Physical activity throughout pregnancy is key to preventing chronic disease

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Abstract

According to The Developmental Origins of Health and Disease theory, the intrauterine environment of the developing fetus may impact later life physiology, including susceptibility to chronic disease conditions. Maternal exposures during pregnancy can affect the intrauterine environment and result in fetal programming for chronic diseases through changes in the structure or function of specific organs. Negative maternal exposures, such as poor nutrition intake, have been shown to increase the risk for later life chronic diseases. On the contrary, healthful behaviors, such as physical activity, may have a positive and protective effect against chronic disease risk. This narrative review summarizes literature to discuss the potential preventative role prenatal physical activity may have on prevalent chronic diseases: obesity, type 2 diabetes, and cardiovascular disease. We describe the natural physiological response to pregnancy that may increase the risk for complications and consequently later life disease for both mother and baby. We then present evidence highlighting the role prenatal exercise may have in preventing pregnancy complications and downstream chronic disease development, as well as proposing potential mechanisms that may explain the protective maternal and fetal physiological response to exercise. As the prevalence of these non-communicable diseases increase globally, intervening during pregnancy with an effective exercise intervention may be the key to preventing chronic disease risk in more than one generation.

Introduction

The Developmental Origins of Health and Disease (DOHaD) theory proposes that the intrauterine environment of the developing embryo and fetus may have a major impact on later life physiology, including potential in utero programming for chronic disease risk (Barker 2007). Developmental plasticity suggests that a genotype gives rise to a range of physiological or morphological states in response to different environmental conditions sensed during development (Barker 2007, Gluckman et al. 2007). This plasticity may be reflected as fetal programming, which is a permanent or long-term change in the structure or function of a specific organ resulting from a stimulus or insult at critical periods of development and early life (Hales & Barker 2013).

The DOHaD theory is based on the link between maternal exposures during pregnancy, birth outcomes and later life chronic disease risk (Painter et al. 2005, Guarner-Lans et al. 2020). This is exemplified by the Dutch winter famine during 1944–1945 as medical records showed that women who experienced the famine early in gestation were more likely to have a small for gestational age (SGA) baby and a preterm delivery compared to women who were exposed to famine later in their second or third trimester or not exposed at all (Roseboom et al. 2000, Painter et al. 2005). Babies born preterm or SGA when examined longitudinally were at greater risk of developing cardiovascular disease and type 2 diabetes as adults, compared to babies that were born with an appropriate birthweight for gestational age at delivery (Roseboom et al. 2011).

The majority of the maternal exposure studies have focussed on the impact of nutrition on fetal development and chronic disease risk which consistently show that poor nutrition (inadequate or excessive intake) is associated with an increased risk for pregnancy complications (e.g. gestational hypertension, excessive or inadequate gestational weight gain, gestational diabetes) and later-life chronic diseases that can impact both the mother and developing fetus (e.g. cardiovascular disease, obesity, diabetes) (Roseboom et al. 2011, Hsu & Tain 2019). Physical activity during pregnancy has also been examined as a maternal exposure and has been associated with improved
Prevention of obesity with exercise during pregnancy for mother and offspring

The prevalence of obesity globally has been an increasing trajectory for nearly two decades, with recent global statistics suggesting that 18% of men and 21% of women will have a BMI $\geq 30.0$ kg/m$^2$ by 2025 (Collaboration 2016, Swinburn et al. 2019). Obesity is a chronic disease condition defined by excess adiposity, increasing the risk for other co-morbidities, including high blood pressure, mental health complications, and insulin resistance (Sharma & Kushner 2009). BMI has been criticized as a marker of measuring obesity, as BMI utilizes standard cut-offs based on height and weight and this does not assess body fatness and co-morbidities (Sharma & Kushner 2009). Although a BMI cut-off of $\geq 30.0$ kg/m$^2$ should not be used as the sole criteria to diagnose obesity, it remains a commonly used and accessible population-level measurement approach (Gutin 2018). During pregnancy there is a natural increase in insulin resistance and adaptations are made by metabolic and cardiovascular systems to support fetal development; however, women with obesity may have higher baseline blood glucose values and blood pressure, thus increasing their risk for additional complications, such as GDM or preeclampsia (Barbour 2014).

Furthermore, obesity during pregnancy has been associated with an increased risk for EGWG (Suliga et al. 2018). Gaining excessively during pregnancy may result in higher fetal adiposity and thus infants are more likely to be born LGA (Geserick et al. 2018). LGA newborns may experience childhood and adult obesity (Geserick et al. 2018), thus potentially perpetuating a cycle of obesity that actually had its origin in utero (Ruchat & Mottola 2012). Higher fetal adiposity, as a result of EGWG, has been linked with greater adipocytes, and increased fat storage capability in the offspring (Abeysekera et al. 2016). Additionally, studies have shown that EGWG and maternal obesity are associated with decreased cord blood leptin methylation (Lesseur et al. 2013, Kadakia et al. 2017), which suggests that there may be in utero programming of appetite dysregulation, and when coupled with an increase in fat storage capacity, can predispose infants to later life obesity (Lesseur et al. 2013, Abeysekera et al. 2016).

One study found that 35% of LGA babies born from mothers who had a pre-pregnancy BMI of obese, also had obesity by age 11 (Boney et al. 2005). Individual patient data from over 100,000 women and children pairs showed that the risk for childhood obesity (ages 2–5 years) was 1.72 times higher among children of women who had gained excessively than appropriately during pregnancy (Voerman et al. 2019). In addition to delivering LGA newborns, which in itself has consequences for labor and birth, pregnant women who gain excessively are at risk for postpartum weight retention and this, in turn, can lead to later life obesity for the mother (Ruchat & Mottola 2012).

Infants born SGA who experience rapid weight gain or ‘catch-up growth’ in the first year of life are also at greater risk of developing obesity later in life (Singhal 2017). A proposed mechanism for obesity among infants born SGA is a potential mismatch between nutrient exposure during pregnancy and in the first year of life (Ezzahir et al. 2005). Due to poor placental nutrient transport or inadequate maternal nutrition intake, it is hypothesized that infants are more likely to be born SGA and in utero are programmed for a thrifty phenotype that upregulates fat storage (Hales & Barker 2001, Dulloo 2006). However once born, if nutrient availability increases, then the infant may continue to store fat and have high adiposity as a child and adult, and consequently develop obesity and obesity-related co-morbidities (Dulloo 2006). In fact, a recent systematic review and meta-analysis summarized longitudinal data from 17 studies and found that rapid catch-up growth up until age 2 was positively correlated with both percent body fat and BMI in the child at 6 years of age (Chen et al. 2020).

Exposure to exercise during pregnancy may be an effective intervention to prevent LGA and SGA babies, EGWG, postpartum weight retention in the mother and consequently, later life obesity for both mother and child. In a large sample of 962 pregnant women, a supervised light to moderate resistance and aerobic exercise program found that those women who exercised gained less weight than the inactive control group (Ruiz et al. 2013). Furthermore, high-quality evidence from a systematic review and meta-analysis (135 studies) suggested that prenatal exercise reduced the odds of delivering an infant born large by 39%, and did not increase the risk for SGA (Davenport et al. 2018b). Similarly, a systematic review and meta-analysis that included 84 studies found that exercise interventions delivered during pregnancy significantly reduced total gestational weight gain and postpartum weight retention in comparison to sedentary controls (Ruchat et al. 2018).
A recent animal study examined the multigenerational effect of physical activity in pregnant rats, and found that prenatal exercise reduced adiposity and glucose concentrations in offspring up to three generations later compared to rats that were sedentary throughout gestation (Martins Terra et al. 2020). Limited research has evaluated the effect of exercise during pregnancy on cord blood leptin levels and adipocytes in human models. One human study found that a healthy lifestyle intervention including physical activity and healthy eating during pregnancy, reduced leptin levels in female neonates compared to standard care (van Poppel et al. 2019). Furthermore, a follow-up study that included 1555 pregnant women with obesity found that prenatal exercise was associated with a decrease in infant adiposity at 6 months of age compared to the standard antenatal care group (Patel et al. 2017). Finally, contrary to the misconception that exercise will reduce maternal blood flow to the developing fetus, exercise during pregnancy improves endothelial function and increases vascular endothelial growth factors, and this, in turn, may be protective against SGA (Skow et al. 2017). Figure 1 summarizes the effect exercise during pregnancy may have on obesity prevention.

Prevention of type 2 diabetes with exercise during pregnancy for mother and offspring

According to the World Health Organization, 422 million individuals were affected by diabetes in the year 2014, with a rising incidence of early diagnosis of type 2 diabetes (https://www.who.int/news-room/fact-sheets/detail/diabetes; Accessed July 27 2020). Glucose intolerance that develops with first onset or recognition during pregnancy is defined as GDM (Plows et al. 2018). During a normal pregnancy, there is a cascade of hormonal events that create a pseudo-diabetic state of insulin resistance at the peripheral tissues with declining insulin sensitivity (Mottola & Artal 2016b). Since the fetus requires maternal blood glucose as a major source of energy for growth and development, these maternal adaptations occur to augment the maternal blood glucose supply (Plows et al. 2018). In order to maintain normal glucose regulation with the accompanying insulin resistance, the maternal pancreas and beta cells respond to the increasing insulin demand. Glucose intolerance may develop because of the inability of the maternal pancreatic beta cells to keep up with the insulin demand leading to hyperglycemia above normal values in the mother (Plows et al. 2018).

Epidemiological evidence has shown that GDM increases the risk for the child to have type 2 diabetes later in life, including the potential for earlier diagnosis during childhood or adolescence (Sellers et al. 2016). The increased risk for type 2 diabetes for the child may be due to the fetal response in utero to the high glucose concentrations crossing the placenta, which includes increasing fetal pancreatic insulin beta cell secretion to counter the high glucose resulting in potential pancreatic dysfunction (Thompson et al. 2013). Furthermore, at birth, when the umbilical cord is cut, the high glucose supply from the mother is immediately stopped, while the fetal pancreas continues to secrete high insulin concentrations, thus creating a state of hypoglycemia in the newborn (Thompson et al. 2013). Moreover, women who develop uncontrolled GDM are also at risk of having type 2 diabetes post-delivery (Thompson et al. 2013).

Exposure of exercise during pregnancy may be an effective method to prevent GDM, and as a result, reduce the risk for type 2 diabetes for mother and child. A systematic review and meta-analysis, including 106 studies, found that prenatal exercise interventions reduced the risk for GDM by 25% compared to standard care (Davenport et al. 2018b). These results were supported by an additional meta-analysis that found exercise during pregnancy significantly reduced the relative risk for GDM compared to physical inactivity in women with an overweight or obese pre-pregnancy BMI (Du et al. 2019). Furthermore, a recent systematic review and meta-analysis found that lifestyle interventions incorporating exercise reduced fasting and postprandial blood glucose concentrations, improved glucose tolerance and delayed or prevented the initiation of insulin in women diagnosed with GDM (Allehdan et al. 2019).

Exercise is considered an adjunctive therapy for women diagnosed with GDM by medical societies (Hopkins & Artal 2013); and there may be many mechanistic explanations for why exercise during pregnancy can also be protective against the development of GDM. First, engaging in low-moderate activity has acute benefits, including reducing maternal blood glucose concentration (Mottola & Artal 2016a). Secondly, maternal exercise promotes appropriate gestational weight gain and this also has a protective effect against GDM, as EGWG increases blood glucose concentrations.

Figure 1 Summary of the role of exposure of exercise/physical activity during pregnancy on the prevention of obesity, type 2 diabetes and cardiovascular disease for both mom and baby. PA, physical activity.
that are associated with a dysregulation of adipokines that normally regulate insulin sensitivity (Mottola & Artal 2016a). Moreover, the fetal-insulin hypothesis suggests that exposure to high levels of glucose in utero will promote an over-production of fetal insulin, and this will stimulate growth causing an increased risk for LGA newborns, hypoglycemia at birth, and consequently a predisposition to developing type 2 diabetes later in life (Hattersley & Tooke 1999). Alternatively, exposure to exercise during pregnancy reduces maternal circulating blood glucose and maternal-fetal transmission of glucose, and therefore prenatal exercise may prevent the development of type 2 diabetes in the child by reducing the risk for GDM, LGA birthweight and hypoglycemia at birth (Fig. 1) (Mottola & Artal 2016a,b, Davenport et al. 2018b).

Prevention of cardiovascular disease with exercise during pregnancy for mother and offspring

Cardiovascular disease (CVD) is the leading cause of mortality due to non-communicable diseases globally and accounts for approximately 17 million deaths around the world annually (https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds); Accessed May 21, 2020). There are natural adaptations to the maternal cardiovascular system during pregnancy to increase blood flow to the placenta and promote fetal development (Ouzounian & Elkayam 2012). There is an increase in maternal blood volume, cardiac output and maternal heart rate (Ouzounian & Elkayam 2012). The increase in maternal blood volume and cardiac output are coupled with a decrease in arterial blood pressure and systemic vascular resistance, thus controlling blood pressure (Ouzounian & Elkayam 2012). However, these natural responses, and with potential co-morbidities such as elevated blood pressure prior to pregnancy or obesity, may increase the risk for cardiovascular complications, such as gestational hypertension and preeclampsia. Preeclampsia may be diagnosed after 20 weeks of gestation if the pregnant woman has persistent hypertension (blood pressure >140/90 mmHg) and proteinuria (24 h urinary protein level ≥ 0.3 g/day) (American College of Obstetrics and Gynecology 2002). Previous longitudinal studies have shown an increased risk for later life cardiovascular disease if there was exposure to high blood pressure or preeclampsia in utero (Lee & Tubby 2015).

As discussed earlier, babies born SGA from mothers that experienced famine in their first trimester had a greater incidence of adult CVD (Roseboom et al. 2011). Hattersley and Tooke (1999) hypothesized that this may be due to abnormal vascular development causing poor vasodilation and blood circulation. Research has also shown that the risk of CVD increases with accelerated growth in the early years of life by examining blood pressure in 346 men and women at age 22 and weight measurements at birth and at 10 years of age (Law et al. 2002). Results showed that babies who were born SGA and experienced accelerated growth between ages 1–5 had the highest blood pressure at 22 years of age (Law et al. 2002). Mothers who have hypertensive disorders during pregnancy may experience continued high blood pressure post-delivery and are at risk for CVD (Lee & Tubby 2015).

Prenatal exercise improves maternal blood pressure and reduces the risk for developing gestational hypertension and preeclampsia (Davenport et al. 2018b). A systematic review and meta-analysis reported that women who meet physical activity guidelines reduced the risk of developing gestational hypertension and preeclampsia by 38% (Davenport et al. 2018b). In addition, exposure to prenatal exercise has been shown to improve placental growth and vascularity, and thus promote effective nutrient transport for fetal development (Weissgerber et al. 2010). Studies have demonstrated that prenatal exercise increases placental villous tissue volume (Weissgerber et al. 2010). This would reduce the risk for fetal hypoxia, intrauterine growth restriction and fetal malnutrition, and therefore there would be an improvement in fetal organ development that may have a preventative effect on developing heart disease in later life (Weissgerber et al. 2010). Meeting prenatal activity guidelines has been shown to reduce inflammatory markers, including C-reactive protein, which is associated with a reduced risk of elevated blood pressure during pregnancy (Hawkins et al. 2015). In addition to reducing inflammatory markers, exposure to exercise during pregnancy improves endothelial functioning, such as increasing angiogenesis and vasodilation, which may explain the reduced risk for preeclampsia and improvement in blood flow and nutrient transport to the placenta (Dubé et al. 2017, Skow et al. 2017). Potential factors contributing to the preventative effects of maternal exercise on CVD risk are summarized in Fig. 1.

Summary

According to the DOHaD theory, the risk for prevalent non-communicable chronic diseases, including obesity, type 2 diabetes, and cardiovascular disease, may be programmed in utero based on maternal exposures during pregnancy (Barker 2007, Gluckman et al. 2007). Natural physiological responses to pregnancy include gestational weight gain, an increase in circulating maternal blood glucose, and cardiac output (Ouzounian & Elkayam 2012, Thompson et al. 2013, Suliga et al. 2018). Exceeding gestational weight gain recommendations has been positively correlated with LGA newborns and postpartum weight retention, and this increases the risk for later life obesity (Ruchat & Mottola 2012). In addition, EGW may increase fetal adiposity and adipocytes, which increases fat storage. Infants born SGA, who experience rapid catch-up
growth in the first year of life, may also develop later life obesity and associated co-morbidities (Singhal 2017). Exposure to prenatal exercise reduces the risk for EGWG, postpartum weight retention in the mother and the risk of SGA, LGA and excessive fetal adiposity (Davenport et al. 2018a, Ruchat et al. 2018, van Poppel et al. 2019). Therefore engaging in moderate exercise during pregnancy can prevent later life obesity for mother and child.

Gestational diabetes and high maternal blood glucose results in an increase of glucose transported to the growing fetus which has detrimental effects on the development of the fetal pancreas and beta-cell functioning (Thompson et al. 2013). An increase in maternal blood glucose concentrations promotes fetal overgrowth leading to LGA newborns, macrosomia, and hypoglycemia at birth (Mottola & Artal 2016b). Prenatal physical activity reduces circulating maternal blood glucose, promotes appropriate fetal growth and development, and prevents GDM and thus reduces the risk for later life type 2 diabetes (Mottola & Artal 2016b).

Finally, the natural increase in maternal blood volume, cardiac output and heart rate coupled with co-morbidities, such as high blood pressure or obesity, increases the risk for gestational hypertension and preeclampsia (Skow et al. 2017). Newborns exposed to gestational hypertension or preeclampsia in utero are more likely to develop CVD in the future (Lee & Tubby 2015). However, engaging in prenatal physical activity improves maternal blood pressure, reduces inflammation, and prevents endothelial dysfunction, and therefore protects against hypertensive disorders during pregnancy (Skow et al. 2017). Figure 1 summarizes the preventative effects of prenatal physical activity on obesity, type 2 diabetes and cardiovascular disease discussed in this review.

**Recommended prenatal exercise/physical activity guidelines**

The 2019 Canadian Guideline for Physical Activity throughout Pregnancy is an evidence-based guideline that has been informed by 12 systematic reviews and is endorsed by national and international health organizations (Mottola et al. 2018). In consensus with other international guidelines (Evenson et al. 2014, 2019), the Canadian guideline suggests that pregnant women without any contraindications to exercise are encouraged to be active throughout gestation (Mottola et al. 2018). Women should aim to achieve 150 min of moderate-intensity exercise every week, which can be accumulated by exercising for 30 min on most days of the week (Mottola et al. 2018). There are three ways to monitor intensity during pregnancy: (1) talk-test: individuals should be able to maintain a conversation but not sing; (2) using the Borg’s Scale for Rating of Perceived Exertion: individuals should aim for a 12–14 (somewhat hard) on a 20-point scale; and (3) refer to heart rate cut-offs based on maternal age (Mottola et al. 2018).

Popular and safe physical activities during pregnancy, include walking, stationary cycling, swimming and aerobic prenatal group fitness classes (Mottola 2016). Women should also aim to include 2–3 days of resistance training, using lighter weights and more repetitions (Mottola 2016). Women who were sedentary prior to pregnancy are encouraged to start at the light-intensity level and continue, making any necessary modifications such as reducing the intensity or duration of the activity (Mottola 2016). Women who were sedentary prior to pregnancy are more likely to develop CVD in the future (Lee & Tubby 2015). However, engaging in prenatal physical activity protects against hypertensive disorders during pregnancy (Skow et al. 2017). Figure 1 summarizes the preventative effects of prenatal physical activity on obesity, type 2 diabetes and cardiovascular disease discussed in this review.

**Recommendations for future work**

Recommendations for future work related to pregnancy and exercise/physical activity includes diversifying the population being studied and determining effective strategies to increase adherence to guidelines. Majority of the research that has evaluated the preventative effects of prenatal exercise on pregnancy complications and future chronic conditions has included healthy pregnant women, with singleton pregnancies, no chronic conditions, no use of substances, similar ethnic backgrounds (mostly Caucasian) and high education levels. In addition, all studies that have examined prenatal obesity and exercise, have used BMI as a marker of obesity instead of more appropriate measurement methods of obesity as a chronic condition, such as the Edmonton Obesity Staging System (EOSS) (Sharma & Kushner 2009). The EOSS evaluates metabolic markers, presence of co-morbidities, and psychosocial factors to appropriately diagnose obesity, and this has been shown to be a better predictor of a chronic condition vs the BMI cut-off of ≥30.0 kg/m² which may account for EGWG, postpartum weight retention in the mother and the risk of SGA, LGA and excessive fetal adiposity (Davenport et al. 2018a, Ruchat et al. 2018, van Poppel et al. 2019). Therefore engaging in moderate exercise during pregnancy can prevent later life obesity for mother and child.

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for individuals who have an elevated BMI but are metabolically healthy (Richard et al. 2017). More research is needed to elucidate the potential protective effects of prenatal exercise on pregnancy complications for women who enter pregnancy at high risk, such as women who have type 2 diabetes, obesity or high blood pressure. In addition, we do not have exercise guidelines for women who may have twin or triplet pregnancies, and therefore we need randomized controlled trials that include this population group. Furthermore, as women may be active prior to pregnancy and engaging in higher intensity programs, future research should also further investigate the effects of high-intensity interval training during pregnancy on maternal and fetal outcomes.

Despite the known health benefits of prenatal physical activity, only 15% of pregnant women in North America report meeting guidelines (Huberty et al. 2016). Common barriers to physical activity include a lack of time, childcare and low self-efficacy to perform an exercise (Evenson et al. 2009). Future interventions should consider taking a patient-oriented approach to deliver exercise interventions to address and overcome individual barriers to behavior change. At the beginning of this review, we introduced the DOHaD theory, however, this theory can be extended and also include programming of behavioral mechanisms in utero, referred to as the Developmental Origins of Behavioral Health and Development (DOHaD) (Van den Bergh 2011). The DOHaD theory takes into account that maternal exposures during pregnancy also have an impact on fetal brain development and consequently future behaviors, such as mood and emotion regulation, knowledge processing, motivation and stress–response (Van den Bergh 2011). Therefore future interventions should include assessment of behavioral development of the newborn based on maternal exposures during pregnancy, including physical activity.

Conclusion
Exercise during pregnancy may be the key to reduce the prevalence of chronic conditions that currently have an increasing global trajectory including obesity, type 2 diabetes and cardiovascular disease. Encouraging women to lead an active lifestyle during pregnancy can reduce the risk for complications, promote appropriate fetal growth and improve overall health and well-being for mother and child. Future knowledge translation and implementation practices for increasing physical activity levels during pregnancy may include incorporating prescriptions or referrals for exercise during pregnancy into standard prenatal care practices to encourage all women to be physically active throughout gestation.

Declaration of interest
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