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The Influence of Exercise Types During Pregnancy on Maternal, Placental and offspring Outcomes: A Narrative Review

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ABSTRACT

Although exercise during pregnancy is safe for the mother and child. The majority of research has focused on continuous and aerobic-focused activities, such as calisthenics, yoga and aerobic exercise, such as swimming, jogging and dancing. Thus, obstetric and health guidelines from many countries, such as the American College of Obstetricians and Gynecologists (ACOG), the US Department of Health and Human Services Physical Activity Guidelines for Americans and the World Health Organization (WHO) state that pregnant and postpartum women should do 150 minutes of moderate-intensity aerobic activity per week. These guidelines also list resistance exercises, such as using weights and elastic bands, as examples of exercises. However, less direction and guidance are provided related to resistance or strength training during pregnancy. Thus, there is a disconnect between the evidence related to exercise types during pregnancy and the benefits for the mother, placenta and the offspring. Therefore, this is the first narrative review to summarize the current state of literature focused on the influence of gestational exercise types (aerobic, resistance/strength, combination/concurrent, light/yoga/Pilates) on maternal, placental and offspring responses at the gross and cellular levels.

Keywords: Pregnancy, Mother, Child, Placental, Fetal development, Aerobic exercise

Abbreviations: ACOG: American College of Obstetricians and Gynecologists; WHO: World Health Organization LDL-C: Low-Density Lipoprotein Cholesterol; HDL-C: High-Density Lipoprotein Cholesterol; CRP: C-Reactive Protein; CMR: Cardiometabolic Risk; MVPA: Moderate-To-Vigorous Physical Activity; ROS: Reactive Oxygen Species; HIIT: High-Intensity Interval Training; PW: Placental Weight

1. Introduction

Exercise during pregnancy initially started with ensuring it was safe for the mother and child. Initial activities assessed for safety included calisthenics, yoga and aerobic exercise, such as swimming, jogging and dancing[1,2] (ref). Thus, initial recommendations from the American College of Obstetricians and Gynecologists in 1985 were restrictive, limiting maternal heart rate to below 140 bpm, limiting strenuous activity to only 15 minutes and focused on women who were already active, while discouraging sedentary women from starting a new program during pregnancy[3]. Since the 1985 ACOG guidelines until now, substantial evidence supports not only the safety, but also the benefit of exercise throughout gestation for the mother, placenta and fetal development. Although a 2024 review denotes the safety of resistance training during pregnancy[4], the updated ACOG guidelines from 2020[5] and the 2018 update of the US Department of Health and Human Services Physical Activity Guidelines for Americans[6], state that women should do “at least 150 minutes of moderate intensity aerobic activity per week during pregnancy and the postpartum period[5]”. It also states that “women who habitually engage in vigorous-intensity aerobic activity or who were physically active before pregnancy can continue these activities during pregnancy and the postpartum period[5]”. Importantly, it lists resistance exercises, such as using weights and elastic bands, as an example of exercises with extensive research. However, it also states, “There are few maternal medical conditions in which aerobic exercise is absolutely contraindicated. When questions exist regarding the safety of aerobic exercise in pregnancy, consultation with relevant specialists and subspecialists is required[6].” Thus, it seems there is still a disconnect between the evidence related to exercise types during pregnancy and the benefits for the mother, placenta and the offspring. Therefore, this narrative review aims to summarize the current state of literature focused on the influence of gestational exercise types (aerobic, resistance/strength, combination/concurrent, light/yoga/Pilates) on maternal, placental and offspring responses at the gross and cellular levels.

1.1. Prenatal Exercise Types and Maternal Health Parameters

Pregnant individuals are advised to complete at least 150 minutes of moderate-intensity exercise each week. Activities that increase heart rate and induce mild to moderate sweating, such as walking, swimming, stationary cycling and low-impact aerobics, are ideal. Muscle-strengthening activities, including resistance exercises, weight training and yoga, are also encouraged[7,8]. Numerous studies support the safety and benefits of physical activity and exercise in pregnancy for gestational individuals. This includes reduced risk of excessive gestational weight gain and multiple adverse pregnancy conditions (i.e., gestational diabetes, hypertensive disorders and preterm birth)[9,10]. Exercise during pregnancy may promote a more favorable gestational (parent) environment through modifying parameters that influence cardiometabolic health, such as body weight and composition[11], blood lipid profiles[12,13] and inflammatory biomarkers[14,15]. Considering the individual physiological benefits that accompany regular aerobic and/or resistance exercise in non-pregnant adults, the exercise benefits for gravid individuals may differ, depending on exercise modality or type. This section will provide an overview of research related to the effects of aerobic, resistance or combination (aerobic + resistance) exercise during pregnancy on the gestational parent’s body composition and blood parameters (i.e., lipids, inflammation, metabolome and proteome), with a particular focus on the comparison of the exercise types.

1.2. Exercise Type and Body Composition

In non-gravid individuals, chronic exercise has profound effects on body composition, including changes to fat mass, lean mass and bone mineral density. Research consistently demonstrates that the adaptations are contingent on the magnitude and type of exercise performed. Aerobic exercise has been shown to reduce total fat mass and body fat percent[16]; have minimal or no effects on lean mass[17]; and result in moderate improvements to bone mineral density, particularly in the lumbar spine with load-bearing activity[18]. Resistance exercise alone demonstrates substantial increases in lean mass, even under caloric restrictions[19,20] and bone mineral density[21]. Although reductions in fat mass with resistance training are typically smaller, it can elicit decreases in body fat percentage when compared with non-exercising populations[17]. Finally, combination exercise appears to provide the most comprehensive benefits for body composition. This exercise type results in reduced fat mass and increased lean mass, similar to that of aerobic or resistance exercise alone, respectively[17]. Systematic reviews support the significant effect of combination exercise for optimizing overall body composition, highlighting additive or synergistic effects on both adipose and lean tissues compared with single-modality intervention programs; resistance components within these protocols help attenuate declines in bone mineral density that may accompany aerobic exercise or weight loss alone[19,21].

Pregnancy involves dramatic shifts in body composition throughout gestation in response to and to elicit changes in fetal development. These adaptations include increased blood volume as well as changes in the gestational parent adipose and musculoskeletal tissues. However, weight gain above the appropriate limit can lead to health complications for both the gravid individual and the fetus, such as hypertension, gestational diabetes, preterm birth, low birth weight and large-for-gestational-age infants[22]. Importantly, gestational exercise may influence how fat mass, lean mass and bone mineral density change across gestation for the gravid individual and fetus, aiding in appropriate weight gain. Although research is more limited in pregnant individuals, studies have been conducted to examine the associations between gestational physical activity and body composition outcomes.

Aerobic exercise and general physical activity during pregnancy have been associated with changes in fat mass and body fat percent. Observational studies indicate that pregnant individuals who maintain a higher volume of aerobic activity or greater daily step count gain less fat mass and exhibit lower visceral adipose tissue relative to less active individuals[23]. Although randomized trials of structured aerobic exercise, such as supervised walking or cycling programs, have shown only modest effects on total fat mass relative to standard care[24], habitual daily activity appears to correlate with more favorable fat accumulation patterns[25,26]. It's been reported that pregnant individuals with overweight or obesity have reduced excessive gestational weight gain and an attenuation of adipose tissue accumulation with antenatal aerobic exercise relative to controls[27]. Similarly, structured prenatal exercise programs have been associated with lower fat storage and improved body composition trends in pregnant individuals relative to inactive controls[28]. Collectively, these findings support aerobic activity during pregnancy, aiding in limiting excess adipose tissue gain.

Research examining structured resistance training during pregnancy, regardless of intensity, is limited. Light-to-moderate intensity resistance exercise may help preserve lean mass and fat-free mass[23]. Observational research indicates that maintaining muscular fitness activities may reduce muscle tissue loss, which can occur in the third trimester as adipose tissue accumulation increases[29]. Long-term follow-up studies further support that prenatal exercise exposure may influence body composition trajectories beyond pregnancy, with associations observed up to one-year postpartum[30]. Despite the effect of resistance training on body composition for non-gravid individuals and the existing literature supporting favorable outcomes for pregnant individuals, there is a lack of large-scale randomized trials isolating resistance training in pregnancy. Fully elucidating the effects of resistance training alone during pregnancy on the body composition of the gestational parent is imperative, as it has the potential to add a protective effect for both the pregnant individual and the developing fetus.

Similarly, research on the effect of combination exercise in pregnancy is sparse. Multi-component programs during gestation offer balanced benefits, including lower fat-mass gains and preserved lean mass compared to non-exercisers[23,27]. Considering the effects in non-gravid adults, utilizing a combination (aerobic + resistance) exercise approach may optimize tissue-specific outcomes, resulting in lower fat-mass and body fat percent, while maintaining or increasing lean mass without negatively impacting parental and fetal health.

Exercise may also influence bone mineral density during pregnancy. Normal gestation involves calcium mobilization to support fetal skeletal growth, often resulting in declines in BMD of the pregnant individual[31,32]. Observational studies indicate that adults who maintain higher habitual physical activity experience smaller reductions in BMD between early and late pregnancy compared with sedentary individuals, suggesting a protective effect of exercise[32]. Direct measurement of bone changes during pregnancy via DXA is limited due to safety concerns. However, indirect evidence (collected via activity tracking and postpartum assessments) supports the potential for physical activity, including aerobic, resistance or combination types, to attenuate pregnancy-related bone loss.

1.3. Exercise Type and Blood Lipids

For non-gravid individuals, regular exercise can significantly impact blood lipid profiles, thus reducing cardiovascular disease risk. These benefits include reduced Total Cholesterol (TC), Low-Density Lipoprotein Cholesterol (LDL-C) and triglyceride levels with increased High-Density Lipoprotein Cholesterol (HDL-C)[12,13]. Moreover, it promotes a shift toward larger, less dense LDL and HDL particles, which are less likely to contribute to atherosclerosis[33]. By enhancing the body's ability to use fat as a fuel source, exercise further improves overall lipid balance[34,35].

Although research regarding differences in exercise type in pregnancy is limited, exercise in general has been shown to improve lipid profiles, thus supporting better cardiometabolic health. Similar to non-gravid populations, exercise during pregnancy can result in reduced TC and LDL-C levels, which naturally rise during pregnancy to support fetal development[36,37]. At the same time, physical activity can increase HDL-C, providing further protective cardiovascular benefits. While triglyceride levels also increase during pregnancy to supply energy for the developing fetus, exercise can help moderate excessive increases, keeping them within a healthy range[38-40]. Additionally, regular physical activity improves lipid metabolism, enhancing the body's ability to utilize lipids for energy and reducing the risk of lipid-related complications, such as gestational hyperlipidemia[36,41-43].

Pregnant individuals need to maintain a healthy body composition and metabolic profile through balanced nutrition and regular physical activity to optimize fetal development and reduce the risk of adverse outcomes in offspring. By managing lipid profiles and overall metabolic health, gestational parents can significantly improve their children's long-term health and well-being.

1.4. Exercise Type and Inflammation

Exercise during pregnancy may promote a more favorable gestational environment, in part, by controlling inflammatory levels[14,15]. This is evidenced by reduced pro-inflammatory (e.g., tumor necrosis factor alpha (TNF-α), C-Reactive Protein (CRP), Interleukin 1B (IL-1B)) and increased anti-inflammatory markers (e.g., IL-10)[41,44-47]. Interestingly, in non-gravid individuals with and without chronic disease, some evidence suggests the magnitude of the exercise effects on these biomarkers may differ between exercise types[48,49]. Yet, to our knowledge, there has not been a direct comparison of exercise type during pregnancy on inflammatory markers in the gestational environment.

Interventions using self-reported (questionnaires) or objectively-measured (pedometers, accelerometers) physical activity reported lower CRP[46,47,50]. For example, pregnant individuals who achieved at least 11,000 steps per day had lower CRP at 28-30 weeks' gestation[46]. Another study found that pregnant individuals who continued load-bearing endurance exercises across pregnancy experienced lower TNF- α and leptin in late pregnancy relative to non-exercisers and exercisers who discontinued their activity during pregnancy[45]. This included completing at least 40-minutes of moderate intensity load-bearing exercise on at least 4 days per week[45]. Collectively, these data suggest aerobic-based physical activities or exercises help reduce pro-inflammatory markers, especially if they are continued across gestation.

A recent systematic review on exercise interventions done at a moderate-to-vigorous intensity reported that concurrent or combination exercise had a particularly positive effect on pregnant individuals' inflammatory markers[14]. Acosta-Manzano and colleagues explored this relationship by having participants complete two sessions per week of resistance circuits, alternating with cardiovascular blocks and one session per week dedicated to aerobic training. All sessions were 60 minutes, including warm-up and cool-down periods[44]. Exercisers experienced reduced TNF- α in late pregnancy and lower IL-1β with increased IL-10 at delivery compared to the non-exercise group[44]. A later analysis found that those pregnant exercisers who increased IL-8 also had more favorable lipid levels, as evidenced by lower TC and LDL-C gains[41]. Although IL-1B, IL-6, nor TNF- α were identified as having a mediatory effect on metabolism, it was proposed that these pro-inflammatory markers may instead have an indirect role in other processes related to gestational health[41].

The effect of resistance training alone on gravid individuals' inflammatory markers is largely unstudied[15]. For non-gravid individuals, a recent meta-analysis reported resistance exercise to reduce CRP, but found no significant pooled effect for TNF- α or IL-6[49]. Considering the positive effects of resistance training on reducing body fat in non-gravid individuals[51] and the link between adipose tissue signaling for systemic inflammation, it's important to further define the relationship between resistance exercise and inflammation, particularly for pregnant individuals.

Lastly, it is worth highlighting that physical inactivity has been associated with a less favorable gestational environment for cardiometabolic + pro-inflammatory biomarkers based on composite Z-scores[52]. In mid- and late-pregnancy, sedentary time was associated with lower IL-6 and higher IL-10, TNF- α and leptin levels[53]. Taken together, the data highlight the importance of regular physical activity across gestation to support an improved gestational environment.

Although shifts in inflammation are important to support a healthy pregnancy[54], prolonged, excessive inflammation has been linked with adverse pregnancy outcomes (e.g., gestational diabetes, preeclampsia)[55-57]. Thus, determining the best method for controlling pregnancy inflammation is important. The existing literature supports that exercise during gestation is safe, regardless of type and may be beneficial for gestational parent inflammation. Although some results conflict, this could partially be due to differences in the exercise mode across studies, as well as other methodological differences, making it difficult to draw comparisons. More research is needed to better define the relationship between exercise type and pro- and anti-inflammatory markers during gestation. Defining the key differences between exercise types may have a significant role in creating better, individual-based exercise prescriptions for pregnant individuals, resulting in the greatest benefits.

1.5. Exercise Type and Omics: Metabolomic and Proteomic Highlights

Omics analyses have been used to identify and characterize molecular differences in biological systems, allowing the field to better characterize the extensive effects of physical activity and exercise. While there are various types of omics analyses utilized in understanding the biological differences during pregnancy[58], metabolomic and proteomic approaches explore more downstream outcomes of molecular changes. The metabolome and proteome can be assessed by utilizing high-throughput technology via targeted or untargeted approaches. Targeted methods utilize prior knowledge to assess and quantify specific analytes of interest. Whereas untargeted approaches are more discovery-based approaches to comprehensively characterize the profiles of a biological sample. In non-gravid individuals, a recent review on the use of omics sciences in the exercise science field highlighted the importance of different training metrics, including exercise type, on multiomic profiles due to the different physiological demands of the exercise[59]. However, much of the existing literature in pregnant individuals explores differences in pregnancy outcomes or conditions (i.e., delivery mode, obesity, hypertensive disorders, gestational diabetes) rather than comparing physical activity or exercise parameters[60–63].

Using metabolomic approaches, some research exists examining the changes in metabolites and metabolic processes that occur with physical activity in pregnancy. Briefly, habitual physical activity and acute aerobic exercise have been found to influence metabolites in breast milk, some of which correlated with infant growth and body composition[64]. A diet + exercise intervention found 132 differential metabolites in pregnant individuals with gestational diabetes compared to the control group. Of those identified, glycerophospholipids, steroids/steroid derivatives, fatty acyls and carboxylic acids were among the most enriched metabolites and sphingolipid signaling and inflammatory processes were among the enriched pathways[65]. Another study found that higher physical activity energy expenditure (MET*h/day) was associated with predominantly decreased amino acids and carbohydrates, most in the valine, leucine, isoleucine and glucose metabolic pathways, respectively[66].

Proteomics has been used to map physiological changes to proteins across normal pregnancies[67]; for specific pregnancy outcomes[60]; and with acute or chronic aerobic exercise[68,69] and resistance training[70] in non-gravid adults. Despite this, exploring the exercise effect in pregnancy on the gravid individual specifically is under-researched. One study explored the proteomic changes of acute exercise and High-Intensity Interval Training (HIIT) during pregnancy. This study reported that 8-weeks of HIIT training led to reduced urinary proteins following a cardiopulmonary exercise test compared to pre-intervention. The authors highlighted that many of the reduced proteins were related to immune system pathways, calcium ion binding and enzyme inhibitory activity, while increased proteins were predominantly related to cellular components[71]. Therefore, regular exercise during pregnancy appears to alter the gestational parent's proteome. However, it is important to note that this comparison was done following an aerobic exercise test at pre- and post-intervention and thus, does not elucidate the potential impact of exercise training on resting physiological processes. Recent evidence has reported that gestational exercise type differentially influences the placental and cord blood proteomes[72,73]. Given the differential effects of placental and fetal environments during pregnancy and the differences observed following acute exercise in trained pregnant individuals, it is plausible that there is an effect on the gestational parent environment as well.

Collectively, the current evidence suggests that physical activity during pregnancy may lead to metabolomic and proteomic changes in pregnant individuals. However, due to a lack of consistency in methodological approaches, including differences in metabolomic/proteomic approaches, equipment, exercise parameters and biological sample type assessed, it is difficult to fully characterize the extent of these changes. Additionally, most of the existing literature explores physical activity in general without examining specific exercise metrics, including exercise type. This highlights an important gap in the literature and our understanding of the underlying metabolic and proteomic changes that may occur with exercise during healthy pregnancies. Thus, more research is needed to 1. better characterize biological changes in healthy pregnant individuals and 2. characterize the differences in exercise types to identify potential strengths and/or limitations of each for the gestational individuals' proteome and metabolome.

1.6. Cardiometabolic Risk in Pregnancy

Pregnancy induces coordinated cardiovascular and metabolic adaptations that support fetal development[74,75]. However, these adaptations resemble cardiometabolic dysfunction observed in non-gravid populations (e.g., dyslipidemia, glucose dysregulation, elevated blood pressure)[76-78]. As a result, pregnancy has been conceptualized as a physiological "stress test," during which underlying cardiometabolic vulnerability may become apparent earlier than in typical adult life[79-83]. This period also represents a clinically relevant window for behavioral intervention, given increased healthcare contact and engagement in health-related behaviors[84]. However, since these physiological adaptations overlap with markers traditionally used to define cardiometabolic disease, distinguishing normal gestational changes from pathological risk remains challenging[81,84,85]. This overlap complicates the interpretation of individual cardiometabolic markers and underscores the need for integrated approaches to risk assessment during pregnancy[83].

Cardiometabolic Risk (CMR) is characterized by the clustering of risk factors, including adiposity, high triglycerides, low High-Density Lipoprotein (HDL), elevated blood pressure and elevated plasma glucose[86,87]. These risk factors are linked through shared underlying pathophysiological mechanisms (e.g., insulin resistance, subclinical inflammation, altered substrate metabolism) that contribute to the development of both metabolic and cardiovascular disease[88-91]. Accordingly, alterations in one component often co-occur with or contribute to, changes in others, reflecting an integrated risk rather than isolated abnormalities[88,90,92].

This interdependence has important implications for the assessment of cardiometabolic health during pregnancy. While these risk factors are routinely measured in clinical settings and can inform individualized risk profiles[93,94], evaluating them in isolation may fail to capture the cumulative burden of risk[80,83,92]. This limitation is particularly relevant in pregnancy, where physiological changes in lipid metabolism, insulin sensitivity and hemodynamics may resemble adverse cardiometabolic alterations in non-gravid populations[75,78,85]. Consequently, distinguishing normal gestational adaptation from emerging CMR remains challenging when relying on single markers[75,85]. Furthermore, widely used CMR models - such as the Framingham Risk Score - were developed in non-pregnant populations and have been debated for their utility for women under 70 years of age[81]. Collectively, these highlight the need for approaches that capture the interrelated nature of CMR, particularly within the unique context of pregnancy[81,95].

Given the interrelated nature of CMR, continuous risk scores have emerged as an approach to capture cardiometabolic health across multiple domains[93]. Rather than relying on categorical thresholds, these scores combine standardized values of individual risk factors into a single continuous metric[96]. This approach may be particularly advantageous during pregnancy, where dynamic physiological adaptations and the absence of established clinical cut-points complicate the interpretation of individual markers[74,97]. By accounting for changes across cardiometabolic domains, continuous scores may provide a more sensitive and comprehensive assessment of cardiometabolic risk during gestation[83]. However, the application of continuous CMR scores in pregnancy remains limited and important methodological considerations persist, including reliance on sample-specific standardization, lack of external validation and uncertainty regarding clinical thresholds[74,81.] While continuous approaches offer a promising framework for evaluating CMR in pregnancy, further work is needed to establish their validity, comparability and clinical utility within this unique physiological context[79,81].

2. Exercise Type and Cardiometabolic Risk

Observational studies provide evidence linking physical activity to cardiometabolic health during pregnancy. Higher engagement in Moderate-to-Vigorous Physical Activity (MVPA) during pregnancy, as well as reduced sedentary behavior, has been associated with more favorable cardiometabolic profiles, including improved body composition and lower overall risk burden[5,98-100]. Sandborg et al. [101] reported that greater time spent in MVPA and lower sedentary time were associated with improved cardiometabolic health and weight. Furthermore, increases in leisure-time physical activity also contributed to favorable body composition and cardiometabolic health in late pregnancy, suggesting that total movement across the intensity spectrum may be beneficial. Similarly, Motevalizadeh et al. [83] observed that clustered CMR increased across gestation; however, higher levels of physical activity were associated with lower clustered CMR score. This finding highlights the potential protective role of prenatal activity. Despite these consistent inverse associations, important limitations must be considered. Most observational studies rely on self-reported questionnaires or accelerometry to assess physical activity, which may introduce measurement error and limit the ability to accurately characterize exercise dose, intensity and modality[102]. As a result, while these studies support a relationship between physical activity and CMR, they provide limited insight into the specific exercise prescription necessary to optimize cardiometabolic health during pregnancy.

Intervention studies provide insight into the potential effects of prenatal exercise on cardiometabolic health; however, most are designed as behavioral interventions designed to increase overall physical activity or improve lifestyle patterns rather than isolate the effects of specific exercise prescriptions[101,103]. This limits the ability to determine how specific exercise characteristics - such as mode - independently influence gestational CMR. Although some modality-specific interventions have been examined, findings are primarily limited to individual cardiometabolic markers. Aerobic exercise has been associated with reduced gestational weight gain and improved insulin response[104,105]. Whereas combined aerobic and resistance training has demonstrated improvements in cardiorespiratory fitness, LDL and triglyceride levels. Despite these favorable changes, most intervention studies do not assess composite CMR, limiting insight into how exercise influences the overall cardiometabolic profile during pregnancy. As a result, it remains unclear whether specific exercise modes or prescriptions differentially impact composite CMR across gestation.

While numerous CMR prediction models have been published, these frameworks were developed largely in non-pregnant populations[81,94]. This absence of pregnancy-specific CMR assessment makes it difficult to accurately define normal gestational physiological adaptation versus meaningful variation in CMR[74]. As a result, there is no consensus on which variables should be included in a pregnancy-specific CMR score or how risk should be interpreted across gestation. Without a standardized framework, findings are difficult to compare across the literature. There is also a limited use of composite CMR in prenatal research, which restricts the understanding of how exercise influences overall pregnancy CMR rather than isolated physiological markers[83]. Most prenatal exercise studies evaluate isolated outcomes such as gestational weight gain, glucose tolerance, blood pressure or lipids rather than clustered CMR. Although these findings are informative, they fail to capture the cumulative burden and multidimensional nature of CMR. This limits the ability to determine whether interventions meaningfully alter pregnancy CMR. In addition, the lack of well-characterized exercise prescription, particularly with respect to mode, dose and supervised delivery, hinders the development of targeted prenatal exercise recommendations, specifically in the context of reducing CMR[5,100,106]. Observational studies rely on self-report or accelerometry and many intervention studies are designed to increase general activity or improve lifestyle behaviors, making it difficult to understand the isolated effects of structured exercise. Without specificity in prescription, it is difficult to translate findings into practical clinical recommendations. Finally, the scarcity of longitudinal parent and offspring follow-up restricts understanding of the long-term effect of prenatal exercise on cardiometabolic health for the pregnant individual and offspring. Most studies stop at delivery, limiting the ability to define whether prenatal cardiometabolic adaptations persist postpartum as well as elucidate the effect of gestational exercise on offspring cardiometabolic health beyond birth. Together, these gaps highlight the need for improved, pregnancy-specific CMR assessment and precisely defined exercise interventions to better understand and optimize cardiometabolic health in pregnancy and early life.

3. Prenatal Exercise Types and Placental Outcomes

3.1. Placental growth, vascular function and efficiency

Placental growth and morphology reflect integrated adaptations in uteroplacental perfusion, vascular function and exchange efficiency - processes that may respond differently to different exercise modalities (i.e., aerobic, resistance or combination of both) during pregnancy. Available evidence indicates that prenatal exercise does not adversely affect placental growth. Despite this, evidence regarding the impact of different exercise modalities is lacking. Commonly reported outcomes of placental growth include Placental Weight (PW) and birthweight to placental weight ratio (BW-to-PW), which represents a measurement of placental efficiency. Evidence in pregnant women demonstrates that women who averaged at least 150 minutes of exercise per week during pregnancy had lower placental weight compared to their inactive counterparts[107]. A meta-analysis conducted by Kubler et al.[108] of 9 studies (7 randomized controlled trials and 2 cohort studies), including 44,102 women, investigated the effect of prenatal exercise on placental composition and reported no difference in placental weight or the placental weight to birth weight ratio between women who exercised during pregnancy and their non-exercising counterparts. Interestingly, when stratified by exercise modality, women who performed combined aerobic and resistance exercise tended ($p=0.06$) to have lower placental weight compared to non-exercising women, but women who performed aerobic exercise had similar placental weight to non-exercisers. Furthermore, when stratified by exercise intensity, placental weight for women performing low-to-moderate intensity exercise tended to be lower than that of non-exercisers, whereas women performing moderate intensity exercise tended ($p=0.08$) to have higher placental weights compared to non-exercisers. Findings from another study demonstrate that in comparison to non-exercising women, those who performed combination exercise had significantly lower placental weight and higher placental efficiency[109]. Placental weight has also been associated with maternal exercise frequency, where placental weight decreases with increasing frequency of exercise[110]. Additionally, a positive relationship exists between increased exercise volume and increased placental volume (i.e., greater exercise volume corresponds to greater placental volume)[111]. Exercise volume also plays a role in altering the placental proteome[112].

Across randomized controlled trials, aerobic exercise does not consistently alter absolute placental weight, indicating that functional improvements may occur without changes in gross placental mass[108,113]. However, very high exercise volumes or intensities performed late in pregnancy have been associated with transient reductions in uterine and umbilical blood flow, particularly when exercise intensity approaches maximal maternal capacity[114]. Evidence regarding resistance and weight-bearing exercise suggests gestational age-dependent effects on placental and fetoplacental growth. Moderate resistance exercise initiated in early pregnancy has been associated with increased fetoplacental growth rates, particularly in women who were physically active before conception[108]. In contrast, sustained high-volume or high-intensity weight-bearing exercise during mid to late gestation has been linked to reduced fetoplacental growth and lower umbilical blood flow, indicating possible adaptive or restrictive placental responses to increased metabolic demand[108,114]. Reductions in exercise volume during late pregnancy have been shown to reverse these effects and restore fetoplacental growth trajectories[108]. The effects of resistance exercise on placental weight remain inconsistent, with several studies reporting no significant differences between exercising and non-exercising groups[108,113]. Resistance exercise performed in the supine position remains a concern due to potential reductions in uteroplacental blood flow[115]. Combined aerobic and resistance exercise programs are commonly prescribed during pregnancy, although placental-specific outcomes are less frequently reported independently[116]. Available evidence suggests that moderate-intensity combined exercise supports placental functional capacity by maintaining endothelial function and uteroplacental perfusion[117]. These physiological adaptations may contribute to improved placental efficiency and reduced risk of fetal compromise by supporting effective maternal-fetal exchange[114]. However, inconsistent reporting of placental endpoints limits conclusions regarding the independent effects of combined exercise modalities[118].

Building on structural adaptations, exercise during pregnancy may also influence uteroplacental blood flow and vascular function, thereby shaping the delivery of oxygen and nutrients to the developing fetus. Specifically, aerobic exercise during pregnancy has been consistently associated with improvements in uteroplacental and umbilical blood flow, suggesting enhanced placental perfusion and exchange capacity[114,115]. Doppler ultrasound studies summarized in multiple reviews indicate that aerobic exercise reduces placental vascular resistance, reflected by favorable umbilical artery systolic/diastolic ratios[108]. Moderate-intensity aerobic exercise initiated in early pregnancy has been shown to support placental circulation and fetal cardiovascular adaptation, likely mediated by improved maternal hemodynamics[115]. Structural adaptations, including increased villous vascularization and preservation of placental parenchymal tissue, have been reported among women engaging in regular aerobic activity[108]. Evidence in pregnant women demonstrates that placentas of women who averaged at least 150 minutes of exercise per week during pregnancy have increased placental protein and mRNA expression of vascular endothelial growth factor (VEGF), an angiogenic growth mediator, compared to their inactive counterparts[107], which suggests that exercise during pregnancy increases placental vascular development (vasculogenesis and angiogenesis). Furthermore, findings from preclinical models of maternal obesity suggest that exercise may protect the placenta from the adverse effects of maternal obesity on placental vascularization[119]. Additionally, regular maternal exercise has been shown to increase placental villous area, which aids in the maintenance of fetal oxygen and substrate availability[120].

3.2. Placental Mitochondrial Metabolism, Redox Balance and Nutrient Transport

At the cellular level, emerging evidence indicates that placental mitochondrial function and metabolic regulation may respond differently to prenatal exercise modality, reflecting variation in metabolic demand and energetic stress across exercise types. Considering aerobic exercise predominantly utilizes oxidative metabolism, while resistance exercise primarily utilizes anaerobic pathways, it is plausible that different modes of exercise elicit different placental adaptations. Findings from preclinical models that examined the impact of prenatal aerobic exercise (treadmill) on primary placental trophoblast cells demonstrate increased peroxisome proliferator-activated receptor γ coactivator-1α (PGC-1α) activation in trophoblasts of exercising rodents, as well as increased mitochondrial biogenesis and oxidative metabolism[121]. Combined aerobic and resistance (combination) exercise during pregnancy is also shown to elicit beneficial effects on placental mitochondria. Specifically, findings demonstrate that compared to non-exercising women, placentas of women who performed combination exercise during pregnancy had higher mitochondrial DNA (mtDNA) copy number and lower mtDNA deletions[122]. Interestingly, the placentas from combination exercisers also had significantly higher concentrations of manganese - an important mineral present in mitochondrial antioxidant Superoxide Dismutase (SOD) - which also corresponded with greater mtDNA density and lower mtDNA deletions[122].

Adaptations to placental mitochondria are inherently accompanied by alterations in Reactive Oxygen Species (ROS) production and redox balance, both of which are important for maintaining placental signaling mechanisms. However, excess ROS production, as well as low antioxidant buffering capacity, can lead to oxidative stress, which may negatively affect placental function. Mitochondria are major producers of ROS and mitochondrial ROS production helps provide a balance of pro-angiogenic and anti-angiogenic growth factors. Considering how different exercise modalities vary in their metabolic intensity and reliance on oxidative pathways, prenatal exercise type may differentially influence placental ROS production and redox balance. A placental transcriptomic analysis of placental tissue from women who performed moderate-intensity cycling at the recommended levels revealed an upregulation of antioxidant genes and downregulation of pro-inflammatory genes with exercise, which may help regulate placental redox balance and reduce oxidative stress[123]. A different study investigated the impact of combination exercise during pregnancy and reported that combination exercise leads to a 4-fold increase in Nitric Oxide (NO) production and a 2-fold increase in endothelial NOS (eNOS) expression in placental cytosol[109]. Placental mitochondria from women who performed combination exercise also had decreased levels of mitochondrial superoxide and decreased H_2O_2 production rate[109]. Together, these results suggest that aerobic and combination exercise may both help decrease placental oxidative stress by increasing antioxidants while decreasing ROS production and inflammation.

The placenta actively regulates nutrient allocation to the fetus through tightly controlled transport systems and energy-sensing pathways that integrate maternal metabolic signals, including those altered by exercise[124]. The placenta uses intrinsic nutrient sensors, including AMP-Activated Protein Kinase (AMPK) and mammalian target of rapamycin (mTOR), which respond to changes in maternal hormone levels, particularly insulin-like growth factor 1 (IGF-1), insulin, leptin, adiponectin, cortisol and cytokines[125]. Importantly, the placenta's ability to sense changes in maternal nutrient supply (i.e., overnutrition, undernutrition) enables it to balance fetal nutrient demand with maternal nutrient supply[125]. The mTOR signaling pathway plays a key role in regulating the expression of nutrient transporters in response to nutrient availability, exercise and the signaling of growth factors such as IGF-1[126]. Considering exercise elicits hormonal changes, it is plausible that exercise-induced changes in levels of circulating maternal hormones impact placental nutrient-sensing pathways. The regulation of placental nutrient transport and energy-sensing pathways, including mTOR and AMPK, may be particularly sensitive to prenatal exercise modality, as different exercise types impose distinct anabolic and energetic signals on the maternal-placental unit. Current evidence demonstrates that placentas from women who met physical activity guidelines during pregnancy had lower gene expression of fatty acid transport protein 4 (FATP4), IGF-1 and AMPK and higher expression of SNAT2[127]. Interestingly, this study also reported correlations with maternal sugar intake, where sugar intake positively correlated with GLUT1 expression and inversely correlated with mTOR and IGF-1 expression, which highlights the role of dietary intake in addition to maternal exercise in placental nutrient transport[127]. Findings from preclinical models of prenatal resistance exercise show increased expression of placental glucose transporters GLUT1 and GLUT3, increased expression of amino acid transporters SNAT1 and SNAT2 and increased mTOR expression in response to resistance training during pregnancy[128].

3.3. Placentokine-exerkine crosstalk

In addition to metabolic and transport roles, the placenta functions as an endocrine organ and exercise during pregnancy may influence placental hormone secretion and signaling. Cytokines secreted by the placenta, termed placentokines, including apelin, SOD_3, irisin, leptin, chemerin and adiponectin, mediate fetal development and maternal metabolism[129,130]. Furthermore, evidence from non-pregnant individuals demonstrates the differential impact of exercise modality on exerkines (cytokines elicited by exercise) - aerobic exercise primarily elicits hormonal responses that facilitate substrate mobilization and metabolic homeostasis, whereas resistance exercise preferentially stimulates anabolic and tissue-remodeling hormones. Considering the difference in hormonal response between exercise modalities, it is plausible that distinct prenatal exercise modalities may differentially alter placental endocrine function and placentokine signaling, potentially mediating modality-specific communication between maternal tissues, the placenta and the developing fetus. It is also possible that modality-specific exerkines may differentially impact the placenta by influencing trophoblast function and uteroplacental blood flow[131].

4. Limitations and Considerations

Despite increasing evidence that prenatal exercise induces adaptive placental remodeling in a modality-specific manner, several limitations should be considered. It is important to note that much of the evidence describing exercise-induced placental adaptations is derived from indirect measures, such as Doppler ultrasound indices and placental weight ratios, rather than direct histological assessments. Resistance exercise and high-intensity interval training protocols remain underrepresented and few studies are explicitly designed to compare exercise modalities. In addition, placental outcomes are inconsistently reported and potential sex-specific placental responses are rarely examined. Considering factors like preconception exercise habits, exercise volume and timepoint during gestation can all modify the effects of exercise on placental growth and function[132], standardized reporting of exercise modality, intensity, timing and placental endpoints will be essential to advance the current knowledge base of modality-specific placental mechanisms and outcomes.

4.1. Prenatal Exercise Types and offspring Outcomes

Current recommendations from the American College of Obstetrics and Gynecologists state that while some modifications to exercise may be necessary due to physiologic changes that occur during pregnancy, exercise is generally safe and encouraged[5]. Evidence suggests that exercise during pregnancy can plausibly influence the body composition of offspring and potentially also influence early childhood lipid biology. While specific pathways of influence remain unclear, possible theories include prenatal exercise leading to improved maternal glucose and lipid metabolism, leading to reduced risk for gestational hyperglycemia or hyperlipidemia. Additionally, influences on offspring outcomes may also be due to prenatal exercise causing changes in fetal metabolic programming.

While there is some evidence to suggest linkages between prenatal exercise and associations with body composition outcomes of the offspring, data is limited in both quantity and scope. Findings suggest exercise during pregnancy is associated with a reduction in macrosomia in the offspring, as well as Large-for-Gestational Age (LGA)[133]. Both macrosomia and LGA are associated with a higher risk of morbidity and mortality of the offspring[134]. Moreover, studies investigating the neonatal body composition overall provide mixed evidence. Generally, greater activity levels during pregnancy are associated with lower levels of neonatal adiposity[135]. This relationship is also suggested to be stronger when observed in mothers with higher-risk conditions during pregnancy, such as obesity[136]. Interestingly, long-term follow-up on these effects is limited and has mixed results, with some trials showing no difference in adiposity in childhood, while others report higher adiposity in the exercise group; however, it should be noted that the result was reported as an outlier in a smaller sample size[137-139]. The data on offspring lipid profiles are also very limited, but some observational studies report an increase in High-Density Lipoprotein Cholesterol (HDL-C) with increased maternal activity[140]. While prenatal exercise can broadly influence metabolic outcomes on cardiac health, exercise-specific connections remain underinvestigated[141]. It is also important to note that many studies currently in the literature utilize birth weight or Body Mass Index (BMI) as a metric for adiposity. Studies utilizing more direct measures of adiposity, such as skinfold measurements or dual-energy X-ray absorptiometry (DXA), report that in some cases, maternal exercise may reflect no changes in birthweight but may cause changes in fat mass and fat-free mass overall[135].

The current literature is also sparse in investigations into the influence of types of exercise on child body composition outcomes. Some studies have found that aerobic activity, such as walking, cycling, swimming, etc., is correlated with a lower risk of macrosomia or LGA at a population level[133,134]. Additionally, aerobic activity has been associated with negligible changes in the actual birth weight average, but possible decreased in overall neonatal fat mass in studies that have used direct adiposity measures as previously mentioned[133-135]. When considering resistance exercise, studies investigating resistance-only programs of exercise are relatively rare, with more studies combining aerobic exercise with resistance for overall conditioning. What is known is that resistance training can improve maternal insulin sensitivity and help limit excessive gestational weight gain, both of which are factors that may influence fetal lipid accumulation[5,142]. However, since resistance-only exposure is rare in the literature, conclusions regarding the specific influence of this exercise type on children's body compositions remain unclear. Conversely, combined aerobic and resistance exercise programs seem to be the most widely studied in this population, with more evidence to support a connection between exercise and child body composition. In a trial studying pregnant mothers with obesity, combined exercise was associated with lower cellular and whole-body adiposity measures in offspring[136]. There is mixed evidence to support this relationship when looking at early childhood populations. One study found that combination exercise in obese mothers was not associated with any detectable change in offspring anthropometrics at 2 and 3 years old[139]. However, another study reported an increase in regional adiposity at roughly 7-year-old offspring born to mothers who did exercise during pregnancy[137]. These mixed results may suggest that combined exercise programs may improve perinatal risk factors, such as macrosomia, but may not have durable effects on adiposity or body composition into childhood and may also be dependent on postnatal environment, maternal risk factors and exercise timing and quantity[133-135,137,139].

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