tam et al., 2010). Gestational diabetes affects 7%–12% of pregnancies and increases the risk for these women of developing Type 2 diabetes in the future (ADA, 2004; Coustan, 2013; Hiersch & Yogev, 2014).

Diabetes contributes a large financial burden as well. Direct diabetes costs were an estimated $100 billion annually in the United States during the 1990s (Fleming, 2001). The most recent U.S. estimates from 2012 put the direct cost of diabetes at $176 billion, with an additional $69 billion in indirect costs from lost productivity and death (CDC, 2014; DNCC, 2013). This was a rise of 41% compared to spending just 5 years earlier (DNCC, 2013). Medical costs for

T1DM in pregnancy can run nearly twice that of a pregnancy without diabetes while T2DM and GDM lead to increased costs (Jovanovic et al., 2015).

Significance of Research to Science

The effects of diabetes can be seen for both the woman and child starting in early pregnancy and continuing through their lives. The impact of diabetes on mother, fetus, and infant is discussed in detail in Chapter 2. If the effects of diabetes on the fetus start early in the pregnancy and continue through to the newborn stage into childhood and beyond, then further studies are needed to explore management of diabetes, to find targeted treatments to prevent diabetes during pregnancy, and to treat early fetal compromise based on the characteristics of the study community (Dixon et al., 2012; Tam et al., 2010; Tisi et al., 2011). Epigenetics and continued understanding of the pathogenesis of diabetes are adding knowledge so providers can counsel women. Understanding the impact of diabetes on the pregnant body and the developing fetus is critically important for assisting researchers in developing meaningful and reasonable studies that translate into outcomes seen in clinical practice.

Less detail is known about the effects of diabetes during pregnancy in the planned study community, so the effect of diabetes on fetal and infant outcomes within this population will add to science. The knowledge gained will help practitioners understand the challenges diabetes presents to this community, which is seeking to decrease disparities in infant mortality. This research may have wide-reaching implications for the infant, the woman, and future generations within this community if variables are found that increase risk.

Research Problem and Purpose

Expand Understanding of the Prevalence of Diabetes in the Study Population

Information on the prevalence of diabetes within the pregnant population and infant outcomes related to diabetes have yet to be investigated, though the data for the study population exist in the PeriData.Net® database. This database has been assessed for infant outcomes related to maternal variables such as blood pressure, race, income, and age, but no research has been conducted looking at diabetes or insulin resistance from obesity as a cause of concern. The full scope of diabetes in pregnancy in the study community has not been quantified from this database. An update is needed regarding diabetes and obesity, a marker for insulin resistance, in the pregnant population of this community and the impact on the infant.

Assess Effects of Diabetes on Pregnancy Outcomes of Infants

Diabetes is known to affect fetal and infant outcomes, causing significant morbidity and mortality (ADA, 2106; Coustan, 2013; Hawdon, 2008; Yang, Cummings, O'connell, & Jangaard, 2006). Infants born to women with diabetes have more prematurity, respiratory difficulties, birth trauma, altered fetal growth and NICU admission (Billionnet et al., 2017; Cordero et al., 2015; Kwik et al., 2007; Russell, Higgins, Amaruso, Foley, & McAuliffe, 2009). Diabetes is known to cause birth defects, macrosomia, shoulder dystocia, and hypoglycemia as well as many other significant stressors on the developing fetus and the newborn infant and will be discussed further in the literature review found in Chapter 2 (ADA, 2106; Coustan, 2013; Hawdon, 2008; Athukorala, Crowther & Willson, 2007). For the study community, which experiences high infant mortality, the PeriData.Net® database needs to be explored to determine the impact of diabetes on fetal and infant outcomes. This research provides the community with a

better understanding of opportunities for improved care of women with diabetes, which can have a significant impact on adverse fetal and infant outcomes.

Study Questions

Study Question 1. Are there differences by race in maternal, fetal, and infant outcomes when any maternal diabetes is present?

Study Question 2. What is the impact during pregnancy of any maternal diabetes, including preexisting and gestational diabetes, with and without insulin, on adverse fetal and infant outcomes?

Study Question 3. What is the effect of pregnancy BMI, gestational weight gain, and maternal diabetes on maternal outcomes that affect infant morbidity (delivery type and shoulder dystocia) when preeclampsia and parity are taken into consideration?

Study Question 4. What is the combined impact of any maternal diabetes during pregnancy and of prepregnancy BMI on adverse fetal and infant outcomes?

The maternal environment is critically important for the development of the fetus and for prevention of poor infant outcomes. Understanding something of the complex interplay between maternal environment and fetal outcomes and having a basic understanding of the effects of diabetes on organ systems and stress levles assist the researcher to choose variables of potential value. Variables for this study were chosen based on the current state of the evidence. The goal of these specific variables is to look at relevant maternal data and their effect on infant outcomes. The selection of variables is, however, limited to the variables available in the PeriData.Net® database for secondary analysis, and there are no linked longitudinal data to describe individual

effects over time. Variable selection, definitions, research questions, and specific methods are discussed in Chapter 3 in greater detail.

Ultimately, the goal of research into diabetes in pregnancy is to find variables that nursing can influence to improve infant outcomes in a population of known higher risk. The goals of this particular study are to develop an understanding of diabetes-related infant complications in the community and to quantify the impact of diabetes on adverse fetal and infant outcomes. With the significant disparities in infant mortality that exist in the study community, diabetes as an additional source of stress is important to understand. This secondary analysis of the PeriData.Net® database will provide significant insight into the effect of diabetes and metabolic states so that interventions can be developed in the future.

CHAPTER 2: LITERATURE REVIEW

Diabetes combined with pregnancy can result in poor maternal, fetal, and infant outcomes with significant short-term and long-term consequences for the woman and child. Adverse pregnancy outcomes for the woman, fetus, and infant are linked to maternal risk factors and warrant further study; this study focused on adverse fetal and infant outcomes related to diabetes. This chapter explores current literature regarding the impact of diabetes on fetal and infant outcomes, identifies knowledge gaps, and describes the variables of interest for inclusion in this secondary analysis.

Disparities Within the Population Related to Problem

Type 1 Diabetes and Pregnancy

T1DM accounts for 5%–10% of the population with diabetes and is found mostly in young, otherwise healthy individuals who often are of appropriate weight (ADA, 2014; Jovanovic, 2001). Women with T1DM who have a higher BMI or poor glucose control have higher swings in their insulin requirements than those with BMI less than 27, making management a challenge during pregnancy (Jovanovic, 2001). In T1DM, early detection and good control prevent ketoacidosis and microvascular complications in the future (DeFronzo, 2009). People with T1DM are at particular risk for developing diabetic ketoacidosis as autoimmune destruction of insulin-producing beta cells limits insulin production such that insulin administration is required (Atkinson, 2012; Damascenco et al., 2014; De Veciana, 2013; Jovanovic, 2001; Parker & Conway, 2007; Ramin, 1999). However, pregnant women with diabetes are at even higher risk of diabetic ketoacidosis due to metabolism changes of pregnancy,

stress, decreased buffering capacity, and increases in prolactin and cortisol (Chauhan & Perry, 1995; De Veciana, 2013; Parker & Conway, 2007).

Type 2 Diabetes and Prediabetes

T2DM is closely associated with obesity, metabolic disorders, and age, but it has increasingly become an issue for children and young adults, including women of childbearing age (ADA, 2014; Coustan, 2013; DeFronzo, 2009; Magriples et al., 2015; Ryan, 2009; Stuber, 2015). Key features of T2DM, prediabetes, and GDM are insulin resistance (difficulty using insulin) and glucose intolerance (difficulty processing glucose) (ADA, 2014; DeFronzo, 2009). Insulin resistance, a major concern in T2DM and GDM, begins with poor lifestyle choices and genetic predisposition, leading to increased abdominal adiposity and obesity (ADA, 2014; DeFronzo, 2009). Hyperglycemia-driven adaptation of organs can explain diabetes-related changes found throughout the body (DeFronzo, 2009). Diabetes complications from hyperglycemia include nephropathy, neuropathy, cardiovascular disease, and retinopathy (DeFronzo, 2009; Nickens, Long, & Geraci, 2013).

Women with prediabetes, or mild insulin resistance, have shown altered glucose metabolism and insulin resistance not severe enough to be T2DM (Coustan, 2013; DeFronzo, 2009; HAPO, 2008). Prediabetes increases a woman's risk for developing GDM (Coustan, 2013; DeFronzo, 2009; HAPO, 2008).

Gestational Diabetes and Pregnancy

GDM is diagnosed when glucose intolerance and hyperglycemia appear because of metabolic maladaptation during pregnancy (Castorine & Jovanovic, 2011; Coustan, 2013; HAPO, 2008). The added insulin resistance of normal pregnancy leads to hyperglycemia until delivery in women with preexisting insulin resistance (Davis et al., 2007). At the end of the

second and beginning of the third trimester, maternal liver increases glucose production by 15%–30% to meet increased fetal demand needed for growth and brown fat production (Inturrisi & Lintner, 2011). Later identification of insulin resistance gives less time for intervention (Inturrisi & Lintner, 2011).

Testing and treatment for GDM is unique, as GDM-related hyperglycemia resolves with delivery when placental hormones that contributed to insulin resistance in pregnancy are reduced (ADA, 2014, 2015; Coustan, 2013; Hollander, Paarlberg, & Huisjes, 2007). The decision to screen is based on individual risk factors such as age (>25 years), weight, family history, race, and past pregnancies because using just high-risk factors (previous GDM history or BMI over 30) would miss half of the women with GDM (ADA, 2004, 2014; Chong et al., 2014; Coustan, 2013; HAPO, 2008; Hollander et al., 2007). Because of the rise in prediabetes and other metabolic issues, nearly all women will be screened for GDM between 24 and 28 weeks using either a two-step 100-g or one-step 75-g oral oGTT (Table 1; ADA, 2004; Coustan, 2013; HAPO, 2008; Hollander et al., 2007). Early identification and subsequent intervention decrease maternal, fetal, and infant complications, particularly the risk of altered fetal growth (Alunni, Roeder, Moore, & Ramos, 2015; Hartling et al., 2013; Hollander et al., 2007; Seshiah et al., 2008). Nearly 40% of average risk women diagnosed with GDM would meet criteria for diagnosis weeks before the usual testing at 24 weeks' gestation (Hollander et al., 2007; Seshiah et al., 2008). Fetal growth was much higher in women diagnosed after 30 weeks with GDM however there was no increase in fetal growth if the GDM was mild (Seshiah et al., 2008; Palatnik et al., 2015). High-risk women, like those with prediabetes or a history of GDM, should be screened earlier in the pregnancy and then again during the second and third trimesters of pregnancy (Alunni et al., 2015; Chong et al., 2014; HAPO, 2008; Hollander et al., 2007).

Compared to lean women, obese women have a 4 times greater risk for development of GDM, and very obese women are 9 times as likely to develop GDM (Chu et al., 2007; Snapp & Donaldson, 2008). Asian women are at the highest risk for GDM and should be screened with a BMI of 23 rather than a BMI of 25, while Latino and African American women were at moderate risk and Caucasian women at least risk (ADA, 2014; Chong et al., 2014; Coustan, 2013; Mocarski & Savitz, 2012). In Wisconsin, African American and Caucasian women were found to have similar rates of GDM. Native American women in Wisconsin had the highest rates of GDM. Asian women and Hispanic women in Wisconsin had higher rates of preexisting diabetes (Cabacungan, Ngui, & McGinley, 2012).

Several methods for the diagnosis of GDM exist using different variations of the oGTT (Table 1). The newest are the International Association of Diabetes and Pregnancy Study Groups (IADPSG) recommendations, which have been endorsed by the WHO and the American Diabetes Association (ADA, 2014; Trujillo et al., 2015). The IADPSG recommends increasing the number of women diagnosed with GDM by use of the 75-g 2-hour fasting test based on a 75% risk of increased adverse outcomes related to diabetes found in the HAPO (2008) study and other supporting studies (ADA, 2014; Bodmer-Roy, Morin, Cousineau, & Rey, 2012; Ethridge, Catalano, & Waters, 2014; Gui, Li, Su, & Feng, 2014; Trujillo et al., 2015). Nearly one in five women have GDM when newer IADPSG criteria are used (Barbour, 2014).

There are risks and benefits to each of these methods of diagnosis. Although identifying more women with diabetes would lead to more women receiving interventions to control blood glucose levels, more resources would be required, and there may be women who are treated for little benefit or even possible harm from increased stress (Bodmer-Roy et al., 2012; Inturrisi & Lintner, 2011; Mayo, Melamed, Vandenberghe, & Berger, 2015). While there is the potential to

improve outcomes for women and infants, the costs may not justify the increased cost of screening, so the American College of Obstetrics and Gynecologists (ACOG) and most U.S. sites continue to use the two-step procedure (Bodmer-Roy et al., 2012; Inturrisi & Lintner, 2011).

Table 1

Current Thresholds Used in oGTT Tests

		3-hour 100-g oGTT			
	1-hour 50-g screening; if positive, then 3-hour oGTT	O'Sullivan	NDDG	Carpenter & Coustan	2-hour 75-g oGTT (WHO)
Fasting		90	105	95	92
1-hour	>140	165	190	180	180
2-hour		145	165	155	153
3-hour		125	145	140	

Note. Units are mg/dL. NDDG = National Diabetes Data Group; oGTT = oral glucose tolerance test. WHO = World Health Organization. Adapted from "Gestational Diabetes: Detection, Management, and Implications," 1998, by D. B. Carr and S. Gabbe, *Clinical Diabetes*, *16*(1), and *Medical Management of Pregnancy Complicated by Diabetes*, 5th ed., 2013, by D. R. Coustan (Ed.), Alexandria, VA: American Diabetes Association.

In general, HgA1C cannot be used for diagnosis of GDM as rapid changes to a woman's body would not be detected quickly enough with HgA1C (ADA, 2014; Coustan, 2013). Outside of pregnancy, HgA1C is used to diagnose diabetes and helps to predict risk for vascular events, mortality, and microvascular complications in T1DM and T2DM (ADA, 2014; Coustan, 2013; DeFronzo, 2009; Selvin et al., 2011). Most women are healthy when entering pregnancy and may not have had a recent HgA1C to assess for prediabetes or T2DM (O. Langer, 2008). Even when diabetes is preexisting, only 29% of T2DM and 40% of T1DM had a HgA1C just prior to pregnancy (O. Langer, 2008). Currently HgA1C is the best available indicator of potential

adverse maternal, fetal, and infant outcomes in women with preexisting diabetes (Handisurya et al., 2011; Hughson et al., 2014; Rackham, Paize, & Weindling, 2009).

The goal for most people with diabetes is a HgA1C below 6.5% or 7%, but with pregnancy, the goals are lower before and during pregnancy (6% or less) to decrease the complications to woman and fetus (ADA, 2014; Coustan, 2013; Galindo et al., 2006). During pregnancy, HgA1C may still be used as a measure of glucose control in conjunction with testing of blood glucose (Coustan, 2013). However, if mild anemia is present, which frequently happens in pregnancy, the anemia should be corrected before using HgA1C results to manage diabetes; otherwise, blood glucose is used for diabetes management (ADA, 2014; Jovanovic, 2001).

Higher rates of preeclampsia, preterm delivery, fetal macrosomia, birth defects, pregnancy loss and neonatal intensive care unit (NICU) admission are seen when the first-trimester HgA1C is greater than 7% (Galindo et al., 2006; Klemetti, 2016; Rackham et al., 2009). Only 38% of women in the United States had a HgA1C < 7% (O. Langer, 2008). Even women with prediabetes or boarderline GDM had an increased risk of gestational hypertension, cesarean section, large for gestational age (LGA) or macrosomic infants, preterm delivery, and infants with Erb's palsy and NICU admission (Östlund et al., 2003; Ju, Rumbold, Willson & Crowther, 2008; Kwik, Seeho, Smith, McElduff, & Morris, 2007). Women who developed gestational diabetes experienced more cesarean section and pre-eclampsia/eclampsia (Billionnet et al., 2017; Cordero, Paetow, Landon, & Nankervis, 2015). Treatment of mild GDM improves shoulder dystocia, cesearean section, hypertension and macrosomia (Landon et al., 2009). The addition of obesity to GDM results in more adverse outcomes for the pregnancy (O. Langer, 2016; Most & Langer, 2012).

Racial and Ethnic Differences

Race and ethnicity are important risk factors to consider for diabetes and obesity. African American and Caucasian individuals have subtle differences in glycemic markers, implying that there may be a racial difference in metabolic expression (Mocarski et al., 2012; Selvin et al., 2011). African American women's higher glycemic index diets, which are more likely to raise postprandial blood glucose and contribute to obesity, did not explain all the differences (Hu, Block, Sternfeld, & Sowers, 2009). Racial differences in HgA1C are not explained by differences in erythrocyte turnover or hemoglobin; differences in nonfasting blood glucose and postprandial elevation of glucose are present in the African American population (Mocarski et al., 2012; Selvin et al., 2011). African American individuals were found to have higher HgA1C, while people of Asian heritage were considered to have diabetes at lower HgA1C than other ethnic groups (Mocarski et al., 2012).

Rising prevalence of women who are overweight affects women of color more than their Caucasian counterparts (Cabacungan et al., 2012; Hu et al., 2009; Okosun et al., 2004; Selvin et al., 2011). By 2000, 70% of African American women were overweight, compared to 49% of Caucasian women (Okosun et al., 2004; Robbins et al., 2014). On average, 50% of all women 18–44 years old were overweight or obese, with increasing weight corresponding with increasing age or if the woman was Hispanic or African American (Okosun et al., 2004; Robbins et al., 2014). Increased weight increases risk for GDM and other adverse outcomes (Boghossian et al., 2014; Okosun et al., 2004; Robbins et al., 2014).

Maternal morbidity is an important indicator for adverse fetal and infant outcomes. Maternal morbidity encompasses adverse outcomes, including preterm labor, hemorrhage, hypertension in pregnancy, diabetes, infections, cesarean section, and severe perineal lacerations

(Cabacungan et al., 2012). Adverse maternal outcomes occur in higher proportions in non-Caucasian populations and diabetes (Jovanovic et al., 2015; Mascola et al., 2004).

Maternal mortality in the United States has risen over the past 20 years and continues to rise (Nickens et al., 2013). African American women had the highest risk of maternal mortality at 34.8/100,000, while Caucasian women had a rate of 11.3/100,000 (Nickens et al., 2013). African American women had higher rates of diabetes, hypertension, metabolic syndrome, premature delivery and cardiomyopathy (CDC, 2015; Nguyen et al., 2012; Nickens et al., 2013; Potti, Jain, Mastrogiannis, & Dandolu, 2012).

Effects of Diabetes on Maternal Well-Being

Family and Maternal History

The effects of metabolic alterations can be generational and increase the risk of developing diabetes. All women should be assessed for a family or personal history of metabolic syndromes, and risk factors from their own births should be included (Appendix A; Chawla et al., 2014; Coustan, 2013). Women who themselves were small gestational age (SGA) at birth are more likely to develop diabetes during their pregnancies and should be screened earlier in pregnancy (Chawla et al., 2014). When a previous pregnancy was complicated by GDM, a woman's risk of developing diabetes in a subsequent pregnancy is significant, as is the risk for the infant to have anomalous growth patterns (ADA, 2014; Boghossian et al., 2014; Getahun, Fassett, & Jacobsen, 2010; Jones et al., 2012; C. Kim, Newton, & Knopp, 2002; Adams et al., 2015). Native American women can have a 70% chance of having GDM affect another pregnancy (ADA, 2014; Jones et al., 2012; C. Kim et al., 2002). Women who struggled with obesity, sedentary lifestyle, high cholesterol, and high blood pressure had a greater risk of metabolic complications and diabetes (WDHS, 2010). A woman with a first-degree relative with

diabetes or history of GDM should be screened at the first prenatal visit for diabetes, as should the 9%–21% of women who have polycystic ovarian syndrome (PCOS), because insulin resistance along with weight gain is typical of this metabolic syndrome (ADA, 2004, 2014, 2015; Baumfeld et al., 2015; Boghossian et al., 2014; Coustan, 2013; Getahun et al., 2010; Jones et al., 2012; C. Kim et al., 2002).

Maternal Stress and Depression

Maternal stress, depression, and obesity contribute to diabetes development and poor control (Coustan, 2013; Oni, Harville, Xiong, & Buekens, 2015). Stress, diabetes, infection, Western diets, and obesity are some known sources of inflammation; prenatal stress and inflammation have been shown to increase preterm births and decrease birth weights (Davis et al., 2007; Fine et al., 2009; Hobel, 2004; Kachoria & Marseille-Tremblay et al., 2008; Oza-Frank, 2014a, 2014b; Scholl, Chen, Goldberg, Khusial, & Stein, 2011; Sen et al., 2016). Depression has been shown to increase preterm labor, anemia, diabetes, hypertension and cesearean delivery (Bansil et al., 2010; Flynn, McBride, Cely, Wang, & DeCesare, 2015; Sit et al., 2014). Clinically significant depression, outside of pregnancy, affects one out of every four people who have diabetes and has been implicated in poor adherence to diabetes management (Williams, Clouse, & Lustman, 2006). Pregnant women who have chronic illnesses like diabetes have more depression, particularly if their diabetes is poorly controlled (Byrn & Penckofer, 2013; Katon, Russo, Gavin, Melville, & Katon, 2011; Kozhimannil, Pereira, & Harlow, 2009; N. Langer & Langer, 1994). Depression in the antenatal period can lead to issues with maternal and infant attachment (Byrn & Penckofer, 2013; Davis et al., 2007; Lindgren, 2001), preterm birth (Dayan et al., 2006), SIDS (Howard, Kirkwood, & Latinovic, 2007), and developmental delays (Deave, Heron, Evans, & Emond, 2008; Hayden et al., 2012).

The burden of managing a self-care routine for diabetes adds significant stress as women endeavor to maintain normoglycemia (Anderberg, Berntorp, & Crang-Svalenius, 2009; Collier et al., 2011; Delameter, 2006; Hayase, Shimada, & Seki, 2014; Hjelm, Bard, Nyberg, & Apelqvist, 2007; Mersereau, 2010; Nolan, McCrone, & Chertok, 2011; Richmond, 2009). Women have reported that diabetes care and lifestyle management is extremely time consuming, often taking up most of the day (Anderberg et al., 2009; Collier et al., 2011; Mersereau, 2010; Nolan et al., 2011; Richmond, 2009). Through the pregnancy, women have ultrasounds to monitor fetal growth, perform fetal kick counts for assessment of fetal well-being, and monitor blood glucose anywhere from once daily up to 16 times per day (Jovanovic, 2001, 2009).

The sequelae of maternal stress can exert intergenerational epigenetic effects on pregnancy (Fine et al., 2009; Kachoria & Oza-Frank, 2014a, 2014b). Health-related stress from diabetes and stress from racism, poverty, or historical events further challenge women when pregnancy is added (Fine et al., 2009; Oni et al., 2015; Sen et al., 2016). Inflammation and oxidative stress are associated with early loss, prematurity, congenital malformations, intrauterine growth restriction (IUGR), and preeclampsia (Sen et al., 2016; Poston et al., 2011; Rogers et al., 2006). During pregnancy, urban populations and women with high BMI had higher C-reactive protein, a marker for inflammation, which is associated with an increase in preterm delivery and pregnancy-induced hypertension (Al-Gubory, Fowler, & Garrel, 2010; Berglund et al., 2016; Sen et al., 2016). As another example of a stressor women may experience, the more intimate partner violence experienced during pregnancy, the greater is the risk of SGA or low-birth-weight infants and developmental issues (Alhusen et al., 2014).

Management

The goal of hyperglycemia management during pregnancy is normoglycemia, such that adequate but not excessive nutrition is provided for the developing fetus (Castorino & Jovanovic, 2011; Inturrisi & Lintner, 2011). Treatment of hyperglycemia mitigates some of the diabetes-related alterations to both the mother and infant, particularly related to macrosomia and subsequent increases in cesarean section and birth trauma (American College of Obstetricians and Gynecologists [ACOG], 2014; Inturrisi & Lintner, 2011; Östlund et al., 2003). The discovery of insulin and the ability to treat diabetes, plus advances in pregnancy surveillance, have dramatically reduced maternal and fetal mortality from an estimated 44% maternal mortality rate and 60% perinatal mortality rate early in the 20th century to near nondiabetic pregnancy mortality (Coustan, 2013). Use of a low-glycemic-index diet was found to decrease the need for insulin by half without significant compromise of maternal, fetal, or infant outcomes (ADA, 2014; Hollander et al., 2007; Moses, Barker, Winter, Petocz, & Brand-Miller, 2009). Most GDM can be managed with diet and exercise, though some women will require insulin despite excellent lifestyle choices (ADA, 2014; Hollander et al., 2007). Independent of the type of maternal diabetes, there is an increased need for insulin production later in the pregnancy, as the infant grows before delivery (Jovanovic, 2001).

Lifestyle

Lifestyle modifications decrease risk of diabetes-related complications. Positive lifestyle factors, such as not smoking, healthy eating, and moderate exercise of at least 150 min per week, are significantly associated with GDM reduction (Coustan, 2013; Dyck, Klomp, Tan, Turnell, & Boctor, 2002; Leppanen et al., 2014). A lifestyle of physical activity, which increases glucose uptake and decreases insulin resistance, decreases the risk of diabetes and prediabetes for those

who are overweight (ADA, 2015; Coustan, 2013; Oteng-Ntim, Varma, Croker, Poston, & Doyle, 2012). In diabetes, there is reduced uptake of glucose into the muscle cells as muscular insulin resistance increases, leading to elevations in blood glucose (DeFronzo, 2009; Weissgerber, Wolfe, Davies, & Mottola, 2006). Moderate exercises have been shown to decrease blood glucose, regulate pregnancy weight gain, and help maintain normoglycemia; therefore exercise is recommended through pregnancy (Coustan, 2013; Leppanen et al., 2014).

Women's weight, both prepregnancy and gained during pregnancy, is of key importance to maternal, fetal, and infant outcomes (Boghossian et al., 2014; Handisurya et al., 2011; Scifres, Feghali, Althouse, Caritis, & Catov, 2014). In randomized controlled trials, antenatal lifestyle, diet, and activity interventions helped to decrease gestational weight gain and reduce GDM development by 33% but did not necessarily alter birth weight or cesarean delivery (Oteng-Ntim et al., 2012; Rogozinska, Chamillard, Hitman, Khan, & Thangaratinam, 2012; Appendix A). Tomedi et al. (2014) found increases in blood glucose corresponded with steady increases in first-trimester weight. Additionally, the distribution of weight gained in pregnancy, particularly an increase in biceps or triceps skinfold thickness, increased glucose unrelated to BMI (Catov, Abatemarco, Althouse, Davis, & Hubel, 2015; Karachaliou et al., 2015; Tomedi et al., 2014).

Weight Management

The importance of weight control in pregnancy has been highlighted through several studies. Prepregnancy BMI has been positively associated with glucose concentrations and GDM (Black, Sacks, Xiang, & Lawrence, 2013; Tomedi et al., 2014). Nearly 60% of pregnant women with diabetes were classified as overweight or obese (Tomedi et al., 2014). The Institute of Medicine (IOM) has recommended weight gain based on a woman's prepregnancy BMI (Table 2; Black et al., 2013; Harper et al., 2013; Oza-Frank & Keim, 2013; IOM & National Rsearch

Council Committee to Reexamine IOM Pregnancy Weight Guildelines, 2009). Women who were obese or overweight and lost weight, who gained weight of less than 5 kg, or were underweight preprengnacy were more likely to have infants who were SGA, with less fat mass and smaller head circumference (Catalano et al., 2014; Shin & Song, 2015). Women with obesity before pregnancy had similar increases in risk of poor outcomes as those who gained significant weight with pregnancy (Jain, Denk, Kruse, & Dandolu, 2007; N. Li et al., 2013). Most (70.3%) women with pre-GDM gained more than the IOM recommendations for their BMI putting their infants at risk and increasing cesarean section risk (Table 2; Harper et al., 2013; N. Li et al., 2013; Oza-Frank & Keim, 2013; Siegel, Tita, Biggio, & Harper, 2015). Gaining more than 34 pounds of weight during pregnancy, which some 31% of overweight and 27% of obese women did, increased risk of cesarean section, hypertension and macrosomia as well as lowered rates of breastfeeding (Jain et al., 2007; N. Li et al., 2013; Swank et al., 2014). Weight loss during pregnancy is not recommended in women who have a BMI below 35, as it is associated with SGA infants (Asvanarunat, 2014; Oza-Frank & Keim, 2013)

Table 2

Weight Gain During Pregnancy: Institute of Medicine Guidelines

BMI category (kg/m^2)	Weight gain range (lbs.)
Underweight, <18.5	28–40
Normal weight, 18.5–24.9	25–35
Overweight, 25.0–29.9	15–25
Obese (includes all classes), ≥30.0	11–20

Note. BMI = body mass index. Adapted from *Weight Gain During Pregnancy: Reexamining the Guidelines*, 2009, Washington, DC: Institute of Medicine.

Labor Dysfunction and Cesarean Risks

Women with diabetes had increased risk of shoulder dystocia, postpartum hemorrhage, and cesarean delivery, even when compared to their BMI-matched counterparts (Coustan, 2013; Knight, Pressman, Hackney, & Thornburg, 2012; Ray, Vermeulen, Shapireo, & Kenshole, 2001). Even when the provider and patients were blinded to diabetes status, the women with diabetes were 3 times more likely to have arrest of labor necessitating intervention (Acker, Sachs, & Friedman, 1985; Inturrisi & Lintner, 2011; Östlund et al., 2003). The addition of maternal adiposity further increases the risk of labor dysfunction and shoulder dystocia (Acker et al., 1985; Inturrisi & Lintner, 2011). For women with GDM, induction of labor at 38 and 39 completed weeks decreased cesarean rates; however, there is an increased risk of NICU admission with inductions under 39 completed weeks (Melamed et al., 2016; Vilchez, Chelliah, Argoti, Jeelani, & Bahdao-Singh, 2014).

Breastfeeding Challenges

When maternal metabolism and hormones are altered, as in diabetes or PCOS, breast development needed for adequate milk supply can decrease (Stuebe, 2015; Turcksin, Bel, Galjaard, & Devlieger, 2014). Women with gestational diabetes and with higher glucose intolerance were found to have more breastfeeding difficulties (Matias, Dewey, Quesenberry, & Gunderson, 2014; Stuebe, 2015). In the first trimester, women with PCOS, metabolic syndrome, higher BMI, higher fasting insulin, higher blood pressure, or who gained less weight during pregnancy were likely to have minimal changes in breast size, which affected subsequent lactogenesis (Stuebe, 2015). Changes in pituitary- and obesity-related metabolic function alter prolactin response, resulting in later milk production (Inturrisi & Lintner, 2011; Stuebe, 2015). Increases in insulin resistance affected the lactocyte, decreasing milk production (Inturrisi &

Lintner, 2011; Stuebe, 2015). Obesity and overweight were associated with decreased initiation of breastfeeding and shorter duration of breastfeeding; however, women with GDM breastfed at higher rates than nondiabetic women (Johan et al., 2016; Kachoria & Oza-Frank, 2014a, 2014b). African American women who had diabetes or obesity had higher breastfeeding rates than their nondiabetic or obese Caucasian counterparts (Kachoria & Oza-Frank, 2014a, 2014b). However, in women with T1DM, there are lower rates of breastfeeding mostly related to prematurity, neonatal hypoglycemia, and later initiation of feeding (Sparud-Lundin et al., 2011).

Breastfeeding mitigates some of the effects of diabetes women may experience later in life (Kachoria & Oza-Frank, 2014a, 2014b). If lactation does not occur, either through choice, inability, or difficulties with breastfeeding from diabetes-related prolactin changes, fat stores set aside during pregnancy to meet the metabolic needs of the mother during lactation are not used (Kachoria & Oza-Frank, 2014a, 2014b; Stuebe, 2015). These fat stores can lead to increased maternal complications in the future, including hypertension and cardiovascular alterations (Stuebe, 2015). If a woman breastfeeds, her risk of T2DM is lower for up to 15 years after her last delivery (Stuebe, 2015). Blood glucose is lower in women who breastfeed, and HDL cholesterol is higher (Stuebe, 2015). Longer duration of breastfeeding is associated with less metabolic syndrome and slower progression to T2DM in women with GDM (Stuebe, 2015).

Hormonal Changes

Estrogen, progesterone, and prostaglandins increase through normal pregnancy and alter cardiovascular, vascular, and renal performance so that the fetus and the mother have enough resources for metabolism, nutrition, and oxygen demand (Nickens et al., 2013). Diabetes influences hormone interactions, metabolism, and transport (Webber, 2015). Estrogen production is lowered with diabetes-related insulin resistance (Herrera & Desoye, 2016). Women who used

assistive reproductive technology to conceive or who had hormone disorders such as PCOS were much more likely to develop GDM (Luke et al., 2015).

Alterations in insulin, glucose metabolism, and hormone levels resulting from sleep disturbances compound the problems individuals have in maintaining normoglycemia and can lead to the development of diabetes (Izci-Balserak & Pien, 2010; O'Keeffe & St. Onge, 2013; August et al., 2013). Changes in progesterone, a hormone known to cause sleepiness and decreases in REM sleep, plus increases in fetal metabolic needs over time, have been implicated in pregnancy-related sleep disturbances (O'Keeffe & St. Onge, 2013; Santiago, Nolledo, Kinzler, & Santiago, 2001). In addition, sleep is more difficult for pregnant women due to nasal edema, gestational weight gain, and increased urination and fetal movements (Izci-Balserak & Pien, 2010). Glucose levels, risk of GDM, and sleep apnea–related snoring increase when sleep is disturbed (O'Keeffe & St. Onge, 2013; August et al., 2013). For every hour less sleep, there is a 4% increase in glucose; this rise in glucose resolved when hormone balance was restored (ADA, 2014; Reutrakul et al., 2011). In pregnancy, where rapid changes in hormones occur to facilitate fetal development, an increase in sympathetic activity from sleep-disordered breathing and hypoxia causes inflammation and vasoconstriction to rise (Blyton, Sullivan, & Edwards, 2002, 2004; Izci-Balserak & Pien, 2010; Shaw et al., 2008). Pregnancy can alter the hypothalamic–pituitary axis affecting neurohormones such as growth hormone and prolactin (Blyton et al., 2002, 2004; Izci-Balserak & Pien, 2010; Shaw et al., 2008).

Insulin resistance is higher in people with shorter sleep duration, which affects hormone levels, including cortisol and estrogen (Harsch et al., 2004; Izci-Balserak & Pien, 2010). Cortisol, an anti-insulin glucocorticoid hormone necessary for circadian rhythm and increased during times of stress, can increase a woman's risk of developing diabetes (Davis et al., 2007;

DeFronzo, 2009; Larque et al., 2013). When hormones that affect insulin action, such as cortisol, thyroid hormone, and growth hormone, are found in excess, as in cases of stress and diabetes, there is altered insulin regulation and glucose metabolism (ADA, 2014). Exposure to increased glucose or cortisol, whether in utero, childhood, or adulthood, causes physical changes and adds stress on the body and psyche (Davis et al., 2007; DeFronzo, 2009; Tam et al., 2010). Increased cortisol leads to decreased sensitivity to glucocorticoids and problems with glucose and insulin metabolism (Izci-Balserak & Pien, 2010; Meerlo, Sgoifo, & Suchecki, 2008). Glucocorticoids, administered in pregnancy to help develop fetal lungs or treat autoimmune disorders, also increase maternal glucose levels by decreasing the action of insulin (ADA, 2004; Izci-Balserak & Pien, 2010; Meerlo et al., 2008).

During normal pregnancy, increases in glomerular filtration rate and urine glucose and decreases in urea nitrogen, sodium, uric acid, and creatinine are needed to accommodate the vascular, fluid, and cardiac changes of pregnancy (Gyamlani & Geraci, 2013; Stratta, Canavese, & Quaglia, 2006). Additionally, the kidney enlarges by 1–1.5 cm, and there is increased permeability of renal capillaries, which allows more protein to be excreted in about 40% of normal pregnancies (Appendix A; Gyamlani & Geraci, 2013; Stratta et al., 2006).

Women with diabetes and kidney disease should be closely monitored for glucose control before pregnancy to decrease maternal, fetal, and infant complications that can result from renal disease (Fischer, Lehnerz, Hebert, & Parikh, 2004; Gyamlani & Geraci, 2013; Kendrick et al., 2015; Reece, Leguizamon, & Homko, 1998; Stratta et al., 2006; Yogev, Chen, Ben-Haroush, Hod, & Bar, 2010). The prevalence of nephropathy and microalbuminuria, indicative of chronic renal disease, was similar for women with T1DM and T2DM before they became pregnant regardless of HgA1C (Damm, 2013; Reece et al., 1998). African American women have more

diabetic nephropathy than other women or African American men (Crook, Woffor, & Oliver, 2003). Women with chronic renal disease had higher adverse maternal outcomes (11.5% vs. 2% in one study) and poor fetal outcomes twice that of the control (Fischer et al., 2004; Nevis et al., 2011; Stratta et al., 2006). Pregnancies affected by kidney disease without hypertension resulted in 32% of women suffering fetal or infant loss versus 7% of controls and increased SGA infants (Haeri, Khoury, Kovilam, & Miodovnik, 2008; Holley et al., 1996). Women with diabetes are at risk for increases in serum creatinine from declines in kidney function; baseline labs are necessary to distinguish preexisting proteinuria from preeclampsia in women with diabetes (Damm, 2013; Jones & Hayslett, 1996). Women with diabetes and moderate to severe kidney disease who had hypertension or high proteinuria had higher preterm delivery and preeclampsia and had declines in renal function; additionally, women with creatinine 3 or greater had a higher risk of renal failure (Gyamlani & Geraci, 2013; Jones & Hayslett, 1996; Khoury et al., 2002; Stratta et al., 2006; Yanit, Snowedn, Cheng, & Caughney, 2012).

Cardiovascular and Hematologic Alterations

Women experience vascular changes, increases in blood volume, and altered lipid distribution to support the growing fetus during normal pregnancy (Gongora & Wenger, 2015; King, Gerich, Guzick, King, & McDermott, 2009; Mudd, Holzman, & Evans, 2015). When pregnancy, a hypercoagulable state, is added to obesity, which upregulates coagulation factors and increases inflammation, the pregnant obese woman is at a higher risk for thromboembolism and pulmonary embolism (Alessi & Juhan-Vague, 2008; Huda, Brodie, & Sattar, 2010). African American women are significantly more likely to die from a pregnancy-related issue like hypertension and thromboembolic events than Caucasians, with obesity and diabetes increasing the risk of these events (Mascola et al., 2004).

GDM has been added to the cardiovascular risk assessment of the American Heart Association in acknowledgment of the permanent effects of hyperglycemia on microvasculature (Gongora & Wenger, 2015). Obesity and diabetes contribute to heart disease prevalence and are two of the highest risk factors other than smoking in the development of heart disease (Nickens et al., 2013). Women with altered glucose metabolism continue to have increased LDL at 3 months postpartum (Gongora & Wenger, 2015). Women with GDM are at risk for developing cardiovascular disease even if they do not develop T2DM later in life (Gongora & Wenger, 2015; King et al., 2009).

Heart rate increases over the pregnancy after an early rise in cardiac output and stroke volume (Nickens et al., 2013). Women with diabetes have an inability to adapt to metabolic and hemodynamic changes of the pregnancy, which increases pregnancy-related hypertension disorders and preterm birth (Gongora & Wenger, 2015). When combined with preexisting cardiovascular issues, the changes of pregnancy increase perinatal morbidity and mortality (Nickens et al., 2013). It is estimated that 10.1% of women aged 20–39 and 34.4% of women aged 40–59 already have cardiovascular disease (Nickens et al., 2013).

Preeclampsia is the third leading cause of maternal death, is known to put the woman at risk for cardiovascular events later in life, and can impact fetal outcomes particularly through prematurity (Lisonkova & Joseph, 2013; Owens et al., 2010). Higher glucose, as can be detected by HgA1C, was also predictive of vascular change and complications of pregnancy like preeclampsia (HAPO, 2010). This positive association between rising maternal glucose and preeclampsia was seen even in the absence of GDM (HAPO, 2008). Risk factors for preeclampsia include increased BMI, history of diabetes, and elevated blood pressure through the pregnancy (Goel et al., 2015; James-Todd, Janevic, Brown, & Savitz, 2014; Knight et al., 2012;

Lisonkova & Joseph, 2013; O'Brien, McCarthy, Gibney, & McAuliffe, 2014). With every 5–7 kg/m^2 increase in BMI, the risk of preeclampsia doubled (O'Brien et al., 2014).With intensive therapy for diabetes, the risk of preeclampsia decreased in women who had GDM (Alwan et al., 2009).

Advanced glycation end products (AGE) are associated with insulin resistance and vascular complications (Guosheng et al., 2009). Women with GDM had higher concentrations of AGEs, even with acceptable glucose control (Guosheng et al., 2009). Women with GDM who had the highest AGEs experienced increased congenital malformations and stillbirth (Guosheng et al., 2009).

Summary of the Effects of Diabetes on Maternal Well-Being

Diabetes affects the woman and her pregnancy in a myriad of ways. Pregnancy complications, such as cesarean section, severe perineal lacerations, and arrest of labor, are seen more often in pregnancies with diabetes. Hypertension, heart disease, hyperlipidemia, decreased lactogenesis, preeclampsia, thromboembolism, and stroke in pregnancy have all been linked with diabetes. In addition, a woman's weight can increase due to insulin resistance or administration of insulin.

Despite recent advances, there is still work to be done to understand and optimize outcomes for the woman, fetus, and infant. Better understanding of the impact of hyperglycemia for both the woman and child continues to be explored (Hillier et al., 2007).

Effects of Diabetes on the Developing Fetus and Infant

Maternal increases in blood glucose are related to clinically important disturbances in the fetus, leading to adverse fetal and infant outcomes (HAPO, 2008). Infants born to women with diabetes have more prematurity, respiratory difficulties, birth trauma, fetal cardiac

malformations, shoulder dystocia, accelerated fetal growth, NICU admission and hypoglycemia (Billionnet et al., 2017; Cordero et al., 2015; Kwik et al., 2007; Russell et al., 2009).

Risk of Stillbirth/Fetal Death

Poor maternal glycemic control and fetal macrosomia are two risk factors for fetal death at the end of the third trimester; therefore normoglycemia is desired (Inturrisi & Lintner, 2011). Women with T1DM or T2DM before pregnancy were nearly 5 times more likely to have a stillbirth; women with more diabetes-related complications prepregnancy had the greatest stillbirth risk (Hawdon, 2011; Klemetti et al., 2016). Obesity alone or overweight with weight gain outside the IOM recommendations increased risk of neonatal and infant death as compared to normal-weight counterparts with similar weight gain (Chen, Feresu, Fernandez, & Rogan, 2009). Underweight women, particularly those who did not gain recommended amounts in pregnancy, also have an increased risk of fetal death with an odds ratio even higher than that of obese women (Chen et al., 2009). Regardless of diabetes status, obese women and obese women with the highest weight gain had the most risk for neonatal death from respiratory conditions, birth defects, and postnatal SIDS (Chen et al., 2009; Gaudet, Wen, & Walker, 2014).

Epigenetic Changes and Congenital Anomalies

In the United States, congenital anomalies are the leading cause of infant mortality; 1 in 33 newborns have congenital anomalies that contribute to morbidity and mortality (Webber, 2015). A combination of maternal genetics and environmental influences including diabetes directs fetal DNA expression and embryogenesis (Januar, Desoye, Novakovic, Cvitic, & Saffery, 2015; Webber, 2015). These changes in DNA expression affect the intrauterine environment, alter infant outcomes, and influence generational genetics (Januar et al., 2015; Webber, 2015). Congenital anomalies are rarely explained by one pathway but instead result from a combination

of epigenetics, genetics, environment, and hormones (Webber, 2015). It is well documented that women with diabetes, even when well controlled, are at higher risk for birth anomalies and genetic malformations (Coustan, 2013; Siegel, 2015; Webber, 2015; Yang, Cummings, O'connell, & Jangaard, 2006). Additionally, the higher the average maternal blood glucose, the more birth anomalies are present (Reece, 2008). The highest risk for birth defects is in women with preexisting diabetes who have poor glycemic control in the first trimester rather than women with GDM; however, more chromosomal anomalies are seen in infants born to women with GDM than those who do not have diabetes (Allen et al., 2007; Anderson et al., 2001; Moore, Allshouse, Post, Galan, & Heyborne, 2015; Ray et al., 2001; Reece, 2008). The metabolic effects of diabetes occur well before diabetes appears in any measurable way, influencing organogenesis and increasing the risk of congenital anomalies (Anderson et al., 2001; Jovanovic et al., 2015). Infants born to women with any diabetes have a higher risk of T2DM and obesity throughout their lives due to epigenetic changes (McClearly-Jones, 2011).

Four percent of pregnancies affected by diabetes had one or more major congenital anomaly, double the risk compared to those without diabetes (Hawdon, 2008). Similarly, there is more risk of anomalies with rising obesity rates related in part to minor abnormalities in glucose metabolism and undiagnosed diabetes (Reece, 2008). Multiple defects are observed more frequently in fetuses born to obese mothers (Allen et al., 2007; Moore et al., 2002; Reece, 2008). Maternal obesity is a significant risk factor for birth defects like omphalocele, cardiac defects, ancephaly, spina bifida, and hydrocephaly (Appendix A; Anderson et al., 2001; Reece, 2008). The odds ratios for ancephaly, spina bifida, and hydrocephaly were highest for women who were both obese and had diabetes (Anderson et al., 2001). Women without diabetes who reported high sugar intake before conception had increases in birth defects, such as neural tube defects, and

infant weight at 6 months (Phelan et al., 2011; Reece, 2008; Shaw et al., 2003). Therefore researchers continue to look at physiologic pathways for effects on fetal development (Shaw et al., 2003).

Changes to Organs and Other Systems

Infants of women with diabetes may have underregulation and overregulation of both nutrients and genetic expression, resulting in altered, often immature organ systems (Silveira, Portella, Goldani, & Barbieri, 2007). GDM affects the neuromotor function of the infant, causing decreased coordination of sucking and swallowing, as might be seen in a more premature infant (Bomiker et al., 2006). Hyperbilirubinemia, which is an elevated bilirubin often related to immature liver function, increased along with increasing glucose level at subclinical levels (HAPO, 2008; Knight et al., 2012). The fetuses of women with diabetes are at higher risk for developing an enlarged heart, liver, and adrenal glands as they attempt to adapt to hyperglycemia (Coustan, 2013). The infants of women with diabetes are at risk for cardiovascular complications, including perinatal arterial ischemic stroke, which increases cerebral palsy risk (Darmency-Stamboul et al., 2012).

Infants born to women with diabetes are at higher risk of respiratory complications due to alterations in surfactant, higher rates of preterm birth, and altered metabolic patterns (Boghossian et al., 2014; Knight et al., 2012; Tyden, Eriksson, & Berne, 1986;). Infants born to mothers with diabetes have more incidence of idiopathic respiratory distress syndrome (RDS) even at term (Boghossian et al., 2014; Knight et al., 2012; Tyden et al., 1986). The hyperglycemia of diabetes and the fetal response to the hyperglycemia cause a delay in fetal lung development (Bourbon & Farrell, 1985). Also, poor utilization of pulmonary glycogen contributes to decreased surfactant (Tyden et al., 1986).

For infants of mothers with diabetes, respiratory distress is seen when maternal diabetes has been uncontrolled or steroids were not used in preterm delivery to encourage lung maturation (Bental et al., 2011; Longo et al., 2013; Stanescu, 2014). With improvement in treatment and diagnosis of diabetes, as well as increased fetal surveillance, the rates of RDS have decreased significantly over the past century (Bental et al., 2011).

Women who had diabetes were more likely to have steroids completed before delivery, which is a treatment known to improve infant outcomes related to respiratory distress (Bental et al., 2011). Insulin inhibits surfactant proteins from accumulating, so infants of women with diabetes who produced increased amounts of insulin to compensate for maternal hyperglycemia may have more respiratory distress (Bental et al., 2011). It is important to note that growth-restricted infants do not always respond as well to steroids; growth-restricted infants have higher stress levels already, and the addition of steroids may not accelerate fetal lung development (Longo et al., 2013). Excellent glucose control allows the fetal lungs to mature almost normally and lessens fetal alterations to other organs (Tyden et al., 1986).

Placental Changes

Pregnancy creates a state of normal maternal insulin resistance to support the developing fetus and regulate the intrauterine environment. This desired maternal insulin resistance helps to optimize fetal development by supporting placental growth and nutrition exchange, altering maternal physiology, and maintaining hormonal changes of pregnancy (Januar et al., 2015). Intensive glucose monitoring is needed to maintain normoglycemia as maternal insulin needs increase with fetal growth (O. Langer, 2008). The placenta is the conduit for the developing fetus to receive nutrients for growth; it also provides protection for the fetus from the surrounding environment, produces hormones and regulates hormone interactions, and can alter the

expression of fetal DNA to optimize fetal outcomes (Januar et al., 2015; Larque et al., 2014; Larque et al., 2013; Marconi et al., 1996). Glucose, in conjunction with lipid metabolism, is a main source of energy for the growing fetus (Desoye, Gauster, & Wadsack, 2011; Larque et al., 2013). Glucose is transported across the maternal–fetal concentration gradient of the placenta along with amino acids through receptors, altered transport proteins, and enzymes (Desoye et al., 2011; Larque et al., 2013). Diabetes, particularly with uncontrolled hyperglycemia, impairs the ability of the placenta to regulate nutrients and can alter the placental structure (Coustan, 2013; Huynh et al., 2013; Weissgerber et al., 2006).

Nutrient transport mechanisms are not altered in diabetes, but the number and location of receptors, and the increase or decrease of placental sensors, alter the function of the gradient when diabetes is present (Desoye et al., 2011). As the pregnancy proceeds, there is an increase in maternal–fetal glucose concentration that is rate limited by glucose transporter 1 (GLUT1) receptors on the fetal side of the placenta in diabetes and the maternal side in normal pregnancy (Baumann, Deborde, & Illsley, 2002; Edu et al., 2016; Larque et al., 2013; Marconi et al., 1996). It is thought that activation of these sensors is increased when the woman is obese or has diabetes, as the placentas of infants born to women with diabetes tend to be large (Larque et al., 2013). The placenta can show villous immaturity in diabetes, limiting the placenta's ability to accommodate fetal growth (Edu et al., 2016; Huynh et al., 2013). Villous immaturity is linked with fetal mortality and is indicative of a more hypoxic environment (Edu et al., 2016; Huynh et al., 2013). The placentas of women with GDM were found to be larger at weeks 24–28, with most having pathological changes, indicating premature aging from oxidative stress (Edu et al., 2016). Placentas of women with diabetes can have evidence of chorangiosis, or an overgrowth of blood vessels, which can be a sign of hypoxia and is associated with a higher percentage of

fetal mortality and morbidity (Altshuler, 1984; Amer & Heller, 2010). Choriangiosis has been implicated in up to 39% of fetal demises and in over 40% of major malformations, as well as placental abruption and nuchal cord (Altshuler, 1984; Franciosi, 1999). Pro-inflammatory cytokines, from the placenta known as exosomes, are higher in pregnancies affected by diabetes (Salomon et al., 2016). Placental transport of homocysteine, a marker of inflammation, is associated with poor fetal outcomes when maternal levels are high (Larque et al., 2013).

The placenta does not allow insulin or hormones to cross into fetal circulation; the fetus itself produces insulin starting between weeks 9 and 12, and the placenta makes hormones in response to changes in the maternal environment or fetal demands (Larque et al., 2013). Glucose concentrations in the fetus are 15%–20% lower than in the maternal circulation (Dabelea & Crume, 2011; Inturrisi & Lintner, 2011; Pantalone, Faiman, & Olansky, 2011). Women with T1DM and T2DM have similar outcome risks, but the infants of women with T1DM or uncontrolled T2DM are more likely to have hypoglycemia (Handisurya et al., 2011). Maternal hyperglycemia is passed to the fetus through the placenta, causing the fetal β cells to be stimulated and produce excess insulin (Dotsch, Plank, & Amann, 2012). Hyperinsulinemia leads to an increased uptake of glucose in the cells, resulting in macrosomia (Dotsch et al., 2012). The excess insulin produces additional stimulation of insulin receptors in the brain, which leads to a programming of the hypothalamic regulation of appetite and energy expenditure throughout the child's life (Dotsch et al., 2012).

Nutrient sensors located in the placenta are regulated by insulin, oxygen, and amino acids (Larque et al., 2013). The placenta contains many more amino acids than maternal or fetal circulation and plays a large role in amino acid exchange to meet the needs of the fetus (Larque et al., 2014; Larque et al., 2013). Changes in maternal insulin and hormones can cause

overactivation of placental transport when the mammalian target of rapamycin (mTOR) sensor is triggered, which increases cell growth and alters metabolism (Larque et al., 2013). mTOR is decreased when nutrient and oxygen levels are low, leading to growth-restricted infants; activation of the mTOR leads to large infants (Larque et al., 2013). Growth-restricted infants have less adaptable placentas, further increasing their risk for hypoxic episodes (Weissgerber et al., 2006).

Increased transport of lipids across the placenta in pregnancies affected by diabetes contributes to differences in fetal development and size (Desoye et al., 2011; Marseilles-Tremblay et al., 2008; Pagan et al., 2013). In the last months of pregnancy, maternal cholesterol and cholesterol produced by the placenta are used for progesterone production needed to sustain the pregnancy and support breast changes for lactogenesis (Larque, Ruiz-Palacios, & Koletzko, 2013). When lipoprotein or amino acid transport is altered, growth-restricted and SGA infants are seen, though the mechanism is not completely understood (Larque et al., 2013).

Maternal overnutrition, seen in obesity and metabolic conditions, can affect the placental uptake of fatty acids (Larque et al., 2013). The change in fatty acid uptake causes an alteration in the content of triglycerides in the placentas of pregnancies affected by diabetes (Larque et al., 2013). In pregnancies with diabetes, the placenta had higher lipid accumulation (Larque et al., 2013). In infants born to women with diabetes, there is a problem with fatty acid transfer leading to less docosahexaenoic acid (DHA; Larque et al., 2013). Fatty acids such as DHA are critical to brain and organ development throughout pregnancy, and any alteration can be problematic for the future (Hiersch & Yogev, 2014; Larque et al., 2013). There are ongoing studies regarding the functions of other lipids and proteins that have just been identified in placental tissue (Larque et al., 2013).

Kidney Alterations

There is a lack of information about kidney alterations of the fetus in conditions such as diabetes (Dotsch et al., 2012). Women with diabetes have higher rates of preeclampsia and alterations in amniotic fluid, which indicates alterations in fetal kidney function/vascularization and increases potential for early delivery compared to their counterparts without diabetes (Knight et al., 2012). Women with diabetes are more likely to experience oligohydramnios, which is low amniotic fluid, a sign of fetal kidney dysfunction, and poor regulation of fluids (Cabacungan et al., 2012). Higher levels of renal dysfunction are seen in infants of T1DM as they become adults (Khalil et al., 2010). Khahil et al. proposed that there may be less development of nephrons in infants of women with diabetes, leading to glomerular and vascular issues in the future.

Maternal kidney disease, which can occur from diabetes, hypertension, or other pathology, puts the fetus at risk, particularly if the maternal kidney disease is moderate or severe (Fischer, 2007). With mild maternal kidney disease, preterm delivery increased (19%) and fetal loss increased to 21%; with moderate kidney disease, preterm delivery was seen in 55% of women, and fetal loss increased to 27% (Imbarcati & Ponticelli, 1991).

Nervous System and Neurodevelopment

Alterations in brain development from a poor intrauterine environment can have long-term effects (Xu, Jing, Bower, Liu, & Bao, 2014). Obesity and diabetes have an additive effect on complications of the neurologic system due to alterations in fatty acid uptake needed for brain development (Anderson, 2001; Larque et al., 2013). An important alteration seen in placentas of women with GDM is a decrease in DHA, which is necessary for neurodevelopment (Pagan et al., 2013). Glucocorticoids like cortisol are thought to program the fetal brain and influence behavior because of their regulation of the hypothalamic–pituitary–adrenocortical (HPA) axis (Davis et

al., 2007). The level of maternal cortisol in the third trimester (30–32 weeks' gestation) was inversely linked with maternal–infant bonding ability (Davis et al., 2007). Autism spectrum disorders are associated with diabetes during pregnancy (M. Li et al., 2016; Xu et al., 2014).

Hypoglycemia can also cause changes in the neurologic system of the infant as the brain requires glucose for energy (Adamkin & Committee on Fetus and Newborn, 2011). Neurologic symptoms in the infant, including tremors, jitteriness, cyanosis, seizures, apneic episodes, tachypnea, weak or high-pitched cry, floppiness or lethargy, poor feeding, and eye rolling, should be addressed immediately (Adamkin & Committee on Fetus and Newborn, 2011). Seizures occur after prolonged hypoglycemia and are indicative of repetitive hypoglycemia insults (Adamkin & Committee on Fetus and Newborn, 2011). Seizures can lead to serious neurologic damage (Adamkin & Committee on Fetus and Newborn, 2011).

Musculoskeletal Effects and Altered Fetal Growth

An excessive intake of nutrients by the mother or increased placental transfer of nutrients from diabetes increases insulin and insulin-like growth factors that promote broader shoulders and more abdominal fat in the fetus (Acker et al., 1985; Bogaerts et al., 2013; Bollipalli, Dolan, Miodovnik, Feghali, & Khoury, 2010; Brett et al., 2014; El-Masry, El-Ganzoury, El-Farresh, Anwar, & Abd Ellatife, 2013; Fall, 2013, 2015; Inturrisi & Lintner, 2011). Increased birth weight and risk of shoulder dystocia from difficult deliveries was seen with increased maternal glucose before threshold criteria for GDM were met (HAPO, 2008; Kieffer et al., 2006). In the infant, shoulder dystocia can lead to brachial plexus injury, broken clavicles, increased bruising, and decreased oxygenation at the time of delivery and constitutes an obstetrical emergency (Alwan et al., 2009; Cheng et al., 2006; Ray et al., 2001). Therapy to treat GDM has significantly decreased perinatal morbidity from clavicle fracture, nerve palsy, death, and shoulder dystocia as well as

decreased birth weight; however, current recommendations have increased cesarean section and NICU admissions (ACOG, 2014; Alwan et al., 2009; Catalano & Sacks, 2011).

Diabetes can result in either LGA or SGA infants, depending on maternal control of diabetes and alterations to maternal physiology and placenta. SGA and LGA are determined using growth charts based on early ultrasounds for dating and a diverse population (Duryea, Hawkins, Mcintyre, Casey, & Leveno, 2014). Higher proportions of full-term SGA and LGA infants are born to women with uncontrolled diabetes than AGA infants (Catalano et al., 2012; El-Masry et al., 2013). Macrosomia was seen more in infants exposed to T2DM during pregnancy, while SGA was found more in infants exposed to T1DM during pregnancy (El-Masry et al., 2013; Handisurya et al., 2011).

When maternal intake or placental transfer of nutrients does not provide needed energy for the developing fetus as in diabetes, the fetus alters growth to ensure adequate nutrition for developing organs, resulting in SGA infants (Brett et al., 2014; Chawla et al., 2014). Diabetes-linked SGA increased for all women but was higher for African American and highest for Mexican American women (Chawla et al., 2014). Women who were born SGA themselves are at higher risk for developing diabetes throughout their lives and during pregnancy (Chawla et al., 2014). In a study by Bental et al. (2011), there was not a significant change in infant outcomes for infants born to mothers with or without diabetes who were very low birth weight.

Most infants born to women with diabetes have an increased risk of cesarean delivery related to accelerated growth, leading to alterations in body proportions, particularly broader shoulders, larger head circumference, increased weight, and increased length (Coustan, 2013; HAPO, 2008; Khalak, Cummings, & Dexter, 2015; Persson, Norman, & Hanson, 2009; Persson, Pasupathy, Hanson, & Norman, 2012). The risk of having a LGA or macrosomic infant increased

with increasing maternal BMI and elevated 2-hour oGTT glucose level (Athukorala et al., 2007; Berntorp, Anderberg, Claesson, Ignell, & Kallen, 2015; Catalano et al, 2012; Gaudet, Wen, & Walker, 2014). There is an increase in macrosomia and LGA as weight gain during pregnancy increases, even if the woman's diabetes is well controlled (Cheng et al., 2008; Esakoff, Cauphey, Block-Kurbisch, Inturrisi, & Cheng, 2011; Scifres et al., 2014; Siegel, Tita, Biggio, & Harper, 2015). Macrosomia increases the risk of adverse outcomes such as hypoglycemia, respiratory distress, shoulder dystocia, and Erb's palsy (Esakoff et al., 2011). An infant can also be at risk for becoming LGA simply because the woman once had GDM in the past (Boghossian et al., 2014). For GDM, exercise can mediate the size of the infant and decrease LGA infants (Catalano et al., 2003; Snapp & Donaldson, 2008).

Acid/Base Alterations and Electrolyte Imbalances

Electrolytes and pH can be affected by diabetes. Infants born to mothers with GDM are more likely to have hypocalcemia and altered sodium metabolism with insulin resistance (Catalano et al., 2003; Steinberger & Daniels, 2003). Alterations in potassium seen in hyperglycemia have the potential to cause arrhythmias for both fetus and woman (de Veciana, 2013; Kitzmiller, 1982). When nonreassuring fetal heart tracings occur, umbilical cord blood pH becomes more acidic; more severe acidosis is found in infants born to women with well-controlled diabetes than in infants born to women without diabetes (Reif et al., 2013). Acidosis causes the fetus to compensate to avoid asphyxia (Reif et al., 2013). Increased fetal distress on tracings when the mother had diabetic ketoacidosis was likely related to lactic acidosis and hypoxia (de Veciana, 2013).

Hypoglycemia

Neonatal hyperinsulinemia can result in transient hypoglycemia the first day or two of life as the newborn adjusts to glucose intake from feeding rather than the placenta (Hawdon, 2008). The infant makes his or her own insulin, so after the umbilical cord is cut and maternal glucose is no longer provided, the infant experiences a delay in downregulation in insulin production (Coustan, 2013; Longo et al., 2013; Younwainichsetha & Phumdoung, 2013). This mistiming of glucose and insulin leads to hypoglycemia after delivery. Newborn hypoglycemia is linked with increased maternal BMI and diabetes (Coustan et al., 2013; Longo et al., 2013; Suk, Kwak, VanHorn, Salafia, & Narula, 2015; Younwainichsetha & Phumdoung, 2013). Infants born to women with T1DM are particularly vulnerable to hypoglycemia due to the use of insulin (Hawdon, 2008). Monitoring of blood glucose starts 3–4 hours after birth, as all infants have a decrease in blood glucose until they eat and the pancreas adjusts insulin levels to extrauterine life (Hawdon, 2008; Sweet, Grayson, & Polak, 2013). Clinical signs of hypoglycemia, such as poor feeding, low tone, shakiness, lethargy, and apnea, should be treated to bring the blood glucose to a level where there are no longer any clinical symptoms (Adamkin & Committee on Fetus and Newborn, 2011; Hawdon, 2008; Sweet et al., 2013; Youngwanichsetha & Phumdoung, 2013).

Alterations in the woman's milk production or the infant's ability to breastfeed can compromise infant well-being. Infants born to mothers with GDM, particularly if GDM was treated with insulin, demonstrated fewer feeding bursts and fewer overall sucks at the breast (Bromiker et al., 2006). Infants who are breastfed have lower rates of hypoglycemia and require less glucose therapy (Fallon, 2015). At times, formula should be used when the infant is unable to raise glucose through breastfeeding; however, formula feeding can affect frequency and

production of breastmilk in women who may already have some challenges to lactogenesis (Hawdon, 2008; Stuebe, 2015).

Poor Transition to Extrauterine Life or Neonatal Intensive Care Unit Admission

APGAR scoring is a simple test used to evaluate newborn transition to extrauterine life within the first few minutes using heart rate, response to stimuli, strength of cry, muscle tone, and respiratory effort (Coustan, 2013). The infant with low APGAR scores is not compensating well for the stress of birth and is demonstrating poor transition to extrauterine life (Coustan, 2013). Low APGAR scores, seen more in obese women's infants, infants of women with diabetes, and premature infants, are linked with adverse fetal outcomes (Coustan, 2013; Ipekci et al., 2015).

Increases in maternal glucose, even below the threshold for diabetes, are correlated with issues transitioning to extrauterine life and admission to the NICU (HAPO, 2008; Knight et al., 2012). Increased maternal BMI, a risk factor in the development of diabetes, is independently associated with NICU admission and sepsis (Suk et al., 2015; Rastogi, Rojas, Rastogi, & Haberman, 2015). With higher RDS, sepsis, and prematurity rates, infants of women with diabetes can require more support to transition to extrauterine life and have higher intubation rates (Boghossian et al., 2014; Cordero et al., 2015; Knight et al., 2012). Premature delivery increased with increasing maternal plasma glucose levels (HAPO, 2008). Growth-restricted and SGA infants are at higher risk for neurodevelopmental problems around thermoregulation and glucose control and may need time in a NICU incubator until they can maintain a normal temperature and adequate blood glucose (Hawdon, 2008). Growth-restricted infants also experience hematologic and metabolic disturbances and are more likely to experience

retinopathy of prematurity and necrotizing enterocolitis (Coustan, 2013; Hawdon, 2008; Longo et al., 2013).

Delivery Method

Most infants born to women with diabetes do well after birth with evidence-based management strategies that reduce risk of complications. There was a significant increase in cesarean deliveries for infants of women with diabetes, which lowers the risk of birth trauma, stillbirth and chorioamnionitis. (ACOG, 2014; HAPO, 2008; Niu et al., 2014; Stanescu & Stoicescu, 2014). Clinical decisions about route and timing of delivery can be influenced by the measurement of fetal proportions due to concern for shoulder dystocia and arrest of labor (ACOG, 2014; Catalano & Sacks, 2011; Coustan, 2013; HAPO, 2008; Persson et al., 2009; Persson et al., 2012). For every 1 standard deviation rise in maternal blood glucose, there was an increase in primary cesarean section by 8%–11%, in part due to accelerated fetal growth (HAPO, 2008). It is thought that infants born by cesarean section to women with diabetes are at increased risk for diabetes and allergy in later life because the infants have not been colonized with bacteria through a vaginal birth, necessary for proper development of a healthy immune system (Coustan, 2013).

Sex-Based Alterations

Interesting new studies have emerged that evaluate pregnancy and fetal outcomes by fetal sex. Male infants born to women with diabetes have higher risk of cesarean section and hypoglycemia than males who are not exposed to maternal diabetes (Tundidor et al., 2012). Researchers have reported that male infants had higher rates of cord problems, nonreassuring fetal heart rate, acidemia, GDM exposure, cesarean section, macrosomia, and low APGAR scores as well as preterm birth and infant mortality, though more study is needed (Aibar, Puertas,

Valverde, Carrillo, & Montoya, 2012; Ricart et al., 2009; Sheiner et al., 2004; Vattenn & Skjaerven, 2004). In animal models, there were significant differences in puberty onset and testicular development when exposed to high glucose in utero (Amorim et al., 2011; Januar et al., 2015; Padmanabhan, Cardoso, & Puttabyatappa, 2016; Zambrano, Guzman, Rodriguez-Gonzalez, Durand-Carbajal, & Nathanielsz, 2014).

Summary of the Effects of Diabetes on Fetal and Infant Outcomes

Adverse fetal and infant outcomes during a pregnancy complicated by diabetes occur due to complex alterations in the fetus's ability to adapt to hyperglycemia. When diabetes is poorly controlled during pregnancy, there are significant risks for adverse perinatal outcomes like macrosomia, neurodevelopmental delays, disordered cognitive and intellectual performance in the infant, hypoglycemia, jaundice, and stillbirth (Gonzalez-Quintero, 2007; HAPO, 2008; Inturrisi & Lintner, 2011; Rizzo, Metzger, Burns, & Burns, 1991; Rizzo, Metzger, Dooley, & Cho, 1997; Silverman, Metzger, Cho, & Loeb, 1995; Silverman et al., 1991). Even with good maternal glycemic control, there are increased risks to the woman and to the infant with increasing glucose levels and insulin resistance (Coustan, 2013; HAPO, 2008; Inturrisi & Lintner, 2011, O. Langer, 2016). If diabetes was well controlled, the risk of having LGA infants remained high for all women with diabetes but was higher for those with T2DM in pregnancy (Park & Kim, 2015). Maternal diabetes increases the fetal risk for stillbirth, birth defects, over- and undernourishment, altered development, preterm birth, and hypoxia, while also increasing infants' risk for hypoglycemia, hyperbilirubinemia, NICU admission, respiratory distress, bonding issues, feeding difficulty, and birth trauma (Hollander et al., 2007). Maternal obesity increases the fetal and infant risk for compromise, low APGAR scores, meconium in utero, and increased NICU admission (Appendix A; Heslehurst et al., 2008).

Future Risks of Diabetes

Weight gain, increased BMI, and diabetes during pregnancy are all important factors that can contribute to an altered life course trajectory for the woman and infant. The risks of diabetes on health of the child do not end shortly after birth. As the child grows, the influence of diabetes on fat deposition, future development of diabetes, and metabolic syndrome becomes more apparent (Boney, Verma, Tucker, & Vohr, 2005; Hiersch & Yogev, 2014; Vohr & McGarvey, 1997). Exposure to diabetes puts the infant at higher risk for obesity, hypertension, T2DM, and cardiovascular disease for the rest of his or her life and can affect his or her future progeny (Boney, Verma, Tucker, & Vohr, 2005; Fall, 2013, 2015; Shifres et al., 2014). Being born SGA or LGA increases the risk of developing T2DM over a lifetime (Chawla et al., 2014). Larger babies, seen more often in pregnancies affected by diabetes, have more concern for long-term issues of obesity, diabetes, and heart disease (Boney, Verma, Tucker, & Vohr, 2005; Catalano et al., 2009; Shifres et al., 2014; Vohr et al., 1997). Any exposure to diabetes in utero increases risk of metabolic syndrome and overweight at age 15, though disturbances in metabolic markers are seen as early as age 8 (Catalano et al., 2009; W. H. Lam et al., 2010; Tam et al., 2010, van Rossem, Wijga, Gehring, Koppelman, & Smit, 2015). In addition, female offspring have a higher risk of having GDM with their own pregnancies if their mothers had GDM, perpetuating the risks of diabetes generationally (Shifres et al., 2014). Boghossian et al. (2014) reported that having GDM in any pregnancy in the past increases the risk of having a LGA infant even if the current pregnancy is not affected by GDM. The highest risk of all the adverse pregnancy outcomes, such as LGA, shoulder dystocia, preterm birth, and RDS, were seen in infants of women who developed diabetes immediately after a pregnancy with GDM (Boghossian et al., 2014).

A potentially moderating factor is breastfeeding, which may decrease the impact of diabetes on the woman and the newborn (Crume et al., 2011; Fallon, 2009). For both the woman and her infant, breastfeeding decreases the risk of developing diabetes in the future and can help women lose weight after pregnancy (Fallon, 2015; Park & Kim, 2015). In children born to mothers with diabetes and who had breastmilk for more than 6 months, researchers have reported significantly lower BMIs, waist circumferences, and subcutaneous adipose tissue than those infants who breastfed less than 6 months (Crume et al., 2011). These improvements in metabolic measures among children whose mothers breastfed mitigated the effect of the diabetes exposure such that there was no difference in children aged 6–13 based on fetal exposure to diabetes (Crume et al., 2011).

Areas of Further Research

There remain serious consensus issues around diagnosis, treatment, and impact of GDM on fetal and infant well-being despite gains made in research in the past few years (Balbour, 2014). Interactions between diabetes pathophysiology, the effect of increased glucose on genetic expression, and the struggle of providers and patients to cope with diabetes management need to be further researched and understood. When a pregnancy becomes high risk, there are significantly fewer guidelines and evidence-based examples for how to provide high-quality care to improve outcomes or provide interconception care (Bick et al., 2014; Tieu, Bain, Middleton, & Crowther, 2013). For example, there are still questions as to what threshold of blood glucose during daily testing will impact infant outcomes, and there have been no randomized controlled trials exploring this question (Hernandez, 2015). Also, researchers do not know much about the impact of DKA on fetal outcomes other than from reports in a few cases (Parker & Conway,

2007). The use of oral hypoglycemic agents for therapy during pregnancy is controversial, as they cross the placenta (Ryu, Hays, & Hebert, 2014).

One area for improvement in current research is to reach consensus regarding GDM screening, as the methods and thresholds for diagnosis remain controversial (Tieu, McPhee, Crowther, & Middleton, 2014). For high-risk women who would benefit from earlier testing than is recommended under current guidelines, there are also questions surrounding the timing of testing. At this time, no new markers are available for earlier testing for diabetes in pregnancy or for better monitoring fetal concerns during pregnancy.

Further research is needed to develop technological interventions to reduce adverse maternal, fetal, and infant outcomes. Some recent interventions include a smartphone application to upload and transmit blood glucoses to providers and receive guidance via text message; use of continuous glucose monitoring due to frequent changes in hormones and issues like morning sickness, low-glycemic diet, and activity trackers; and myo-inositol with folic acid in early pregnancy (Grant, Wolever, O'Connor, Nisenbaum, & Josse, 2011; Mackillop et al., 2014; Matarrelli et al., 2013; McLachlan, Jenkins, & O'Neal, 2007; O'Brien et al., 2014; Ruifrok et al., 2014). Large, well-designed trials will be required to evaluate most of these interventions, as studies to date have been inadequate (Moy, Ray, & Buckley, 2014).

There is a gap in the literature in regard to lifestyle interventions to affect outcomes, as most studies have been small and underpowered (Oteng-Ntim et al., 2012). Maternal activity was associated with decreased fetal abdominal circumference in a pilot study, so further studies should also look at infant anthropometric measurements (L. Hayes et al., 2014). Yoga has been shown to decrease maternal hypertension, preeclampsia, and GDM and to result in less growth restriction and higher APGAR scores (Rakhshani et al., 2012). Gavard and Artal (2008) reported

that exercise in normal pregnancy increased glucagon, norepinephrine, and epinephrine studies without significantly changing glucose or cortisol, so opportunities exist for further exploration. The effects of women's diabetes status and infant feeding on development are under exploration.

Practitioners continue to learn about the long-term effect of diabetes in the woman and child and are working to understand how interventions alter these effects. There is more data on short-term effects of diabetes, such as birth outcomes and measures of fetal well-being immediately after delivery, such as hypoglycemia, NICU admission, and birth weight, than on long-term consequences (Alwan et al., 2009). As epigenetics has become a growing area of research, developing an understanding of how diabetes alters gene expression has become important for assessing short-term and long-term maternal, fetal, and infant outcomes. There continues to be a gap in the literature about the impact of diabetes on fetal and infant outcomes as more women of childbearing age have diabetes.

Populations all over the world have been studied for the impact of diabetes on maternal, fetal, and infant outcomes. In the United States, where there is significant concern about obesity and diabetes, research gaps remain as to the impact of diabetes on current and future health of the population. There are even less data for diabetes-related pregnancy concerns. For example, some information is available about maternal morbidity in Wisconsin, but fetal morbidity and mortality data, particularly with a focus on the impact of diabetes on fetal and infant outcomes, are lacking. The WISH database provided by the WDHS does not allow for analysis of pregnancies affected by diabetes in the state despite the growing impact of diabesity on women of childbearing age. These data exist in the PeriData.Net® database for participating health care institutions; however, not all hospitals and health centers report data through this database. This

study is designed to provide insight into the impact of diabetes on fetal and infant outcomes on a population in southeastern Wisconsin.

CHAPTER 3: METHODS

A small urban population in southeast Wisconsin has experienced high infant mortality rates, which is considered a key indicator of the health of the community. For this population, identifying factors that contribute to infant morbidity and mortality is needed before further interventions can be considered or implemented. Diabetes has been shown to contribute to maternal, fetal, and infant morbidity and mortality and can have a lasting impact on individuals, families, and the surrounding community (WHO, 2016). Diabetes and obesity have become epidemic within the United States, leading to increasing numbers of women with risk for diabetes in pregnancy. The contribution of diabetes during pregnancy to adverse outcomes for women, fetuses, and infants in southeastern Wisconsin has not been explored. The purpose of this retrospective cohort study was to explore fetal and infant outcomes among women with diabetes during pregnancy in a small southeast Wisconsin urban community by performing a secondary data analysis.

Design

The PeriData.Net® database was used to explore maternal, fetal, and infant outcomes in women with diabetes in a small urban center in Wisconsin currently struggling with high rates of infant mortality and morbidity (Johnson, Malnory, Nowak, & Selber, 2011). These data had not been analyzed previously for diabetes or diabetes-related outcomes in the woman, fetus, or infant. The intention of this retrospective cohort study is to determine the prevalence and impact of maternal diabetes, both preexisting (T1DM and T2DM) and GDM, on maternal, fetal, and infant outcomes using secondary analysis of the PeriData.Net® database.

PeriData.Net® is used by Wisconsin institutions to gather hundreds of variables that describe maternal, fetal, and infant characteristics and outcomes of women who seek care during pregnancy and delivery. For this study, pregnancy and delivery data for women delivering at a single hospital were selected from PeriData.Net® ; the data represented approximately 75% of the births that occurred within the county where the small urban center was located. The variables cover a wide array of data, including demographics, medications, reproductive history and risk factors, prenatal testing, and preexisting maternal conditions. Hospital representatives, researchers, and other stakeholders who are interested in the health of women and infants in a community may use the database to evaluate the impact of systems and individual interventions on maternal, fetal, and infant outcomes. Secondary analysis of fetal and infant outcomes related to diabetes will provide researchers and clinicians with information for which individual and community interventions can be developed and validated for this population. Although the information collected for PeriData.Net® was not collected for a specific research question, the database was designed for health care systems to assess quality indicators or specific variables, such as those listed in this study protocol.

Having the data already collected limits the research questions that can be explored. Therefore there are limitations to the use of PeriData.Net® , as conclusions can be drawn but causality cannot be determined. The questions are limited by how the variables were defined, collected, entered, and interpreted. The data set does not contain survey data or patient perceptions about stress or depression level, and details about progression of chronic diseases, such as diabetes, through the pregnancy are not collected. The database also does not contain serial blood glucose or A1C data for individuals, which is a limitation. Despite standardization in database variables, it can be difficult to explain how the variables were measured, control was

maintained, and missing data were managed. For this study, missing data were excluded from the statistical assessment.

While this study could not discern the severity of disease directly on the woman, her fetus, or her infant, knowledge was gained regarding the contribution of diabetes to adverse fetal and infant outcomes. The goal of this study was to provide an overview of the impact of diabetes on maternal, fetal, and infant outcomes in this population, add to current diabetes literature, and provide direction for future research.

Rationale for Study Design

The purpose of this study was to investigate the impact of diabetes on maternal, fetal, and infant outcomes. The goal of this research was to add to current knowledge such that researchers can optimize pregnancy and birth outcomes through individual and community interventions in the future. Some variables, including fetal size, gestational age, maternal glucose control, maternal diabetes status, and weight gain in pregnancy, and other comorbidities, create challenges to the pregnancy primarily through physiologic mechanisms and are measurable (Coustan, 2013). Although it is important to study the influence of diabetes on maternal, fetal, and infant outcomes, it is also important to recognize that maternal, fetal, and infant outcomes may also be influenced by system issues, differences in care management, discrepancies in care because of systemic racism, perceptions of access to preconception and prenatal care, and personal choices in the management of care. Factors related to racism are less measurable through PeriData.Net® , so race and insurance types were studied instead to evaluate stress, economic challenges, and access issues experienced by women. A study by Knight et al. (2012) served as a model for the current study, as similar outcomes, statistics, and data set

characteristics were used to separate the effects of diabetes from the effects of maternal body weight on perinatal outcomes.

Variable Table

Variables of interest included population characteristics (preexisting maternal characteristics and demographic measures) and maternal and fetal outcome variables. From the literature review conducted in June 2017, variables were found that diabetes, pregnancy, and obesity can impact. Maternal variables were chosen from the available PeriData.Net® variables to assess the physical, psychological, and demographic contributions of diabetes and diabetes-related factors delineated in the conceptual framework. Some variables should be studied while others are controlled in the analysis to better isolate and understand the effect of diabetes in pregnancy (Fain, 2015; Grove, Burns, & Gray, 2012; Hulley, Cummings, Browner, Grady, & Newman, 2013; Polit & Beck, 2012). The variables identified in the literature can influence fetal and infant outcomes. Fetal and infant variables for study were chosen from the same literature review.

Maternal Preexisting and Demographic Measures

Variables in the database are important to define conceptually for consistency during the analysis, to discuss measurement of variables, to clearly evaluate how each variable is treated from the PeriData.Net® data, to raise awareness of potential error and bias, and to compare results with other studies.

Maternal age. As a woman ages from her 20s to her 40s, the risk of diabetes increases, as does the risk of comorbidities, such as hypertension and heart disease (ADA, 2014; Carolan, 2013; Carolan, Davey, Biro, & Kealy, 2012; Coustan, 2013). It is important to note that a woman may have experienced more stressors with age and had more change to her developmental

trajectory (Lu & Halfon, 2003). However, she also potentially had more time to adapt to stressors and mediate any effects of stress on blood glucose and comorbidities (Lu & Halfon, 2003). Therefore, age was considered and potentially controlled for within the statistical analysis if indicated by sample characteristics (ADA, 2014; Coustan, 2013). In PeriData.Net® , age at the time of delivery is calculated from the woman's birth date as reported in the prenatal record for insurance purposes.

Race. Race is of particular importance for this study due to disparities seen in infant mortality of the African American population versus their Caucasian counterparts. It is not known if diabetes is contributing to the increased stressors on these women and their pregnancies or if diabetes is more prevalent in this population. In the current study, race was patient self-reported.

Health insurance. In the current study, insurance was defined as the insurance billing used for the hospital stay. Insurance was used as a proxy for the individual's socioeconomic status, as there are income and eligibility requirements for publicly supported health insurance coverage. The type and quality of insurance paying for the costs of the pregnancy may influence the care received and the number of visits. Women with diabetes, if they enter prenatal care late due to problems with coverage, have less time to work on diabetes control during the pregnancy. This lack of early control can increase risk of miscarriage and birth defects. Women must first have a positive pregnancy test and begin paperwork for coverage before they receive public assistance, making it more difficult to start prenatal care in a timely manner, especially if they are high risk and require earlier intervention (WDHS, 2014a).

Smoking status. Exposure to cigarette smoke is known to cause vasoconstriction, leading to decreased circulation, hypoxia, and decreased fetal growth (Lu & Halfon, 2003).

Cigarette smoking and exposure to cigarette smoke in the home environment are considered together for this study. Smoke exposure can confound the data; therefore the sample was assessed to ensure equal distribution of smoke exposure (Contreras, Kominiarek, & Zollinger, 2010).

Prenatal visits. The number of prenatal care visits is a valuable variable, as education, monitoring, and anticipatory guidance are provided at these visits (Coustan, 2013). Typically, a woman without diabetes has about 10 visits over the course of the pregnancy, as women are encouraged to have a visit every 4 weeks until 28 weeks, every 2 weeks until 36 weeks, and weekly until delivery (American Academy of Pediatrics & American College of Obstetricians and Gynecologists, 2017).

Prepregnancy body mass index. A woman's BMI can be linked with fetal weight and is an indication of her prepregnancy nutritional state and potential for insulin resistance. (Harper et al., 2014; Tomedi et al., 2014). BMI is calculated by taking the weight (kilograms) and dividing by the height squared (meters) and is a rough estimate of body composition (Engstrom, Paterson, Doherty, Trabulsi, & Speer, 2003). Height, in feet and inches, and weight, either in pounds or kilograms, will still have some risk of error, and consequently, BMI will be subject to error as well. Height generally is taken once during the pregnancy and is considered stable, but body position can affect measurement. Variations can be found in weight due to the time of day, recent excretion, or recent food intake. Data about weight gain in pregnancy may rely on the woman's self-reported weight just before pregnancy but have been found to be acceptably close to weight taken in the office (Engstrom et al., 2003). Office weights will be assumed to have a reasonably small error, as an electronic scale was used to obtain weight.

Maternal Preexisting/Outcome Variables

Several aspects of maternal health, such as diabetes, hypertension, and obesity, can be preexisting or can develop during pregnancy and were a focus of this study.

Maternal outcomes. Maternal outcomes included the following.

Diabetes status. Diabetes status encompasses preexisting diabetes (T1DM and T2DM) and GDM, either with or without insulin. The type of diabetes and need for insulin of a pregnant woman give an indirect indication of the severity of the diabetes and the length of diagnosis. Prediabetes, where HgA1C $\geq$ 5.7% but less than the threshold for diabetes at 6.5% implies impaired glucose tolerance and insulin resistance and often is present for years before T2DM becomes obvious. Prediabetes is not captured in PeriData.Net® . T2DM is closely associated with obesity, GDM, metabolic disorders, and age and is diagnosed when HgA1C $\geq$ 6.5%, fasting glucose is $\geq$126, or random glucose is $\geq$200 (ADA, 2004, 2014, 2015; DeFronzo, 2009). Insulin use increases maternal stress when monitoring and injecting insulin are necessary to keep diabetes well controlled without hypoglycemia episodes (Mersereau et al., 2011). Even if the woman is not receiving insulin, there may be significant time and energy to prepare appropriate food, monitor glucose levels, and exercise. Diabetes is a diagnosis outside pregnancy based on HgA1C or fasting blood glucose, or during pregnancy, by using an oral glucose tolerance test. Generally, in the United States, and at the PeriData.Net® study site, the oral glucose tolerance test used is the two-step process of a 1-hour then a 3-hour oral glucose test and the Sullivan criteria for blood glucose (Feldman, Tieu, & Yasumura, 2016). For this study, diabetes status was taken as a dichotomous variable as well as a categorical variable depending on the question of interest.

Hypertension. In the current study, hypertension was determined by a clinician and categorized as developing at some time during the pregnancy or as preexisting. The ACOG definitions of hypertension and severity were used in the current study (ACOG Task Force on Hypertension in Pregnancy, 2013). Mild hypertension was defined as a blood pressure of 140/90 or greater, and severe hypertension was defined as a blood pressure of 160/110 or greater. Either level of hypertension can lead to adverse outcomes, such as preeclampsia or placental abruption. If hypertension develops early in the pregnancy, there is a higher risk of preeclampsia earlier in the pregnancy (ACOG Task Force on Hypertension in Pregnancy, 2013). PeriData.Net® does not contain blood pressure readings, nor is there an indication of the severity of preexisting hypertension prior to pregnancy. In PeriData.Net® , hypertension either exists as treated or untreated, preexisting or gestational, preeclampsia or eclampsia, or there is no hypertension. This variable was categorized into preexisting, gestational, or no hypertension or treated as a dichotomous variable of any hypertension or no hypertension. Preeclampsia and eclampsia were combined into the gestational hypertension category.

Gestational weight gain. The amount of weight, in pounds, a woman gains during pregnancy has been shown to be related to fetal outcomes. Once pregnant, limited but still increased weight to support the pregnancy is important, as weight loss in pregnancy can cause adverse infant outcomes (Cheng et al., 2008; Reece, 2008). The amount of desired weight gain in pregnancy is based on prepregnancy weight per IOM guidelines for women without diabetes. There are no specific guidelines for women with diabetes currently, so the IOM guidelines are used for all women (Katon et al., 2013; Reece, 2008). Weight gain over recommended amounts has been shown to impact fetal weight and adaptation to extrauterine life (Chen et al., 2015; Cheng et al., 2008; Flick et al., 2010). This is a measure of nutritional status and ability to self-

manage diet along with exercise (Fall, 2013). Physiologically, most women do not need to gain more than 25 pounds during pregnancy, as recommended by the IOM guidelines referenced in Table 2 (Cheng et al., 2008; Coustan, 2013; Flick et al., 2010). Weight gain is needed during pregnancy due to extra fluid volume, weight of the fetus, and maintenance of fetal supports (placenta and fluid). Weight gain above IOM recommendations leads to larger infants regardless of starting BMI (Chen et al, 2015; Flick et al., 2010; Shifres et al., 2014; van Rossem et al., 2015).

Delivery method. The type of delivery, whether by cesarean section or an assisted or unassisted vaginal delivery, may vary based on the presence of diabetes. Cesarean section is the surgical delivery of an infant through an incision through the uterus, while vaginal delivery occurs either spontaneously or with assistance though vacuum or forceps after pushing. The weight of the baby does not present the entire picture of fetal adaptation to hyperglycemia, as infants born to women with diabetes are more likely to have broad shoulders and higher rates of cesarean section (Coustan et al., 2013). Accelerated growth, which occurs more when fetuses are exposed to elevated blood glucose levels, or restricted growth, arising from changes to the maternal vascular system from diabetes, can also affect the delivery method. Cesarean section can lead to increased complications for the woman, such as infection, postpartum hemorrhage, delayed maternal interaction, infertility, blood clots, breastfeeding difficulties, pain, and death, and for the infant, the risks include respiratory distress, NICU admission, allergies, autism, and low APGAR scores (Annibale, Hulsey, Wagner, & Southgate, 1995; Dunlop et al., 2015; Mylonas & Friese, 2015; Ramachandrappa & Jain, 2008).

Maternal infection. Maternal infection, in this study, refers to any maternal infection noted in the database, including urinary tract infection, Group B strep, yeast infection, and

bacterial vaginosis. This variable required assessment to determine if women with diabetes had more infections than other women. Diabetes itself can decrease the immune response, particularly for bacterial and yeast-related infections (Casqueiro, Casqueiro, & Alves, 2012; Jovanovic et al., 2015). Often yeast infections are a first sign of diabetes in young women (Casqueiro et al., 2012).

Abnormal amniotic fluid. This was chosen as a dichotomous variable due to the potential for oligohydramnios and polyhydramnios in diabetes-affected pregnancies. Abnormal amniotic fluid can be a sign of placental health as well as fetal health and risk of kidney-related birth defects in the infant (Cabacungan et al., 2012; Khalil et al., 2010).

Dysfunctional labor. This is important as a variable due to the higher risk nature of women with diabetes in pregnancy. With the changes in a woman's vascular system and the placenta from diabetes, there is an increased risk of uncoordinated contractions, change in hormonal signals of labor, and cephalopelvic disproportion from accelerated fetal growth (Acker et al., 1985; Coustan, 2013; HAPO, 2008; Inturrisi & Lintner, 2011; Knight et al., 2012; Östlund et al., 2003; Persson et al., 2009; Persson et al., 2012; Ray et al., 2001). Any of these can alter labor patterns from the expected.

Cephalopelvic disproportion. With the potential for disproportionate fetal growth in the shoulders and macrosomia (Acker et al., 1985; Coustan, 2013; Inturrisi & Lintner, 2011; Knight et al., 2012; Ray et al., 2001), there is higher concern that the fetus will not fit through the pelvis. This can lead to cesarean section or to shoulder dystocia (ACOG, 2014).

Fetal outcomes. Fetal outcomes included the following.

Gestational age. Gestational age at delivery is an important marker of adverse fetal outcomes, as each completed week of pregnancy contributes to fetal development (Fine et al.,

2009; MacDorman & Mathews, 2009; MacDorman et al., 2014; Sen et al., 2016). Prematurity occurs when infants are born before 37 completed weeks or 2 weeks before their due date (Lowdermilk, Perry, Cashion, & Alden, 2012). The earlier the pregnancy ends, the higher the risk of adverse outcomes, including death. Organs like the liver, brain, and lungs are not fully mature, and fat stores the infant needs to help transition to life outside the uterus are not in place fully until the end of the pregnancy (Lowdermilk et al., 2012). Gestational age is determined by the physician using ultrasound dating in the first 20 weeks or by last menstrual period if there is late prenatal care or no ultrasound dating (Butt et al., 2016). Dating by ultrasound is most accurate before 20 weeks' gestation (Butt et al., 2016).

Birth weight. For this study, the weight of the infant in grams was used. Birth weight was used to determine if the infant was SGA, LGA, or macrosomic.

Large for gestational age and macrosomia. Accelerated fetal growth occurs in pregnancies affected by diabetes, leading to LGA infants (LGA ≥ 90th percentile) and infants with macrosomia (weigh more than 4,000 grams; Duryea et al., 2014; Oken, Kleinman, Rich-Edwards, & Gillman, 2003). Excess growth of infants from hyperglycemia results in broad shoulders and extra adiposity, while fetal hyperinsulinemia contributes to enlarged organs and macrosomia (Duryea et al., 2014; Hawdon, 2008; Oken et al., 2003). Macrosomia increases the risk of delivery complications and obstructed labor (Hawdon, 2008). Macrosomia occurs more in diabetes-affected pregnancies, particularly T2DM, and is likely a combination of both genetics and the influence of the intrauterine environment, which changes significantly in the presence of diabetes (Esakoff et al., 2011; Handisurya, 2011). For this study, LGA and macrosomia were combined into one variable so that all accelerated fetal growth was represented.

Small for gestational age and intrauterine growth restriction. Both infants of low and higher birth weight can be identified in pregnancies of women with diabetes. Infants are classified at birth as SGA (≤10th percentile), while IUGR is a diagnosis given after the fetus demonstrates compromise and lack of growth before delivery (Duryea et al., 2014; Oken et al., 2003). Growth can be limited due to placental changes related to microvascular damage and calcifications, hormone alterations, and changes to fetal DNA expression (Altshuler, 1984; Amer & Heller, 2010; Edu et al., 2016; Larque et al., 2013; Salomon et al., 2016). SGA and IUGR do not account for individual variations in size from genetic contributions or traits (Magnus et al., 1984). Smaller infants have less stores of brown fat, which in diabetes-affected pregnancies can occur as the infant uses its stores to counteract variations in maternal glucose, maternal nutrition, or placenta operation to preserve organ function (Shaw, 2003). For this study, growth charts from a diverse and large sample where ultrasound was used for dating determined the SGA and LGA cutoffs (Duryea et al., 2014). Previous growth charts based on last menstrual period using a mostly White population from Denver, which has a higher altitude, have been shown to underestimate LGA and overestimate SGA (Duryea et al., 2014). For this study, SGA and IUGR were combined, as they have related pathogenesis and some similarity in outcomes (Hawdon, 2008; Larque et al., 2013).

Neonatal intensive care unit admission. NICU admission may be indicative of maladaptive responses in the developing fetus to a hyperglycemic environment, leading to hypoglycemia or respiratory distress and necessitating higher levels of surveillance (HAPO, 2008; Hollander et al., 2007; Knight et al., 2012; Suk et al., 2015).

Birth defects. Alterations in the fetal condition from what is considered normal can be seen at birth or found as the child develops (Hollander et al., 2007; Reece, 2008). Birth defects

discovered during the first 3–4 days of infant life are typically entered into the database. As a result, birth defects that are not visible early will likely not be found in the database. Women with preexisting diabetes are at higher risk for birth defects that occur during the first trimester, as organogenesis is occurring (Reece, 2008). In the current study, infants of women with and without diabetes were assessed for any congenital or chromosomal anomalies.

Respiratory intervention. This was chosen for a variable to encompass both RDS and transient tachypnea of the newborn that required intervention. Most transient tachypnea does not require significant intervention; however, in a compromised infant, more intervention may be needed (Bental et al., 2011; Boghossian et al., 2014; Bourbon, 1985; Hollander et al., 2007; Knight et al., 2012; Tyden, Eriksson, & Berne, 1986). Breathing difficulties may also be seen in infants with low blood glucoses (Adamkin & Committee on Fetus and Newborn, 2011). RDS develops when there is insufficient surfactant available to facilitate expansion of the alveoli in the lungs (Bental et al., 2011; Coustan, 2013). Respiratory distress is one well-known complication seen in pregnancies affected by diabetes, particularly when the diabetes is uncontrolled (Bental et al., 2011; Longo et al., 2013; Stanescu, 2014). Diabetes-affected pregnancies lead to a higher risk of respiratory distress at birth due to changes in metabolism that can affect insulin, lipid and protein production in the amniotic fluid, and the inhibition of surfactant proteins in the lungs due to high insulin (Bental et al., 2011). Data for the study community involving the impact of diabetes on RDS have not been studied.

Breastfeeding at discharge. Breastfeeding status affects diabetes risk and has an immediate impact on both maternal and fetal glucose homeostasis. In the current study, breastfeeding was defined as whether or not breastfeeding of any amount was occurring at discharge. Diabetes is associated with infant and maternal breastfeeding issues, including

decreased milk production, decreased sucking bursts and total draws during breastfeeding, and decreased maternal confidence in milk production (Bromiker, 2006; Stuebe, 2015).

Birth injury. Injury to the newborn can be higher in infants born to women with diabetes. The infants may be larger and have broader shoulders, making delivery by cesarean section or by vaginal means more difficult (Coustan et al., 2013). Hawdon (2008) reported that infants born to women with diabetes were 5.2 times more likely to be born LGA, were 2.6 times more likely to have shoulder dystocia, had 11 times increased risk of Erb's palsy, had 2.6 times increased risk for neonatal death, and were 5 times more likely to be born premature (Hawdon, 2008). In the current study, shoulder dystocia, prematurity, and infant mortality were analyzed separately from all other types of birth injury.

Severe hypoglycemia. In the newborn, hypoglycemia, or low blood glucose, is a serious concern leading to interventions to prevent long-term disability and death (Adamkin & Committee on Fetus and Newborn, 2011; Coustan et al., 2013; Hawdon, 2008; Longo et al., 2013; Östlund et al., 2003; Youngwanichsetha & Phumdoung, 2013). For this study, severe hypoglycemia was considered to be present if the infant was symptomatic and treated by intravenous therapy per American Academy of Pediatrics guidelines (American Academy of Pediatrics [AAP], 2011). If the infant has signs of hypoglycemia, he or she is treated until clinical symptoms of altered neurologic function, including adverse feeding, low tone, shakiness, lethargy, and apnea, improve and blood glucose is maintained (AAP, 2011; Hawdon, 2008). Having a higher risk causes a cascade of interventions to monitor blood glucose and, if needed, supplementation of the infant with formula to maintain glucose levels. If severe, NICU admission may be needed for IV therapy (Coustan et al., 2013; Stuebe, 2015).

APGAR score. APGAR scores at 1 and 5 min aid in understanding how well an infant transitions to extrauterine life immediately after delivery; low APGAR scores (less than 7) are linked to adverse fetal outcomes (Coustan, 2013, Lowdermilk et al., 2012). APGAR evaluates heart rate, response to stimuli, strength of the infant's cry, muscle tone, and respiratory effort, with each category rated from 0–2, for a total possible score of 10 (Coustan, 2013; Lowdermilk et al., 2012). The infant with low APGAR scores is thought to be stressed, and low scores demonstrate that the infant is not compensating well for the stress of birth and transition to extrauterine life (Coustan, 2013; Ipekci et al., 2015). In the current study, APGAR scores were either <7 or ≥7.

Fetal intolerance of labor. This is a dichotomous variable that can be indicated on the PeriData.Net® worksheet. Fetal intolerance of labor occurs when the infant is showing signs of distress in labor through severe variables related to cord compression or late decelerations related to poor placental perfusion (ACOG, 2010; CDC, 2018b; Gravett et al, 2016; Westgate et al., 2007). When the infant has poor reserves of energy to support labor or has a dysfunctional labor, then there is a higher risk of intervention with delivery (Acker et al., 1985; ACOG, 2010; CDC, 2018b; Gravett et al., 2016; HAPO, 2008; Hawley, 2015; Inturrisi & Lintner, 2011; Jain et al., 2007; Kieffer et al., 2006; Östlund et al., 2003; Park & Kim, 2015; Westgate et al., 2007).

Hyperbilirubinemia. Elevated bilirubin from an immature liver or a breakdown of red blood cells can lead to jaundice and, if untreated, can result in significant morbidity and even mortality (Alam, Raza, Sherali, & Akhtar, 2006; CDC, 2018a; HAPO, 2008; Knight et al., 2012). Prematurity and diabetes are two possible explanations for hyperbilirubinemia, along with ABO incompatibility (AAP, 2004a, 2004b). For this study, hyperbilirubinemia was assessed as a dichotomous variable, and severity was not assessed.

Newborn infection. Assessed as a dichotomous variable, newborn infection was present if there was suspected chorioamnionitis, sepsis, or symptoms like fever.

Mortality. Either fetal or infant, this is a dichotomous variable and is indicated within the PeriData.Net® database for those who experienced stillbirth, intrapartum death, and death prior to leaving the hospital.

Newborn withdrawal syndrome. Evaluated for this study, this determined if there were differences that needed to be accounted for. Infants who are withdrawing may have more NICU admissions and have been under more stress before and after delivery.

Metabolic disturbances and electrolyte imbalances (sodium, potassium, and calcium alterations). More common in infants of women with diabetes (Catalano et al., 2003; de Veciana, 2013; Kitzmiller, 1982; Reif et al., 2013; Steinberger & Daniels, 2003), electrolyte and metabolic issues were marked in the PeriData.Net® database as a written-in component. These were assessed in the analysis as dichotomous variables.

Data Collection

The data used for this study were collected and maintained within the PeriData.Net® database. This data collection mechanism and system were developed by the Wisconsin Association for Perinatal Care (WAPC) to improve quality assessment, provide a platform for comparison between institutions, and support initiatives that improve patient care. The PeriData.Net® data are part of a greater statewide database; however, each participating institution retains control of its own data. The facility for this study was chosen to collect more than 400 variables. The data collection and design of the PeriData.Net® worksheet, used to physically collect the data, were completed by the medical center for the period of interest, and all data were entered into the database at the institution. Consent for the data collection is part of

the admission process to the hospital (WAPC, 2016). Access to the database is controlled by hospital leadership so that a limited group has access to PeriData.Net® .

Data Collection Process

The ongoing process for the study facility was as follows: (a) Nurses complete a comprehensive form using data collected from the patient directly, from the prenatal record, and from the hospital stay; (b) members of the leadership team review and confirm the accuracy and completeness of the data recorded; and (c) data entry is executed by data support personnel. Access to the PeriData.Net® database for the current study required formal permission from the hospital leadership team and institutional review board (IRB).

Sample and Participants

The target population for this study included women and their infants who delivered from January 1, 2013, through December 31, 2017, in a small urban community in southeast Wisconsin. The births within this institution have been 21%–25% African American, 21%–25% Hispanic, 45% Caucasian, and 5% other races over the last 10 years. All women whose pregnancies were impacted by diabetes from January 1, 2013, through December 31, 2017, in the PeriData.Net® database and who delivered at the study facility were included in the study group and compared with a control group of women without diabetes. Only singleton deliveries were included in this study, eliminating multiple-order pregnancies that have higher rates of diabetes (Croft, Morgan, Reed, & Jablensky, 2010; Jovanovic, 2009; Rauh-Hain et al., 2009;). A power analysis, assuming a small effect by convention (ES of .20) with an alpha of .05 for Type 1 error and a beta of .80 for Type 2 error risk, required that the minimum number of cases was 394 per group (Polit & Beck, 2012).

Exclusion Criteria

Exclusion criteria included the following: (a) women with a multiple pregnancy (twins and above), (b) incomplete data due to transfer of care of either the woman or infant, and/or (c) residence of record out of state.

For this study, all women with diabetes were included in the study, unless they met exclusion criteria, as the percentage of women reported to have diabetes in pregnancy is less than 20% for most populations (CDC, 2014; HAPO, 2008). The women with diabetes were analyzed along with case-matched controls without diabetes in a 1:2 ratio. Matching is used to put subjects into groups based on a few general characteristics, such as age, race, or another demographic variable (Polit & Beck, 2012). For this study, two women without diabetes were matched by prepregnancy BMI and race for each case of diabetes. This is effective where characteristics of the individuals are known, it is not possible to do randomization, or the data have been collected already, such as is found with large databases covering an entire population, such as those seen in census data or in the PeriData.Net® database (Polit & Beck, 2012). Other comorbidities, such as hypertension, will be assessed within the data analysis.

The purpose of this study was to investigate the effects of maternal diabetes, not obesity, on maternal, fetal, and infant outcomes. However, there is an interplay between obesity and risk for diabetes, thus obesity can be a confounding variable for women with diabetes. By case matching women with diabetes with women who did not have diabetes but were of similar BMI and race, the effect that obesity has on infant outcomes can be mitigated so that the effects of diabetes can be studied more easily (Knight et al., 2012). The 1:2 ratio for case matching has been chosen based on previous work with this database and a desire for better power. BMI was case matched to women with diabetes within a few points whenever possible (Knight et al.,

2012). IOM recommendations for weight gain are based on BMI class, so where possible, case matching was done within the same BMI class. Race was matched as closely as possible for each woman with diabetes in the sample, as concerns for disparities based on race exist in this population. Demographic data using all the women in the database were used to evaluate prevalence of diabetes along with racial differences in obesity and diabetes before comparing the matched cases. By using case matching, the groups were chosen to have similar group characteristics to focus on diabetes as the influencer of fetal and infant outcomes.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics, and the level of significance was set at .05. Prior to running comparative analyses, the continuous variables (maternal age, prepregnancy BMI, parity, number of prenatal visits, gestational weight gain, gestational age, and birth weight) were assessed for normality. A skewness value under 2 was accepted as the benchmark for normality (West, Finch, & Curran, 1995). All continuous variables were found to be normally distributed, except for gestational age, which was skewed to the high end of the distribution. The results of all comparative analyses involving gestational age were confirmed by running comparable analyses after applying a normalizing transformation to gestational age, specifically, the inverse of the reflected score (Tabachnick & Fidell, 2007). No differences were found between results using the normalized and the original score. Therefore results using the original score were reported for ease of interpretation.

Study Question 1

Study Question 1 asked, Are there differences by race in maternal, fetal, and infant outcomes when any maternal diabetes is present? This question was tested within the sample of women with diabetes during pregnancy specifically looking at the impact of race on maternal,

fetal, and infant outcomes. Chi-square analyses were used for categorical variables. Each of the three prominent races represented in the sample was compared to the other two races one at a time. Specifically, one set of analyses compared Caucasian versus African American and Hispanic races, one set compared African American versus Caucasian and Hispanic, and one set compared Hispanic versus Caucasian and African American. Women of mixed racial identities were excluded from the analyses to the degree that individual participants self-identified as mixed race, and women of Asian and Native American race were also excluded from the analysis for this question. The continuous variables assessed included gestational age, birth weight, delivery weight, and change in weight from prepregnancy to delivery. Analysis of variance (ANOVA) was used to compare gestational age by race (Caucasian, African American, Hispanic). Analyses of covariance (ANCOVAs) were used to compare the weight variables by the three racial groups, controlling for gestational age.

Study Question 2

Study Question 2 asked, What is the impact during pregnancy of any maternal diabetes, including preexisting and gestational diabetes, with and without insulin, on adverse fetal and infant outcomes? Women with diabetes were compared to women without diabetes, matched by prepregnancy BMI and race, using ANOVAs for continuous outcomes and chi-square analyses for categorical outcomes. ANCOVAs were used to analyze weight variables, controlling for gestational age.

Study Question 3

Study Question 3 asked, What is the effect of pregnancy BMI, gestational weight gain, and maternal diabetes on maternal outcomes that affect infant morbidity (delivery type and shoulder dystocia) when preeclampsia and parity are taken into consideration? This question was

tested using three logistic regression analyses to predict cesarean section (yes vs. no), assisted vaginal delivery (yes vs. no), and shoulder dystocia (yes vs. no) using prepregnancy BMI, parity, any diabetes, gestational weight gain, and any gestational hypertension, including eclampsia, preeclampsia and HELLP syndrome, as predictors. HELLP is a severe form of preeclampia characterized by hemoloysis, elevated liver enzymes and low platelets (Lowdermilk et al., 2012).

Study Question 4

Study Question 4 asked, What is the combined impact of any maternal diabetes during pregnancy and of prepregnancy BMI on adverse fetal and infant outcomes? A series of logistic regression analyses were used to predict adverse fetal and infant outcomes using standardized prepregnancy BMI, any maternal diabetes (yes vs. no), and their cross-product as the predictors.

Protection of Human Subjects

This study protocol has been approved by the study facility IRB and deferral granted to the study facility by the University of Wisconsin-Milwaukee IRB. No patients were contacted during the study, as a waiver for consent for data collection was granted by the IRB and this is a retrospective review for which the data had already been collected. Data in this database were provided to the researcher by the institution already deidentified so that HIPAA regulations could be maintained. Once the sample was determined, infant dates of birth were removed, as they were not relevant to the analysis. The data set will be stored in a secure computer with access limited to the researcher, and patient confidentiality was maintained throughout the study (Polit & Beck, 2012).

CHAPTER 4: RESULTS

Sample Description

A total of 1,989 women and 1,989 infants entered within the time period January 1, 2013, to December 31, 2017, were chosen from the larger PeriData.Net® database for analysis. Multigestational pregnancies and out-of-state households were excluded. The sample of women with diabetes was matched on prepregnancy BMI and race: 1,326 women without diabetes were matched with 663 women with diabetes. There was only one case of documented domestic violence in the study population. Table 3 provides demographic characteristics of the sample. The largest proportion of the sample was Caucasian (45.8%), with Hispanic (21.5%) and African American (17.5%) making up most of the rest of the sample. Most women were multiparous (78%) and did not smoke (76.3%). A majority of women were covered by public insurance. Education of the sample showed half of women had a high school or less education while the other half had some college or an undergraduate degree. Nearly all the women had prenatal care during their pregnancies. A majority of the sample with diabetes had gestational diabetes, while a smaller number of women had preexisting diabetes. Infant gender was equally represented in the overall sample.

Chi-square analyses and ANOVAs were used to compare the women with diabetes to those without diabetes on demographic characteristics. The one significant difference for categorical demographics is displayed in Table 4, and two significant results for continuous demographics are shown in Table 5. Nonsignificant comparisons are provided in Appendix A, Tables A1 and A2. More multiparous women were found in the diabetes sample (Table 4).

Women with diabetes had significantly greater parity and were slightly older than the women in the sample without diabetes (Table 5).

Table 3

Demographic Characteristics of the Entire Sample

	Frequency	Percentage
Race		
Caucasian	911	45.8
African American	348	17.5
Hispanic	428	21.5
Multiracial	234	11.8
Other (Asian, Pacific Islander, North American Indian)	68	3.4
Education		
Less than high school	327	16.4
High school or GED	611	30.7
Some college	573	28.8
Undergraduate/associate's degree	405	20.4
Graduate degree	51	2.6
Unknown	22	1.1
Parity		
Primiparous	437	22.0
Multiparous	1,552	78.0
Payment source		
Private or self-pay	770	38.8
Public (Badgercare, Medicaid)	1,216	61.2
Prenatal care		

No	8	.4
Yes	1,981	99.6
Smoking/exposure		
No	1,517	76.3
Yes	472	23.7
Diabetes status		
None	1,326	66.7
Gestational, no insulin	497	25.0
Gestational, with insulin	46	2.3
Preexisting, no insulin	58	2.9
Preexisting, with insulin	62	3.1
Infant gender		
Male	1,029	51.7
Female	960	48.3

Table 4

Maternal and Infant Categorical Characteristics by Any Diabetes

	Diabetes (n = 660)			No diabetes (n = 1,323)			
	Freq.	Percentage	95% CI	Freq.	Percentage	95% CI	
Multiparous	539	81.7	[78.7, 84.6]	1,009	76.3	[74.0, 78.6]	**

**$p < .01$.

Table 5

Maternal and Infant Continuous Demographics by Any Diabetes

	Diabetes				No diabetes					
	N	Mean	*SD*	95% CI	*N*	Mean	*SD*	95% CI	*F*	
Maternal age	658	30.64	5.57	[30.22, 31.07]	1,317	27.67	5.63	[27.36, 27.97]	123.58	***
Parity	660	1.71	1.55	[1.60, 1.83]	1,323	1.44	1.41	[1.36, 1.51]	15.65	***

***$p < .001$.

Hypothesis Testing

Study Question 1

To answer this question, analyses were performed only between the women with diabetes. To compare categorical outcomes by race, each of the three major races (Caucasian, African American, and Hispanic) was compared to all other single races in turn using chi-square statistics. Because of the number of comparisons being conducted simultaneously, the level of significance was set at $p < .01$ rather than the standard $p < .05$. An ANOVA was used to compare the three major races on gestational age. ANCOVAs, controlled for gestational age, were used to compare the races by maternal and infant weight variables. For the ANOVA and ANCOVAs, post hoc pairwise comparisons with Bonferroni adjustment were used to determine which specific races were different from the others. Women of mixed and other races were excluded from the analyses. The significant results are presented in Tables 6 and 7 with nonsignificant comparisons detailed in Appendix B, Tables B1–B4.

Caucasian women with diabetes had lower rates of infection compared to African American and Hispanic women with diabetes (Table 6). The Caucasian women were more prone to GDM and had less preexisting diabetes, whereas the opposite was true for African American women. In addition, more of the Caucasian women and fewer of the African American women

were breastfeeding at discharge. Fewer of the Hispanic women and significantly more of the African American women had preexisting hypertension. While more of the African American women had hypertension overall, there were no significant differences by race in the prevalence of gestational hypertension (Tables B1–B3). African American women with diabetes had more preterm deliveries and, compared to other women with diabetes, experienced more fetal and infant mortality.

Table 6

Maternal, Fetal, and Infant Outcomes by the Race of Women With Diabetes

	Caucasian (*n* = 305)			Other single race (*n* = 280)			
	N	Percentage	95% CI	*N*	Percentage	95% CI	
Maternal infection	92	32.2	[26.8, 37.6]	112	45.2	[39.0, 51.4]	**
Breastfeeding at discharge	245	81.1	[76.7, 85.5]	193	70.2	[64.8, 75.6]	**
Gestational diabetes	272	89.2	[85.7, 92.7]	211	75.4	[70.3, 80.4]	***
	African American (*n* = 115)			Other single race (*n* = 470)			
	N	Percentage	95% CI	*N*	Percentage	95% CI	
Any hypertension	40	34.8	[26.1, 43.5]	92	19.6	[16.0, 23.2]	***
Prepregnancy hypertension	18	15.7	[9.0, 22.3]	34	7.2	[4.9, 9.6]	**
Preterm	43	37.4	[28.5, 46.2]	111	23.6	[19.8, 27.5]	**
Breastfeeding at discharge	57	51.4	[42.1, 60.6]	381	81.8	[77.9, 84.9]	***
Fetal or infant mortality	5	4.3	[0.6, 8.1]	4	0.9	[0.0, 1.7]	**
Gestational diabetes	75	65.2	[56.5, 73.9]	408	86.8	[83.7, 89.9]	***
	Hispanic (*n* = 143)			Other single race (*n* = 442)			
	N	Percentage	95% CI	*N*	Percentage	95% CI	
Prepregnancy hypertension	5	3.5	[0.5, 6.5]	47	10.6	[7.8, 13.5]	**

**$p < .01$. ***$p < .001$.

As shown in Table 7, the ANOVA by race indicated that the African American mothers with diabetes were heavier prior to pregnancy compared to both Caucasian and Hispanic women with diabetes, and their infants had significantly shorter gestations. After controlling for gestational age, no racial differences were found for birth weight or in the amount of weight the women gained during pregnancy (Table B4), but women of all three races differed from each other in maternal weight at delivery, with Hispanic women weighing the least and African American women weighing the most.

Table 7

Women with Diabetes: Gestational Age, Body Mass Index, and Delivery Weight by Race, Controlling for Gestational Age

Group	*N*	*M*	*SD*	95% CI	*F*		
Prepregnancy BMI							
Caucasian	303	32.4	8.88	[31.39, 33.40]	8.72	***	A
African American	112	35.95	8.85	[34.29, 37.60]			CH
Hispanic	142	32.12	6.19	[31.09, 33.15]			A
Gestational age							
Caucasian	305	38.2	1.96	[37.98, 38.42]	12.66	***	A
African American	115	37	3.63	[36.33, 37.67]			CH
Hispanic	143	38.29	1.71	[38.01, 38.58]			A
Controlling for gestational age: Delivery weight							
Caucasian	305	220.44	52.55	[24.03, 28.19]	14.12	***	AH
African American	115	236.57	53.18	[21.22, 28.01]			CH
Hispanic	143	201.94	39.25	[19.41, 24.24]			CA

Note. Significant post hoc pairwise comparisons at the .05 level are indicated by the comparison group C = Caucasian, A = African American, H = Hispanic. BMI = body mass index.
***$p < .001$.

Study Question 2

This question was tested using a series of chi-square analyses, ANOVA, and ANCOVA statistics. The significant results for categorical variables are displayed in Table 8 and for continuous variables in Table 9. Nonsignificant results are provided in Appendix C.

Table 8

Maternal and Infant Outcomes by Any Diabetes

	Diabetes (n = 660)			No diabetes (n = 1,323)			
	N	Percentage	95% CI	*N*	Percentage	95% CI	
Prepregnancy							
Any hypertension	148	22.4	[19.2, 25.6]	182	13.8	[11.9, 15.6]	***
Prepregnancy hypertension	62	9.4	[7.2, 11.6]	48	3.6	[2.6, 4.6]	***
Labor and delivery							
C-section	296	44.8	[41.1, 48.6]	405	30.6	[28.1, 33.1]	***
Fetal/infant outcomes							
Preterm	167	25.3	[22.0, 28.6]	171	12.9	[11.1, 14.7]	***
NICU admission	119	18.2	[15.1, 21.0]	136	10.4	[8.6, 11.9]	***
Respiratory intervention	62	9.5	[7.2, 11.6]	62	4.7	[3.5, 5.8]	***
Hypoglycemia IV	50	7.7	[5.6, 9.6]	30	2.3	[1.5, 3.1]	***
Hyperbilirubinemia	57	8.6	[6.5, 10.8]	52	3.9	[2.9, 5.0]	***
Large for gestational age	120	18.2	[15.2, 21.1]	154	11.6	[9.9, 13.4]	***
Abnormal amniotic volume	62	9.4	[7.2, 11.6]	62	4.7	[3.5, 5.8]	***

Note. NICU = neonatal intensive care unit.
***$p < .001$.

Women with diabetes had more prepregnancy hypertension and overall hypertension, but there was no difference between the two groups related to gestational hypertension (Tables 8 and

C1). Women with diabetes had more preterm deliveries and their infants had significantly more NICU admissions, respiratory interventions, hypoglycemia requiring IV, hyperbilirubinemia, LGA, and abnormal amniotic fluid than women without diabetes. Diabetes did increase the rate of cesarean section, but no other issues related to labor, including shoulder dystocia and cephalopelvic disproportion, were found to be significant in this sample (Tables 8 and C1).

Table 9

Gestational Age and Maternal and Infant Weight by Any Diabetes, Controlling for Age

Group	*N*	*M*	*SD*	95% CI	*F*	
Gestational age						
Diabetes	660	38.04	2.32	[37.86, 38.21]	40.73	***
No diabetes	1,323	38.79	2.57	[38.66, 38.93]		
Controlling for gestational age						
Delivery weight						
Diabetes	660	219.60	51.23	[215.68, 223.52]	19.51	***
No diabetes	1,317	229.82	46.35	[227.31, 232.33]		
Weight change						
Diabetes	654	24.35	17.27	[23.02, 25.67]	45.32	***
No diabetes	1,317	31.59	21.06	[30.45, 32.73]		
Birth weight						
Diabetes	654	3,348.71	678.43	[3,296.53, 3,400.88]	37.55	***
No diabetes	1,306	3,340.48	646.37	[3,305.4, 3,375.57]		

***$p < .001$.

Infants of women with diabetes were born earlier than those of women without diabetes (Table 9). After controlling for gestational age, ANCOVA revealed that at the time of delivery,

the women with diabetes were lighter and had experienced less weight gain, despite having been matched with women who did not have diabetes on prepregnancy BMI. In contrast, the infants of women with diabetes were slightly heavier at birth (Table 9).

Study Question 3

This question was tested using three logistic regression analyses to predict cesarean section (yes vs. no), assisted vaginal delivery (yes vs. no), and shoulder dystocia (yes vs. no) using prepregnancy BMI, parity, any diabetes, gestational weight gain, and any gestational hypertension (including eclampsia, preeclampsia and HELLP syndrome) as predictors. The results presented in Table 10 indicate that higher prepregnancy BMI, lower parity, any diabetes, and gestational weight gain are all independently predictive of C-section. Gestational hypertension did not contribute significantly to the prediction.

Table 10

Logistic Regression on Cesarean Section

Variable entered	*B*	*SE*	Wald	Odds ratio	95% CI
Prepregnancy BMI	0.050	0.01	57.36***	1.05	[1.04, 1.06]
Parity	−0.128	0.04	13.54***	1.14	[1.06, 1.22]
Any diabetes	0.737	0.10	49.88***	2.09	[1.70, 2.56]
Weight gain	0.013	0.00	23.06***	1.01	[1.01, 1.02]
Gestational hypertension	0.236	0.15	2.42	1.27	[0.94, 1.71]

Note. BMI = body mass index.
***$p < .001$.

The only significant predictor of the need to have an assisted delivery was lower parity (Table 11). Prepregnancy BMI, parity, any diabetes, weight gain, and gestational hypertension were not significantly predictive of shoulder dystocia (Appendix D).

Table 11

Logistic Regression on Assisted Vaginal Delivery

Variable entered	*B*	*SE*	Wald	Odds ratio	95% CI
Prepregnancy BMI	−0.025	0.02	1.80	0.98	[0.94, 1.01]
Parity	−0.549	0.14	15.02***	1.73	[1.31, 2.27]
Any diabetes	−0.374	0.32	1.38	0.69	[0.37, 1.29]
Weight gain	0.005	0.01	0.58	1.01	[0.99, 1.02]
Gestational hypertension	0.541	0.35	2.34	1.72	[0.86, 3.44]

Note. BMI = body mass index.
***$p < .001$.

Study Question 4

To test this question, a series of regression analyses were used to predict adverse fetal and infant outcomes using standardized prepregnancy BMI, any maternal diabetes (yes vs. no), and their cross-product as the predictors. Logistic regressions were used for dichotomous outcomes, and linear regressions were used for continuous outcomes. A significant cross-product (interaction effect) was taken to indicate a significant combined impact of any maternal diabetes during pregnancy and prepregnancy BMI. The outcomes tested included fetal intolerance of labor, preterm birth, 1- and 5-min APGARs under 7, NICU admission, respiratory intervention, IV for hypoglycemia, hyperbilirubinemia, breastfeeding at discharge, birth injury, shoulder dystocia, newborn withdrawal syndrome, metabolic disturbance, electrolyte imbalance, newborn infection, any congenital anomaly, chromosomal anomaly, fetal or infant mortality, SGA, LGA, gestational age, and birth weight. Four significant interaction effects were found.

As shown in Table 12, there were three significant interactions between BMI and diabetes associated with dichotomous fetal and infant outcomes. The combined impact of any

maternal diabetes during pregnancy and prepregnancy BMI was significantly predictive of lower fetal intolerance of labor, lower prevalence of SGA infants, and higher prevalence of LGA infants.

Table 12

Logistic Regressions on Fetal Intolerance of Labor, Small for Gestational Age, and Large for Gestational Age

Outcome predictor	*B*	*SE*	Wald	Odds ratio	95% CI
Fetal intolerance of labor					
Prepregnancy BMI	0.089	0.10	0.79	1.09	[0.90, 1.33]
Diabetes	−0.068	0.18	0.14	0.93	[0.65, 1.34]
Interaction	−0.424	0.19	4.98*	1.53	[1.05, 2.22]
Small for gestational age					
Prepregnancy BMI	0.092	0.09	0.98	1.10	[0.91, 1.32]
Diabetes	−0.409	0.19	4.60*	1.51	[1.04, 2.19]
Interaction	−0.495	0.20	6.22*	1.64	[1.11, 2.42]
Large for gestational age					
Prepregnancy BMI	0.033	0.09	0.15	1.03	[0.87, 1.22]
Diabetes	0.470	0.14	11.92***	1.60	[1.23, 2.09]
Interaction	0.353	0.13	7.46**	1.42	[1.11, 1.83]

Note. BMI = body mass index.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 13 presents the one significant interaction effect for continuous outcomes. While prepregnancy BMI and diabetes are not predictive of infant birth weight in and of themselves, the interaction between these two predictors is significantly predictive, indicating that

prepregnancy BMI is associated with higher infant birth weight only for women with diabetes but not for those without diabetes.

Table 13

Linear Regression on Birth Weight

Predictor	Beta	95% CI	*t*	R^2	*F*
Prepregnancy BMI	−0.044	[−0.040, 0.053]	0.39	0.006	4.00**
Diabetes	0.012	[−0.030, 0.056]	0.54		
Interaction	0.094	[0.030, 0.119]	3.39***		

Note. BMI = body mass index.
**$p < .01$. ***$p < .001$.

CHAPTER 5: DISCUSSION

The purpose of this chapter is to review the results of this study, compare study results to current literature, discuss future implications of the results, and consider recommendations for future research.

Discussion of the Sample

From January 1, 2013, to December 31, 2017, diabetes affected 8.92% of all singleton deliveries at the institution from which the sample for this study was drawn. In this study, 82% of women with diabetes and 7.2% of all singleton deliveries regardless of outcome found in the database were impacted by GDM. At this institution, there were not as many women with GDM at 7.2%, compared to some other studies; GDM complicates at least 3%–7% of pregnancies, with recent studies finding GDM in closer to 12% of pregnancies and up to 25% of women in distinct high-risk populations (specific Native American populations, for example; Alwan et al., 2009; Baker & Haeri, 2012; CDC, 2014; Carolan, Davey, Biro, & Kealy, 2012; Coustan, 2013; Edu et al., 2016; HAPO, 2008; Hunt & Schuller, 2007). However, the study institution follows ACOG recommendations for the two-step 100-g oGTT GDM screening process rather than the 75-g 2-hour oGTT recommended by the WHO, the ADA, and the IADPSG, which is used in most new studies and will increase GDM diagnoses (Bodmer-Roy et al., 2012; HAPO, 2009; Inturrisi & Lintner, 2011; Trujillo et al., 2015; Black et al., 2013). The recommendations endorsed by the ADA and the WHO to use the 2-hour 75-g test would likely increase the number of women diagnosed with GDM to about 18% of all pregnancies, compared to the two-step 100-g screening method recommended by ACOG, which would identify half as many women as having diabetes

(ADA, 2014; Barbour, 2014; Bodmer-Roy et al., 2012; Farrar, Duley, Dowswell, & Lawlor, 2017; Trujillo et al., 2015).

Although identifying more women with diabetes would lead to more women receiving interventions to control blood glucose levels and should improve outcomes for women and infants, more resources would be required, increasing costs, while benefits to some women may not outweigh harm from increased stress (Bodmer-Roy et al., 2012; HAPO, 2008; Inturrisi & Lintner, 2011). Further research is needed to determine the best criteria for screening and diagnosis of GDM to optimize maternal, fetal, and infant outcomes and reach consensus worldwide.

Preexisting diabetes is known to be significantly less prevalent compared to gestational diabetes in the childbearing population in the US; however, African American women and older women have a higher prevalence of preexisting diabetes during pregnancy (Jovanovic et al., 2015; Lawrence, Contreras, Chen, & Sacks, 2008; Lapolla, Dalfra, & Fedele, 2008). Current studies have indicated increases of prediabetes during pregnancy (Lapolla et al., 2008; Lawrence et al., 2008). While pregnancies with preexisting diabetes increased from 10% to 21% of women from 1999 to 2005, overall pregnancies were more affected by diabetes as the prevalence increased from 8.3 per 100 births in 1999 to 9.2 per 100 births in 2005 (Lawrence et al., 2008). The number of women with preexisting diabetes versus GDM in the current study was slightly less than in the Lawrence et al. study, as women with preexisting diabetes accounted for 18% of all the women with diabetes in the current study and represented 1.52% of the total number of singleton deliveries. Lawrence et al. reported that 1.3% of all singleton pregnancies had preexisting diabetes, which is lower than the current study findings.

In the current study, nearly 100% of women had prenatal care. Women with diabetes did not differ from those without diabetes with regard to the number of visits; women in both groups averaged between 11 and 12 prenatal visits. Other researchers have also found that women with diabetes had an average of 12 prenatal visits and that women with diabetes who had more visits had better HgA1C and fewer NICU admissions even adjusted for gestational age (Carter, Tuuli, Odibo, Macones, & Cahill, 2016). In the studies reported from the literature, more prenatal visits were associated with decreased preterm birth, particularly in African Americans, and with better glucose control by HgA1C and fewer NICU admissions for all women with diabetes (Carter et al., 2016; Vintzileos, Ananth, Smulian, Scorza, & Knuppel, 2002). In the current study, African American women had more preterm births and a higher prevalence of preexisting diabetes, indicating that women who are African American might benefit from increased prenatal visits. For this study, nearly all visits would be captured in PeriData.Net® , unless the visit was a visit for testing or occurred at an outside facility and was not recorded.

In this study, 8 women in the community did not receive prenatal care during pregnancy, despite efforts to reach all women for care. However, to the degree that the current study reflected the community, all women were able to access prenatal care. Other data suggested that approximately 6% of women receive very late or no prenatal care, so this community has adequate prenatal care access (DHHS, 2013). In Wisconsin, the Badgercare system covers prenatal care for women who are lower income or without insurance, so women, if they choose to apply, should have access to prenatal care. Approximately 60% of women in the current study had public insurance, while 40% had private insurance or were self-pay. In Wisconsin, 81%–84% of women had a visit in the first trimester or within 42 days of applying for Medicaid or CHIP (Centers for Medicare and Medicaid Services, 2016).

While there are still significantly higher numbers of women with exposure to smoking during pregnancy than desired, there was no statistical difference in smoking exposure between the women with and without diabetes. Reducing the numbers of women exposed to smoking is important, as there are substantial impacts from vasoconstriction on hypertension severity and placental development and elevated blood pressure on maternal and fetal circulation and fetal growth related to cigarette smoking (Altshuler, 1984; Edu et al., 2016; Gongora & Wenger, 2015; Gyamlani & Geraci, 2013; Jones & Hayslett, 1996; Khoury et al., 2002; Kool et al., 1993; Nickens et al., 2013; Stratta et al., 2006; Virdis, Giannarelli, Neves, Taddei, & Ghiadoni, 2010).

In this study, women with diabetes were slightly older and had more children than the women without diabetes. These study results support what other researchers have found: that diabetes risk increases with age (Carolan, Davey, Biro, & Kealy, 2011; Gavard, 2014; Kahlil, Syngelaki, Maiz, Zinevich, & Nicolaides, 2013; Östlund et al., 2003). PeriData.Net® did not allow the researcher to capture in this study if women returned to their prepregnancy weights after each pregnancy. However, based on other studies, it is likely that additional weight was retained with each pregnancy, increasing the risk of diabetes both during pregnancy and before pregnancy (Gunderson, 2009; Thompson et al., 2014).

Gestational age was lower by a few days for women with diabetes versus those without diabetes in this study; however, 50% of women with and without diabetes completed 37 weeks (38.04, *SD* = 2.32 vs. 38.79, *SD* = 2.57). Lower gestational age is related to increased cesarean sections, and macrosomia and recommendations to induce earlier due to risk of stillbirth with diabetes increases cesarean section rates (Hawdon, 2011; Klemetti et al., 2016; Melamed et al., 2016).

In the current study, the women with diabetes and women without diabetes were matched on prepregnancy BMI. However, after controlling for gestational age, the women with diabetes had less weight gain during pregnancy and weighed less at delivery than their nondiabetes counterparts with the same BMI. In this population women with diabetes are likely making lifestyle choices that limited their weight gain compared to women without dietary and lifestyle focused education. Berglund et al. (2016) also found that women with GDM had less weight gain. Prepregnancy weight and pregnancy weight gain have been found to have significant impacts on maternal, fetal, and infant outcomes (Boghossian et al., 2014; Handisurya et al., 2011; Scifres et al., 2014). Restricting gestational weight gain reduces GDM development by 33% but was not shown to alter birth weight or cesarean delivery (Oteng-Ntim et al., 2012; Rogozinska et al., 2015). Tomedi et al. (2014) found increases in blood glucose corresponded with steady increases in first-trimester weight, so controlling weight will mitigate some of the effects of hyperglycemia.

Study Question 1

There were several significant findings in this study related to infection, maternal hypertension, maternal weight gain, fetal and infant morbidity and mortality, and gestational age when racial differences were assessed within the group of women with diabetes.

In this study, there were significant differences by race among women in the type of diabetes. African American women had significantly more preexisting diabetes in this study, while Caucasian women had more GDM than the other women with diabetes. Fifty percent of African American women will have diabetes in their lifetimes (CDC, 2015), and this study shows a predisposition for T1DM and T2DM. However, Cabacungan et al. (2012) found that African American and Caucasian women had similar rates of GDM. More preexisting diabetes

would indicate that African American women will have longer exposure to hyperglycemia than those who develop GDM during pregnancy only. When women experience longer exposure to hyperglycemia from preexisting diabetes prior to pregnancy, this leads to more alterations in maternal organ systems and high glucose episodes from conception through delivery. In this database, the severity of diabetes is not documented, as there are no lab values, creatinine, HgA1C, or diagnosis codes that would be useful for quantifying hyperglycemia or organ damage prior to or during pregnancy. The greater prevalence of preexisting diabetes in African American women with diabetes in the current study is of great concern.

In this study, racial differences in the number of perinatal infections were found, concurring with earlier research by Cabacungan et al. (2012). Additionally, Caucasian women with diabetes in this study were the least likely to have infections during pregnancy, while African American women with diabetes had more infections than Caucasian or Hispanic women. Obesity is also associated with increased infections; as in previous studies, African American women with diabetes in the current study had the highest prepregnancy BMIs when compared to Caucasian and Hispanic women with diabetes (Fine et al., 2009; Heslehurst et al., 2008; MacDorman & Mathews, 2009; MacDorman et al., 2014; Sen et al., 2016). In addition, researchers have demonstrated that in general, African Americans have higher glycemic index diets, HgA1C, and postprandial glucose, which can increase infection risk (Cabacungan et al., 2012; Hu et al., 2009; Mocarski, 2012; Selvin et al., 2011).

Caucasian women with diabetes in this study had significantly fewer preterm deliveries and their infants had less hyperbilirubinemia than African American or Hispanic women with diabetes. In general, infants who are born closer to term have better liver maturity and therefore tend to have less hyperbilirubinemia (HAPO, 2008; Knight et al., 2012). The decrease in preterm

births found in this study is likely related to Caucasian women with diabetes having increased GDM and shortened exposure to hyperglycemia versus African American or Hispanic women with diabetes. In prior studies, prevalence of hyperbilirubinemia increased with higher blood glucoses, indicating that there likely is better control of diabetes in Caucasian women (HAPO, 2008; Knight et al., 2012), although this could not be confirmed in the current study.

In this study, African American women with diabetes had prepregnancy hypertension more frequently than other women with diabetes. This is consistent with a study by Cabacungan et al. (2012) and corresponded to increases in kidney disease, hypertension, and kidney failure in African American women with preexisting diabetes (Damm et al., 2013; Gyamlani & Geraci, 2013; Hughson et al., 2014; Jones & Hayslett, 1996; Khoury et al., 2002; Stratta et al., 2006).

A significant finding related to infant mortality was not expected due to the limited longitudinal data found in PeriData.Net® ; however, this study revealed that disparities related to fetal and neonatal mortality exist from 20 weeks of pregnancy to within a few days postpartum. Poor glucose control, diabetes-related complications, and alterations in fetal growth leading to macrosomia increase risk for fetal death, as Inturrisi and Lintner (2011), Hawdon (2011), and Kelemetti et al. (2016) have demonstrated. Statistically significant increases in fetal and infant mortality were reported in the literature when African American women with diabetes were compared to other women with diabetes. African American women in the community from which the current sample was drawn have a history of significantly higher infant mortality than Caucasian or Hispanic women (WDHS, 2016b).

Researchers have demonstrated that breastfeeding offsets some increased adverse outcomes that infants born to women with diabetes experience, such as hypoglycemia, jaundice, and development of obesity and diabetes in the future (Bromiker et al., 2006; Fallon, 2015;

Kachoria & Oza-Frank, 2014a, 2014b; Stube, 2015). In the current study, Caucasian women with diabetes were more apt to be breastfeeding at discharge than other women with diabetes, while African American women were breastfeeding significantly less than other women with diabetes. Other studies also identified that African American women breastfeed less than their Caucasian counterparts; however, African American women with diabetes were overall more likely to breastfeed at discharge than African American women without diabetes (Kachoria & Oza-Frank, 2014a, 2014b). Women with T1DM were less likely to breastfeed mostly due to interruptions related to maternal or infant stability concerns (Sparud-Lundin, Wennergren, Elfvin, & Berg, 2011). Considering the protective effects of breastfeeding, it will be important in this community to encourage breastfeeding among African American women with diabetes.

In this study, Hispanic women with diabetes were found to have less prepregnancy hypertension than other women with diabetes. This is consistent with research by Berggren, Boggess, Jonsson Funk, and Stuebe (2012) showing that among women with GDM, Hispanic women had less adverse outcomes and had less hypertension than women of other races. Other researchers reported that Latino women with diabetes had higher birth weights and a greater prevalence of shoulder dystocia (HAPO, 2008; Kieffer et al., 2006); however, these effects were not found in the current study. There were no other significant findings for Hispanic women compared to other women with diabetes in this study.

African American women with diabetes had significantly more premature infants in this study than Hispanic and Caucasian women with diabetes. This is consistent with other studies where researchers in many studies reported higher rates of prematurity in African Americans (Al-Gubory et al., 2010; Berggren et al., 2012; Cabacungan et al., 2012; Sen et al., 2016). When

gestational age was controlled in this study, there were no differences in birth weight by race in women with diabetes.

Other researchers have shown that overweight and obesity have many adverse effects in pregnancy (Reece, 2008; Robbins et al., 2014; Salihu et al., 2011; WDHS, 2010). Nearly all the women with diabetes in this study were overweight or obese. Additionally, racial differences were found in maternal weight at delivery after controlling for gestational age in this study. No significant differences were found in the current study for maternal weight change during pregnancy by race after controlling for gestational age, indicating that women with diabetes all gained similar amounts of weight regardless of race.

In this study, African American women with diabetes weighed more at the beginning of pregnancy than other women with diabetes. African American women are known to have higher rates of obesity than other women (NCHS, 2012; WISH, 2014). Maternal obesity, particularly in the presence of diabetes, increases adverse fetal and infant outcomes, challenging the infant into adulthood with obesity, diabetes, and heart disease; maternal obesity has also been associated with autism (N. Li et al., 2016; Mitcanchez et al., 2013). One area of potential intervention in this community is to reduce starting weight entering pregnancy for all women; encouraging African American women who have diabetes and are of childbearing age to begin pregnancy with a lower BMI is particularly important.

Study Question 2

Comparing women with diabetes versus women without diabetes revealed several significant differences that could be used for intervention development.

Women with diabetes in this study did not gain as much weight during pregnancy as those without diabetes despite matching women with diabetes and women without diabetes on

prepregnancy BMI. Though there is still work to do to decrease prepregnancy BMI overall, maintaining pregnancy-related weight gain within IOM standards improves outcomes related to altered fetal growth (Gavard et al., 2014; Asvanarunat, 2014).

Higher rates of cesarean section were found in women with diabetes in this study. The percentage of women with diabetes who had C-sections was 44.8% in this study, which is far above the WHO recommendations for cesarean section rates of 10%–15% (WHO, 2015). Current recommendations encourage higher rates of cesarean section if fetal growth appears accelerated when diabetes is present to decrease the risk of shoulder dystocia (Alwan et al., 2009). Previous studies indicated that women with diabetes have more dysfunctional labor and cesarean section, especially with extra weight gain in pregnancy (Acker et al., 1985; HAPO, 2008; Hawley, 2015; Inturrisi & Lintner, 2011; Jain et al., 2007; Kieffer et al., 2006; Östlund et al., 2003; Park & Kim, 2015). Women without diabetes in this study also had a higher rate of cesarean section than might be anticipated, at 30%, given that the state average was about 26% (American College of Obstetrics and Gynecologists, 2014). Again, with the women from this study case matched by BMI, weight likely played a role in cesarean section; however, diabetes certainly adds to the potential for cesarean section.

Among women in this this study, those with diabetes were much more likely to have infants born preterm than women without diabetes. The increased levels of prematurity among women with diabetes is consistent with other researchers' findings (Boghossian et al., 2014; HAPO, 2010; Knight et al., 2012). Again, this may be explained in part by current recommendations that women have intense monitoring with nonstress tests, ultrasounds, and biophysical profiles as indicated, leading to earlier intervention due to the risk of stillbirth, increased preeclampsia, and need for cesarean section if the infant appears macrosomic (ADA,

2014; Bodmer-Roy et al., 2012; Inturrisi & Lintner, 2011). Any indication of fetal compromise can lead to early induction or cesarean section.

The infants in this study born to women with diabetes experienced increased hyperbilirubinemia, respiratory intervention, and NICU admissions than those born to women without diabetes. There were differences in prematurity between the women with and without diabetes, but previous studies have demonstrated that full-term infants born to women with diabetes can have immature organ systems (Coustan, 2013; HAPO, 2008; Hollander et al., 2007; Inturrisi & Lintner, 2011; Knight et al., 2012; Melamed et al., 2016). Researchers have shown that inducing labor before 39 completed weeks increased NICU admission among women with GDM (Melamed et al., 2016). Though there were significant differences in gestational age between those with and without diabetes in this study, the average gestational age in both groups was over 38 weeks, and only 25% of the women with diabetes gave birth at less than 37 completed weeks of gestation.

Infants born to women with diabetes in this study were more likely to be LGA or macrosomic compared to their non-diabetes-affected counterparts. The acceleration of fetal growth seen in fetuses exposed to diabetes leads to increases in the risk of shoulder dystocia, dysfunctional labor, and cesarean section (Berntorp et al., 2015; Boghossian et al., 2014; Coustan, 2013; Esakoff et al., 2009; HAPO, 2008; Hollander et al., 2007; Park & Kim, 2015; Persson et al., 2009; Persson et al., 2012; Scifres et al., 2014; Siegel, 2015). The findings of this study are consistent with many other studies showing that infants of women with diabetes have altered growth patterns in response to diabetes exposure (Berntorp et al., 2015; Boghossian et al., 2014; Coustan, 2013; Esakoff et al., 2011; HAPO, 2008; Hollander et al., 2007; Park & Kim, 2015; Persson et al., 2009; Persson et al., 2012; Scifres et al., 2014; Siegel, 2015).

The infants affected by diabetes were also more likely to have been exposed to abnormal amniotic fluid levels in utero, which can be seen as an indicator of kidney changes and placental alterations. These alterations in amniotic fluid level in women with diabetes were significant compared to women who did not have diabetes. Researchers have previously shown significant changes to the placenta from diabetes (Altshuler, 1984; Amer & Heller, 2010; Edu et al., 2016; Huynh et al., 2015). Increased maternal glucose increases the volume of amniotic fluid (Dashe, Nathan, McIntire, & Leveno, 2000). Placental choriangiosis, an overgrowth of vessels in the placenta, and oligohydramnios have been found in pregnancies affected by diabetes; these conditions increase the risk of fetal intolerance of labor, cesarean section, and fetal mortality (Dashe et al., 2000; Huynh et al., 2014; Petersen, Khangura, Davydov, Zhang, & Sangha, 2017). As noted, fetuses exposed to diabetes in this study did have higher rates of cesarean section delivery and mortality if African American.

In addition to consequences experienced by women with diabetes that affect the fetus, this study is focused on the outcomes of infants born to women with diabetes. The need for IV therapy for treatment of hypoglycemia was significantly higher in infants born to women with diabetes. This is consistent with other studies showing that exposure to maternal hyperglycemia and resulting fetal hyperinsulinemia lead to higher hypoglycemia episodes in the infant (Coustan et al., 2013; Hawdon, 2008; Longo et al., 2013; Suk et al., 2015; Younwainichsetha & Phumdoung, 2013). Only severe cases were captured in this study. A recommendation for labor and delivery units using the results from this study would be to indicate clearly any intervention for hypoglycemia in the infant, such as feeding or an IV. For future studies, databases should record the infants' lowest blood glucose to capture the severity of the hypoglycemia, a measure currently not considered in PeriData.Net®.

When assessing fetal and infant morbidity, a known contributor to mortality, there were significant differences between the groups with and without diabetes, as discussed previously in this chapter. Maternal stress and stress experienced by the fetus exposed to diabetes can lead to changes in the infant immune system, increases in preterm birth and IUGR, and altered infant birth weight (Cabacungan et al., 2012; Fine et al., 2009; Hayes, Feigal, Smith & Fuddy, 2014). Stress can be explored through qualitative studies, additional surveys, and quantitative evaluation of known stressors, such as domestic violence or preterm labor. Stress has been suggested by researchers as an area for further exploration, particularly as work continues to understand the DOHaD theory and explain disparities in infant mortality (Cabacungan et al., 2012; Fine et al., 2009; D. K. Hayes et al., 2014; Silveira et al., 2007).

When women with diabetes versus without diabetes were compared, there was no significant difference in infant or fetal mortality. However, in this sample, many fetal and most infant deaths were not captured in the database. PeriData.Net® only covers time in the hospital and therefore does not capture the full infant mortality risk during the first year.

Study Question 3

Gestational hypertension can increase the risk of preeclampsia, while parity can alter fetal weight and pregnancy outcomes. When these two factors are considered along with prepregnancy BMI, gestational weight gain, and maternal diabetes, effects can be seen on infant morbidity measures, as described below for this study. Cesarean section, assisted delivery, and shoulder dystocia can all lead to significant infant morbidity and even have lifelong impacts on the child's health (Coustan, 2013).

In the current study, the combination of higher BMI, lower parity, more weight gain, and the presence of diabetes was significantly predictive of cesarean section, as has been seen with

other studies (Jain et al., 2007; Östlund et al., 2003). Hawley (2015) also reported that gestational weight gain increased the risk for C-section. At the institution from which the current study sample was drawn, few providers use forceps, so assisted delivery is usually done when the fetus is low enough in the pelvis for vacuum assistance; otherwise, cesarean section is performed. Working with women to lower BMI before pregnancy and continuing to work with women to limit their weight gain during pregnancy would likely have a significantly positive impact on the rates of cesarean section.

The only predictor for assisted vaginal delivery of any significance was parity. Certainly women with no previous deliveries do not have a proven pelvis, and first-time labors are longer (Neal et al., 2010). In the case of diabetes, labors can also be more dysfunctional (Acker et al., 1985; Inturrisi & Lintner, 2011; Östlund et al., 2003).

Prior studies have suggested shoulder dystocia may be higher when diabetes is present or when prediabetes is present (HAPO, 2008; Kieffer et al., 2006). In the current study, shoulder dystocia was not predicted by any of the variables, including diabetes; however, the odds ratio of shoulder dystocia was higher for women with diabetes. This increase in shoulder dystocia is clinically interesting, even though it did not reach significance. However, the fact that significantly higher shoulder dystocia was not found in the current study was somewhat expected, because therapy to treat hyperglycemia, current surveillance with ultrasound, and guidelines for cesarean delivery may have decreased the opportunity for altered fetal growth and shoulder dystocia (Alwan et al., 2009). Only a small number of women in this sample experienced shoulder dystocia (46 cases, or 2% of the total sample), as it is a rare though serious complication.

Study Question 4

When prepregnancy BMI increased in women with diabetes, less fetal intolerance of labor was found in this study; this is likely due to the decision to move toward delivery with a cesarean section earlier if the infant has been compromised rather than to have the woman labor (Acker et al., 1985; Coustan, 2013; HAPO, 2008; Inturrisi & Lintner, 2011; Persson et al., 2009; Persson et al., 2012).

In the current study, regardless of what delivery method was used, APGARs were lower and congenital anomalies were higher in the infants born to women as prepregnancy BMI increased in agreement with previous work by Coustan (2013) and Heslehurst et al. (2008). Lower APGARs among infants correspond to poor adjustment to extrauterine life immediately after delivery despite neonatal resuscitation interventions starting within 30 s of delivery. Other studies have also shown higher congenital anomalies in infants with increasing maternal BMI (Anderson et al., 2001; Chen et al., 2009; Reece, 2008). More fetal and infant anomalies are likely seen in women with higher BMI due to decreased absorption of nutrients like folic acid, increased metabolic syndrome, and difficulties visualizing the fetus with ultrasound (Catalano et al., 2003). More fetal and infant anomalies would be anticipated with maternal diabetes, but significant differences were not identified in this sample. No differences in anomalies related to diabetes may be due to the fact that data on anomalies in PeriData.Net® only reflect those anomalies noticeable very early in life. Most chromosomal issues would not be identified until after data had been entered into PeriData.Net® unless they were visible or identified via ultrasound in pregnancy.

In the current study, a decision was made to combine the categories of IUGR and SGA because of the low numbers of IUGR fetuses and the lack of consistency in recording IUGR in

PeriData.Net®. Infant size was generally larger for infants born to women with diabetes; however, fewer infants than anticipated were SGA, as diabetes compromises the placenta and can cause downregulation of fetal growth, leading to the thrifty phenotype. A higher prevalence of SGA was reported by other researchers in women with T1DM (El-Masry et al., 2013; Handisurya et al., 2011), though there is some conflicting evidence (Balsells, García-Patterson, Gich, & Corcoy, 2009). PeriData.Net® does not capture T2DM and T1DM separately, so the exact number of women with T1DM is unknown but is likely very small. There is also some concern regarding the growth charts used at the study site, as discussed further in the limitations.

Infants in this study with macrosomia and LGA infants were captured in one variable so that excess growth could be quantified. In this study, increased prepregnancy BMI was found to increase the odds of LGA, but only when diabetes was present. These increased odds of LGA with diabetes corresponded with previous studies (Knight et al., 2012). However, other studies have shown that maternal BMI alone increases LGA, which was not seen in this study (Dennedy et al., 2012). The overall BMI of the chosen sample was higher, at 33.16, than the average BMI of 29.15 for all the pregnant women who delivered from 2013 to 2017 at the current institution. In other studies, LGA and macrosomia were found to be higher in T2DM and GDM; in one study, even when diabetes was well controlled in normal-weight women, more LGA was noted (El-Masry et al., 2013; Handisurya et al., 2011; Park & Kim, 2015). The current study, in agreement with previous studies, showed that there is an additive effect between higher BMI and diabetes, increasing LGA, and macrosomia (Berntorp et al., 2015; Esakoff et al., 2011; Scifres et al., 2014; Siegel, 2015).

Limitations and Recommendations

This study was conducted using is a secondary analysis, which limited the nature of the variables that could be studied, as the data had already been collected. Results should be generalized with caution, because the sample was selected from a single community. There is some concern regarding the assessment of SGA and LGA, because the institution from which the sample was drawn and many other institutions continue to use an older fetal growth curve for determining SGA and LGA. There are also ongoing discussions within the perinatal community regarding whether the traditional cutoffs for SGA and LGA of 10% and 90% are appropriate or if the cutoffs should be 3% and 97%. For this study, growth curves developed more recently from women of different backgrounds and locations, which are more representative of the study sample, were chosen to produce the designations of SGA and LGA (Duryea et al., 2014).

The PeriData.Net® database limited the analysis that could be conducted due to the variables available. For future research, having HgA1Cs at the beginning and through pregnancy would be helpful to understand the severity of diabetes through the pregnancy. It would be of key importance to understand whether the preexisting diabetes was T1DM or T2DM, as there can be different pathophysiology, therapy, and severity (Cundy et al., 2007).

Another key area where PeriData.Net® could be improved would be to organize the variable collection and labels to make it easier to find related variables and reduce the amount of written data within the database. In the categorizations of infant outcomes, there were several places for birth defects, and they had to be hand coded to ensure that the outcomes were captured within the right category. Another recommendation would be for the hypoglycemia protocol to be identified clearly as to whether it was implemented in PeriData.Net® , along with any interventions used. It is also important to note if formula was needed for sugar maintenance

given the impact on breastfeeding outcomes. Formula use has been shown to have a negative impact on the infant's microbiome (Madan et al., 2010). Hypertension prior to pregnancy, gestational hypertension, preeclampsia, and eclampsia could be found in the database; however, each was expressed as a separate variable, and all variables needed to be consolidated to fully capture hypertension-related influences. It would be helpful to researchers to have a quantitative measure of the severity of the hypertension, as this is not indicated clearly and had to be deduced from the presence or absence of variables. There was also very little data about lifestyle in PeriData.Net® , for example, no mention of exercise was found in the database.

Conclusion

Diabetes contributes to elevated infant morbidity and mortality found in one small urban community in Wisconsin and has more of an impact on pregnancies than previously realized. Secondary analyses are, by their very nature, somewhat limiting, as the researcher has no control over the data collection or variable definitions. The questions that could be answered were limited by the level of some of the variables. Nevertheless, some interesting results emerged in this study that may have an impact on future interventions and that provided a greater understanding of the impact of diabetes on maternal and fetal outcomes within this population.

In agreement with other studies, the current study found higher rates of cesarean section reducing rates of fetal intolerance of labor within this population. Diabetes did increase the odds of having shoulder dystocia, and diabetes along with elevated maternal BMI increased the prevalence of LGA and macrosomic infants. This study indicated that there are positive signs that women with diabetes are improving their lifestyles to decrease weight gain and that they are accessing prenatal care, but there are still ongoing challenges with smoke exposure during pregnancy, prepregnancy BMI, prepregnancy hypertension, gestational hypertension, cesarean

section rates, and maternal infections. Fetuses and infants of women with diabetes in this community were shown to have concerns with prematurity, hyperbilirubin, hypoglycemia, abnormal fetal growth pattern, NICU admission, abnormal amniotic levels, and respiratory intervention. There is the potential for increased breastfeeding within the entire population as the rates for any breastfeeding are still below Healthy People goals particularly in the African American population where infant mortality is markedly increased compared to Caucasians. The risk of diabetes development in the future can be decreased for both the woman and her infant though breastfeeding.

Diabetes has the potential to profoundly impact maternal, fetal, and infant health during pregnancy and beyond. Researchers continue to add to the opportunity to significantly impact individual women, their developing fetuses, families, and the community, compelling nurse researchers to conduct studies to understand the impact of diabetes during pregnancy. Despite advances in medical management, understanding the pathophysiology of diabetes and being aware of the risks that diabesity has on pregnancy remain vital.

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APPENDIX A: NONSIGNIFICANT DEMOGRAPHIC COMPARISONS BY ANY DIABETES

Table A1

Maternal and Infant Categorical Characteristics by Any Diabetes

	Diabetes (*n* = 660)		No diabetes (*n* = 1,323)	
	Frequency	Percentage	Frequency	Percentage
Private payment source	411	62.5	801	60.6
Cigarette smoking/exposure	158	23.9	312	23.6
Male gender	317	48.0	636	48.1

Table A2

Maternal and Infant Continuous Characteristics by Any Diabetes

	Diabetes			No diabetes		
	N	*M*	*SD*	*N*	*M*	*SD*
Educational level	651	2.44	0.89	1,310	2.46	0.91
Number of prenatal visits	656	11.22	3.20	1,319	11.42	3.16
Head circumference	646	34.27	2.22	1,291	34.34	1.97

APPENDIX B: NONSIGNIFICANT RESULTS FOR STUDY QUESTION 1

Table B1

Women with Diabetes: Maternal and Infant Characteristics and Events by White Race

	White race (*n* = 286)		Other single race (*n* = 248)	
	Frequency	Percentage	Frequency	Percentage
Any hypertension	67	22.0	65	23.2
Prepregnancy hypertension	28	9.2	24	8.6
Gestational hypertension	39	12.8	41	14.6
Abnormal amniotic fluid	32	10.5	23	8.2
Dysfunctional labor	3	1.0	2	0.7
Cephalopelvic disproportion	2	0.7	2	0.7
C-section	145	47.5	113	40.4
Assisted vaginal delivery	6	2.0	8	2.9
Fetal intolerance of labor	22	7.2	25	8.9
Preterm	76	24.9	78	27.9
APGAR 1 min under 7	22	7.3	23	8.3
APGAR 5 min under 7	1	0.3	3	1.1
NICU admission	55	18.2	51	18.5
Respiratory intervention	28	9.3	26	9.5
IV for hypoglycemia	19	6.3	26	9.5
Hyperbilirubinemia	24	7.9	25	8.9
Birth injury	8	2.6	12	4.3
Shoulder dystocia	5	1.6	10	3.6
Newborn withdrawal syndrome	2	0.7	0	0.0
Metabolic disturbance	0	0.0	0	0.0

Table B1 (*continued*)

	White race (*n* = 286)		Other single race (*n* = 248)	
	Frequency	Percentage	Frequency	Percentage
Electrolyte imbalance	1	0.3	1	0.4
Newborn infection	20	6.6	17	6.1
Any congenital anomaly	9	3.0	11	3.9
Chromosomal anomaly	2	0.7	2	0.7
Fetal or infant mortality	3	1.0	6	2.1
Small for gestational age	20	6.6	20	7.1
Large for gestational age	52	17.0	56	20.0

Note. NICU = neonatal intensive care unit.

Table B2

Women with Diabetes: Maternal and Infant Characteristics and Events by Black Race

	Black race (*n* = 115)		Other single race (*n* = 470)	
	Frequency	Percentage	Frequency	Percentage
Maternal infection	49	49.0	155	35.7
Gestational hypertension	22	19.1	58	12.3
Abnormal amniotic fluid	12	10.4	43	9.1
Dysfunctional labor	1	0.9	4	0.9
Cephalopelvic disproportion	1	0.9	3	0.6
C-section	49	42.6	209	44.5
Assisted vaginal delivery	4	3.5	10	2.1
Fetal intolerance of labor	10	8.7	37	7.9
APGAR 1 min under 7	14	12.6	31	6.6
APGAR 5 min under 7	2	1.8	2	0.4
NICU admission	26	23.4	80	17.1

Table B2 (*continued*)

	Black race (*n* = 115)		Other single race (*n* = 470)	
	Frequency	Percentage	Frequency	Percentage
Respiratory intervention	17	15.3	37	7.9
IV for hypoglycemia	12	10.8	33	7.1
Hyperbilirubinemia	12	10.4	37	7.9
Birth injury	6	5.2	14	3.0
Shoulder dystocia	6	5.2	9	1.9
Newborn withdrawal syndrome	0	0.0	2	0.4
Metabolic disturbance	0	0.0	0	0.0
Electrolyte imbalance	0	0.0	2	0.4
Newborn infection	12	10.4	25	5.3
Any congenital anomaly	5	4.3	15	3.2
Chromosomal anomaly	0	0.0	4	0.9
Small for gestational age	9	7.8	31	6.6
Large for gestational age	22	19.1	86	18.3

Note. NICU = neonatal intensive care unit.

Table B3

Women with Diabetes: Maternal and Infant Characteristics and Events by Hispanic Race

	Hispanic race (*n* = 143)		Other single race (*n* = 442)	
	Frequency	Percentage	Frequency	Percentage
Maternal infection	52	40.9	152	37.3
Any hypertension	23	16.1	109	24.7
Gestational hypertension	18	12.6	62	14.0
Abnormal amniotic fluid	10	7.0	45	10.2
Dysfunctional labor	1	0.7	4	0.9
Cephalopelvic disproportion	1	0.7	3	0.7
C-section	61	42.7	197	44.6
Assisted vaginal delivery	2	1.4	12	2.7
Fetal intolerance of labor	14	9.8	33	7.5
Preterm	29	20.3	125	28.3
APGAR 1 min under 7	9	6.3	36	8.3
APGAR 5 min under 7	1	0.7	3	0.7
NICU admission	22	15.4	84	19.3
Respiratory intervention	9	6.3	45	10.3
IV for hypoglycemia	12	8.5	33	7.6
Hyperbilirubinemia	10	7.0	39	8.8
Breastfeeding at discharge	117	82.4	321	73.8
Birth injury	5	3.5	15	3.4
Shoulder dystocia	3	2.1	12	2.7
Newborn withdrawal syndrome	0	0.0	2	0.5
Metabolic disturbance	0	0.0	0	0.0
Electrolyte imbalance	0	0.0	2	0.5
Newborn infection	5	3.5	32	7.2

Table B3 (*continued*)

	Hispanic race (*n* = 143)		Other single race (*n* = 442)	
	Frequency	Percentage	Frequency	Percentage
Any congenital anomaly	6	4.2	14	3.2
Chromosomal anomaly	2	1.4	2	0.5
Fetal or infant mortality	1	0.7	8	1.8
Small for gestational age	11	7.7	29	6.6
Large for gestational age	33	23.1	75	17.0
Gestational diabetes	117	81.8	366	82.8

Note. NICU = neonatal intensive care unit.

Table B4

Women with Diabetes: Maternal Weight Gain and Infant Birth Weight by Race, Controlling for Gestational Age

	Caucasian			African American			Hispanic		
	N	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*
Birth weight	303	3,355.88	614.79	114	3,160.53	878.55	142	3,433.77	672.35
Weight gain	303	26.11	18.41	112	24.62	18.13	142	21.82	14.55

APPENDIX C: NONSIGNIFICANT RESULTS FOR STUDY QUESTION 2

	Diabetes (*n* = 660)		No diabetes (*n* = 1,323)	
	Frequency	Percentage	Frequency	Percentage
Gestational hypertension	86	13.0	134	10.1
Labor and delivery				
Dysfunctional labor	5	0.8	5	0.4
Cephalopelvic disproportion	4	0.6	8	0.6
Fetal intolerance of labor	51	7.7	104	7.9
Birth injury	22	3.3	34	2.6
Shoulder dystocia	17	2.6	29	2.2
Maternal infection	232	38.4	470	37.2
Fetal/infant outcomes				
APGAR 1 min under 7	49	7.5	85	6.5
APGAR 5 min under 7	5	0.8	13	1.0
Newborn infection	44	6.7	77	5.8
Congenital anomalies	22	3.3	49	3.7
Breastfeeding at discharge	490	75.2	927	70.8
Newborn withdrawal syndrome	4	0.6	4	0.3
Electrolyte imbalance	3	0.5	1	0.1
Small for gestational age	44	6.7	123	9.3
Fetal or infant mortality	9	1.4	16	1.2

APPENDIX D: NONSIGNIFICANT RESULTS FOR STUDY QUESTION 3

Variable entered	*B*	*SE*	Wald	Odds ratio
Prepregnancy BMI	0.009	0.02	0.21	1.01
Parity	−0.046	0.11	0.18	0.96
Any diabetes	0.298	0.32	0.88	1.35
Weight gain	0.013	0.01	2.63	1.01
Gestational hypertension	−1.124	0.73	2.36	0.33

Note. BMI = body mass index.

CURRICULUM VITAE

PERSONAL DATA

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EDUCATION

2018	Doctor of Philosophy: Nursing	College of Nursing University of Wisconsin – Milwaukee Milwaukee, Wisconsin
2010	Master of Science: Women's Health Nurse Practitioner Master of Science: Nurse Educator	School of Nursing University of Wisconsin- Madison, Madison, Wisconsin
2004	Bachelor of Science: Nursing	College of Nursing University of Wisconsin- Milwaukee Milwaukee, Wisconsin
2000	Bachelor of Science: Chemical Engineering	College of Engineering University of Wisconsin-Madison Madison, Wisconsin

CURRENT LICENSES AND CERTIFICATIONS

2015	Florida ARNP license	ARNP9404349
2011	Electronic Fetal Monitoring: NCC Certification	DZI1-0435-6719
2010	Wisconsin APNP license	WI4380
2010	Women's Health Nurse Practitioner: Board Certification	DZI1-0435-6719

PROFESSIONAL EXPERIENCE

10/15 – current	Nurse Practitioner Endocrine Specialist, Naples, FL
05/15 – 09/15	Nurse Practitioner North Florida Medical Center at River Valley - Mayo, FL
05/14 – 05/15	Adjunct Faculty Bryant and Stratton College, Wauwatosa/Bayshore, WI
09/13 – 05/14	Adjunct Faculty/ Nurse Practitioner Milwaukee School of Engineering, Milwaukee, WI

09/11- 09/13	Clinical Nurse Specialist/ Clinical Development Coordinator Wheaton Franciscan Healthcare - All Saints, Racine, WI
01/11 – 05/13	Clinical Lecturer/ Guest lecturer University of Wisconsin – Milwaukee, Milwaukee, WI
01/05 - 09/11	Registered Nurse, Labor and Delivery/Postpartum Meriter Hospital, Madison, WI
02/07 - 03/07	Registered Nurse, Volunteer Harvesters Reaching the Nations orphanage, Yei, Sudan.

SCHOLARSHIP

Presentations

03/17	9th International DIP Symposium on Diabetes, Hypertension, Metabolic Syndrome, and Pregnancy, Barcelona, Spain. Poster presenter and attendee.

Research

2009	Nurses feelings about birth technologies. UW Madison School of Engineering – Dr. Monteque, researcher. Question development and logistical support to the study.

PROFESSIONAL ACTIVITIES

Sigma Theta Tau International Nursing Honor Society
Golden Key International Honor Society
Association of Women's Health, Obstetrical, and Neonatal Nursing
Nurse Practitioner's in Women's Health
American Academy of Nurse Practitioners