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DIABETES AND PREGNANCY (M-F HIVERT AND CE POWE, SECTION EDITORS)

Exercise in Pregnant Women with Diabetes

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Abstract

Purpose of Review Diabetes affects an increasing number of pregnancies. Regular exercise is recommended for pregnant women without diabetes, but whether exercise during pregnancy also benefits women with gestational diabetes (GDM) or preexisting (type 1 or type 2) diabetes or if these women have any specific risks is unclear.

Recent Findings Recent evidence suggests that low- to moderate-intensity exercise improves blood glucose and may delay insulin initiation for women with GDM. Exercise is also safe, with no reports of increased maternal or neonatal complications. Few studies evaluated exercise as adjunct therapy for pregnant women with preexisting diabetes, precluding a thorough assessment in this population.

Summary Low- to moderate-intensity exercise during pregnancy safely improves glycemic control among women with GDM. More studies are needed to evaluate the impact of exercise in pregnant women with preexisting diabetes. Whether a specific type, volume, or timing of activity is most effective is not known.

Keywords Diabetes · Pregnancy · Exercise · Physical activity · Gestational

Introduction

Diabetes is increasingly common among women during the reproductive years [1–4], and over 6% of pregnancies in the USA are affected by some form of diabetes, including gestational diabetes mellitus (GDM), type 1 or type 2 diabetes [5]. Importantly, diabetes during pregnancy is associated with increased risks of adverse pregnancy outcomes [6, 7], which can be mitigated by improved glycemic control [8, 9].

Lifestyle modification with diet and exercise is first-line treatment for GDM and is an important adjunct to pharmacotherapy for type 1 and type 2 diabetes during pregnancy. Of note, over 75% of women with GDM are able to meet glycemic targets with lifestyle intervention alone [8, 10]; for those women with GDM and persistent hyperglycemia despite improvements in diet and exercise, treatment with insulin to target fasting and/or postprandial hyperglycemia is typically recommended as the next step in management [11, 12].

Physical activity is a component of a healthy lifestyle during pregnancy, and guidelines recommend that pregnant women achieve 150 min per week of moderate-intensity physical activity [13–15]. However, specific recommendations and precautions for exercise among pregnant women with diabetes must be considered due to differences in physiology as well as the potential for interactions with medical treatment of diabetes in pregnancy. Therefore, pregnant women with diabetes comprise a unique population for whom targeted, evidence-based guidelines should be applied to ensure the safety of exercise and efficacy for improving maternal and offspring health outcomes.

Exercise refers to structured activity performed for maintenance of physical fitness and is a component of overall physical activity, which is a more complex behavior [16, 17]. In non-pregnant individuals with diabetes, exercise improves insulin sensitivity [18], although effects vary according to the type, intensity, and duration of exercise, concurrent treatment modalities (e.g., insulin use), and the type of diabetes. Regular

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moderate-intensity aerobic exercise, and perhaps particularly when combined with resistance training, improves insulin sensitivity and glycemic control in insulin-resistant populations including men and women with type 2 diabetes, independent of weight loss [18, 19]. Furthermore, observational studies have shown that individuals with type 1 diabetes who report higher activity levels have lower hemoglobin A1c, less microvascular disease, and better control of blood pressure and dyslipidemia [20]. Exercise is also beneficial for reducing insulin requirements [21, 22], controlling body weight, and improving fitness among individuals with type 1 diabetes even in the absence of glycemic benefits [23].

However, for individuals with type 1 diabetes and those with insulin-treated type 2 diabetes, exercise also requires careful consideration of the effects of exogenous insulin on the risk of hypoglycemia during and after activity. The management of insulin-treated diabetes during exercise depends on specific aspects of exercise as well as circulating insulin and glucose levels prior to the activity [24–26]. Thus, individuals with insulin-treated diabetes must have knowledge of strategies for managing insulin preceding, during, and after exercise to limit the risks of hyper- and hypoglycemia during and in the 24-h following exercise [27].

Pregnant women with diabetes comprise a population with a similar need to consider potential interactions of exercise with insulin therapy but with unique physiology. Moreover, for women with diabetes in pregnancy, strict glycemic targets mandate frequent blood glucose monitoring and may result in the initiation of insulin and the need for substantial adjustments of insulin doses throughout pregnancy. Furthermore, increasing insulin resistance and fluctuating insulin needs during pregnancy create specific challenges for exercise, as women treated with insulin need to adjust insulin doses and carbohydrate intake to manage glycemic control in the context of exercise [28]. For women with diabetes during pregnancy, potential benefits of exercise must be balanced with these specific risks.

This review examines recent evidence for the effects of exercise during the gestational period among women with diabetes. Although it is conceivable that habitual activity and/or reduced sedentary time may also play a role in modulating health outcomes for pregnant women with diabetes and their offspring, this review will focus on exercise as opposed to overall physical activity or sedentary behaviors, considering that exercise is a primary target of behavior modification. We will evaluate evidence of the effects of exercise in pregnant women with diabetes on glycemic control and insulin use as well as maternal and neonatal outcomes. This review focuses on pregnant women with gestational diabetes (GDM), type 1 or type 2 diabetes, and does not evaluate exercise prior to pregnancy for prevention of GDM or following pregnancy for prevention of type 2 diabetes among women with GDM.

Exercise in Pregnancy

Exercise during pregnancy is safe in the absence of any contraindications and with avoidance of high-risk activities (Table 1), and most obstetrical society guidelines recommend that pregnant women exercise for 20–30 min per day or 150 min per week [14, 15, 29•]. A summary of current guidelines for exercise during pregnancy from eight countries reported a general recommendation that healthy pregnant women engage in 60–150 min per week of aerobic exercise with an upper limit of 30 min per day, and the addition of resistance exercise was recommended by five guidelines [30].

Potential benefits of exercise for all pregnant women include improved fitness, less gestational weight gain (GWG), and reduced risk of GDM and hypertensive disorders of pregnancy [13, 31–33]. Theoretical risks such as preterm birth, small for gestational age, or miscarriage have not been observed for healthy women performing moderate-intensity exercise throughout pregnancy [34, 35•]. However, few pregnant women meet the current activity guidelines; estimates show that only approximately 25% of pregnant women perform sufficient activity during pregnancy [36, 37]. Cited barriers to physical activity during pregnancy include inactivity prior to pregnancy, first trimester symptoms of fatigue or nausea, and/or mechanical limitations as pregnancy progresses [38, 39]. Moreover, pregnant women with insulin-treated diabetes, particularly type 1 diabetes, may avoid exercise due to fear of hypoglycemia [40]. In addition, healthcare providers may not provide specific advice regarding exercise during pregnancy [41] or may give recommendations that are not actually based on guidelines [42, 43].

To identify a specific "dose" of exercise to recommend and to also optimize feasibility, it is important to evaluate components of exercise. Specifically, the type (e.g., aerobic, resistance training), setting (supervised or unsupervised), timing (prepartum, trimester-specific, acute or habitual), frequency and duration (number of sessions per week, minutes per session, and weeks throughout gestation), and intensity (light, moderate, vigorous) of exercise to achieve the greatest benefit without incurring risk should be determined [17, 44]. Although measurement of exercise during pregnancy is complex [45, 46], use of various methods including self-report and objective measures such as pedometers, accelerometers, and heart rate monitors, in combination with measures of exertion such as pregnancy-specific heart rate targets or subjective intensity ratings via the modified Borg's scale [14] can assess adherence and acceptability of exercise interventions.

Evidence for the efficacy of exercise in pregnant women with diabetes has mostly focused on glycemic control, insulin use and/or dose, GWG, and limited safety outcomes such as maternal and neonatal complications. As the effects of exercise in pregnant women likely differ by the type of diabetes, we will address each diabetes type (i.e., GDM, type 1 or type 2 diabetes) separately.

Table 1 Safety precautions for exercise during pregnancy

(a) Contraindications to exercise during pregnancy [14, 29•]

Absolute	Relative*
Ruptured membranes	Intrauterine growth restriction*
Premature labor	*Uncontrolled type 1 diabetes***, hypertension or thyroid disease*
Placenta previa after 26–28 weeks of gestation	Other serious cardiovascular, respiratory or systemic disorder (e.g., unevaluated maternal cardiac arrhythmia, chronic bronchitis)*
Preeclampsia	Gestational hypertension*
Incompetent cervix	Symptomatic or severe anemia*
High-order multiple pregnancy	Malnutrition or eating disorder or extreme underweight (BMI < 12 kg/m^2)
	Recurrent pregnancy loss
	History of spontaneous premature birth
	Unexplained persistent second or third trimester vaginal bleeding
	Twin pregnancy after week 28
	Heavy smoker
	History of extremely sedentary lifestyle
	Orthopedic limitation
	Poorly controlled seizure disorder

(b) Activities that are safe or should be avoided during pregnancy [14]

Types of exercise that are safe during pregnancy	Types of exercise to avoid during pregnancy
Walking	Contact sports (e.g., soccer, hockey)
Swimming	High falling risk (e.g., surfing, downhill skiing)
Stationary cycling	Scuba diving
Low-impact aerobics	Sky diving
Yoga, pilates	Hot yoga/pilates
Safe for women who participated prior to pregnancy	
Running or jogging	
Strength training	
Racquet sports	

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*Conditions which may be considered absolute or relative contraindications, depending on society guideline (ACOG 2015 vs Canadian 2019 guidelines)

**Please refer to the text for a detailed discussion of this contraindication

Physiology of Exercise in Pregnant Women with Diabetes

Pregnancy is characterized by myriad metabolic adaptations that affect glucose levels and may also alter the effects of exercise on glycemic control. Glucose is the primary source of fetal energy and is required for optimal fetal growth and development. Accordingly, hormonal changes of pregnancy and effects of the placenta drive preferential feto-placental glucose delivery; maternal glucose production increases and maternal insulin sensitivity is reduced as pregnancy progresses, particularly at the level of skeletal muscle [47], in order to shift glucose to the developing fetus [44, 47].

Among healthy pregnant women, regular exercise during pregnancy reduces insulin resistance and upregulates skeletal muscle glucose transporter GLUT4 [48, 49], and these effects may be more pronounced for overweight and obese pregnant women [50•]. Notably, the gestational timepoint at which a woman exercises is important, as even among low-risk pregnant women, insulin resistance increases during the second and third trimesters.

Effects of Exercise in Pregnant Women with Diabetes on Glycemic Control and Insulin Use

Gestational Diabetes

Many prior studies have focused on exercise interventions for women with GDM, particularly as a means for improving glycemic control (Appendix Table 2). In a systematic review and meta-analysis of randomized controlled trials (RCTs), Brown, et al. [51••] reported that low- to moderate-intensity aerobic and resistance exercise reduced fasting blood glucose (FBG) by a mean difference of 0.59 mmol/L (95% CI − 1.07 to − 0.11) and post-prandial glucose (PPG) by 0.85 mmol/L (95% CI − 1.15 to − 0.55) compared to control conditions. Importantly, there was substantial heterogeneity in the effect of exercise on glycemic control across studies; this may have resulted from differences in the timing or the types of interventions, which included walking, cycling, resistance training, and yoga. A more recent systematic review and meta-analysis of exercise intervention studies during pregnancy included a subgroup analysis of women with GDM and observed that acute exercise decreased post-exercise blood glucose levels (mean difference − 1.42 mmol/L, 95% CI − 1.69 to − 1.16) and chronic exercise lowered FBG (mean difference − 2.76 mmol/L, 95% CI − 3.18 to − 2.34) compared to control conditions [50•]. Prenatal exercise also reduced insulin requirements by 0.08 units/kg (95% CI − 0.16 to − 0.01), although exercise interventions did not limit the need for women with GDM to commence insulin, and no evidence was reported on time to insulin initiation. Another systematic review including 6 studies of women with GDM evaluated the impact of the specific type of exercise during pregnancy [52•]. The authors determined that aerobic exercise interventions lowered capillary blood glucose and may reduce insulin dose and requirement. On the other hand, resistance exercise did not affect glucose levels, although fewer women who participated in resistance training required insulin compared to controls. In addition, one study of combined aerobic and resistance exercise showed lower PPG but not FPG in the exercise group; no participants in this single study required insulin.

More recent exercise intervention studies have also reported an effect of exercise on improved glycemic control for women with GDM. A RCT of a combined exercise intervention including 30 min of brisk walking per day as well as 50 min twice per week of aerobic exercise (20 min), resistance training (20–25 min), and pelvic floor exercises and relaxation (10 min) for 6 weeks reported lower PPG but no difference in FPG in women with GDM, none of whom required insulin, compared with standard GDM care [53•]. Within the exercise group, glucose levels were lower following the exercise session for both women who were active prior to pregnancy and those who did not exercise before pregnancy, and although average blood glucose levels dropped below 4.0 mmol/L, no symptoms or adverse effects of hypoglycemia were observed [54]. Of note, blood glucose levels have been observed to be 20% lower among pregnant women due to glycemic adaptations during pregnancy [60]; therefore, the threshold of hypoglycemia for pregnant women has been defined as < 3.3 mmol/L instead of < 4.0 mmol/L [61]. Furthermore, a pre-post intervention study that included objective measurement of exercise via pedometer and glucose measurement using continuous glucose monitoring (CGM) observed improved PPG following moderate-intensity treadmill walking for 30 min compared with 30 min of sitting for women with GDM, none of whom required insulin [55]. However, this intervention study included only eight women over a 5-day study period. In contrast, a randomized intervention of moderate-intensity, supervised aerobic exercise consisting of two 70 min sessions per week of treadmill walking/jogging, stationary cycling, or aerobics from 20 weeks gestation did not result in any differences in FBG, PPG, or insulin requirements at 32 weeks of gestation [56•], although women in the exercise group had lower PPG at 36 weeks and a trend toward later initiation of insulin.

Taken together, these results show some evidence for a benefit of light- to moderate-intensity aerobic and combined exercise during pregnancy on fasting and post-prandial glycemic control among women with GDM. Moreover, current evidence suggests that the effect of exercise may be more pronounced for PPG than FPG. Additionally, there is weak evidence that progression to insulin requirement may be delayed for pregnant women with GDM who exercise. Furthermore, women with GDM who are treated with insulin appear to also show glycemic benefits without increased risk of hypoglycemia. However, it is not possible to determine the specific type or timing of exercise or whether a threshold of exercise intensity or frequency exists to safely exert an influence on glycemic control for women with GDM.

Type 2 Diabetes

Evidence is strong that exercise reduces insulin resistance and lowers hemoglobin A1c in the general population with type 2 diabetes [19, 62, 63]. Furthermore, the American Diabetes Association (ADA) recommends that women with preexisting diabetes, including type 2 diabetes, engage in regular physical activity during pregnancy (grade C) [64]. However, the specific benefits and risks of exercise for pregnant women with type 2 diabetes are not clear; despite the rising prevalence of pregnancies affected by type 2 diabetes [1–4], only one study has evaluated the effect of exercise in pregnant women with type 2 diabetes [57•], and previous systematic reviews have deemed this study of "very low" quality evidence [65•, 66].

One study (Appendix Table 2) evaluated an exercise intervention among pregnant women with type 2 diabetes, all of whom were obese and required insulin [57•]. Women in the exercise group participated in 30 min of moderate-intensity stationary cycling on three occasions per week at 60% of maximal heart rate starting at 24 weeks of gestation. Compared with women

with type 2 diabetes who received usual prenatal care, after 10 weeks of the intervention, women in the exercise group had lower average blood glucose (mean difference −45.7 mg/dL [−2.5 mmol/L], $P = 0.001$). However, the authors did not assess differences in insulin doses or episodes of hypoglycemia between groups, and baseline glycemic control, fitness, and activity levels were not reported for the two groups.

Type 1 Diabetes

Although the ADA advises women with type 1 diabetes to engage in regular activity during pregnancy [64], uncontrolled type 1 diabetes is considered a contraindication to exercise during pregnancy by some society guidelines (Table 1a) [14, 29•]. While such a classification was likely made to reduce the potential harms of hyper- or hypoglycemia attributable to exercise among women with labile glucose control, this may create confusion for patients and providers with respect to the safety of exercise during pregnancy for women with well-controlled type 1 diabetes.

Only two previous studies (Appendix Table 2) evaluated the effect of an exercise intervention among pregnant women with type 1 diabetes [58•, 59], one of which included only women with well-controlled diabetes [59]. One RCT showed no difference in glycemic control or insulin requirements following 20 min of unsupervised postprandial walking three times weekly for 30 sessions starting in the late first trimester, compared with usual prenatal care and provision of a pedometer [58•]. However, hemoglobin A1c and average glucose levels were lower following the intervention in women who exercised, and there was no increase in hypoglycemia in the exercise group. Yet, this study did not prescribe a particular intensity of walking, and as both the intervention and control groups were given a pedometer, exercise in the control group may have been affected thereby limiting the ability to detect differences between groups. Furthermore, there was no difference in insulin doses between the exercise and control groups with type 1 diabetes, although current clinical recommendations would suggest reducing at least basal insulin and possibly bolus doses depending on the timing of exercise [27].

A brief pre-post intervention study of pregnant women with type 1 diabetes showed improved average glucose measured by CGM on exercise days (6.0 mmol/L compared with 7.7 mmol/L, $P = 0.028$), which included approximately 2 h of walking (three 20-min post-prandial walks and two 50-min treadmill walks per day, with energy expenditure measured objectively by a combined heart rate monitor and accelerometer) compared with free-living days [59]. This study also reported a slight increase in the time spent in the hypoglycemic range, which was defined as ≤ 3.0 mmol/L with symptoms or ≤ 2.5 mmol/L without symptoms, during the exercise days (4.9% vs 2.4%), although the difference was not statistically significant. Of note, the 2-h exercise sessions in this intervention extend beyond the duration recommended by most clinical guidelines and may not be feasible for many pregnant women.

Effects of Exercise in Pregnant Women with Diabetes on Maternal and Neonatal Outcomes

Gestational Diabetes

Studies of exercise interventions during pregnancy for women with GDM have not observed differences in maternal complications, including rates of preeclampsia, Caesarean section, gestational weight gain, induction of labor, or duration of labor (Appendix Table 2) [35•, 51••, 53•, 54]. Neonatal outcomes including gestational age, preterm birth, neonatal morbidity or mortality, or neonatal hypoglycemia also did not differ for pregnant women with GDM following exercise interventions [34, 51••, 53•, 54]. In addition, whereas no differences in macrosomia or birthweight were observed in the Cochrane review [51••], the systematic review by Davenport et al. [67•] reported that offspring of women with GDM who exercised during pregnancy had lower birthweight compared to women without GDM. While these results suggest that exercise for pregnant women with GDM is safe, few studies reported on a full range of outcomes of interest, and the overall quality of data was low [34, 51••, 53•, 67•].

Type 2 Diabetes

In the single study of exercise in pregnant women with type 2 diabetes (Appendix Table 2), offspring of women who exercised during pregnancy had Apgar scores that were one point higher at 1 min, and there was no difference in Apgar scores at 5 min [57•]. Umbilical artery blood flow measured by Doppler ultrasonography was also improved in the exercise group, with lower resistance and pulsatility indices suggestive of improved placentation, which may confer improved fetal outcomes in high-risk pregnancies [68, 69]. No other maternal or neonatal outcomes were reported.

Type 1 Diabetes

Only one study (Appendix Table 2) reported on maternal and neonatal outcomes in the context of exercise for women with type 1 diabetes during pregnancy [58•]. Following an exercise intervention, there was no difference in gestational weight gain, but women with type 1 diabetes were less likely to have a Caesarean section. While a non-significant increase in preterm labor was observed, this trend was seen for both women with and without type 1 diabetes who exercised, and those women with type 1 diabetes who experienced preterm labor were noted to engage in a greater than recommended volume of exercise, walking > 4 miles per day as opposed to the intervention goal of 20 min daily. Notably, offspring of women with type 1 diabetes in the exercise group experienced less hypoglycemia, hypocalcemia, hyperbilirubinemia, and macrosomia compared to

controls, although no differences were observed for neonatal birth weight or body mass index.

Conclusions

Exercise appears to be safe for pregnant women with diabetes, and women with diabetes who are active during pregnancy likely achieve similar benefits in fitness and weight management as pregnant women without diabetes. Moreover, pregnant women with diabetes who exercise gain additional benefits, such as improved glucose control for women with GDM, but also confront additional challenges, namely the potential risk of hypoglycemia in women on insulin. While current evidence is reassuring and does not show that pregnant women with diabetes who exercise experience excess hypoglycemia, this evidence is not conclusive and thus healthcare providers must counsel women regarding specific safety concerns.

There is insufficient evidence of the effect of exercise in pregnant women with preexisting diabetes. Although the absolute number of pregnancies complicated by preexisting diabetes is low, the prevalence is rising [1, 2, 4], particularly as type 2 diabetes is diagnosed more frequently among women of reproductive age [4]. Currently, clinical guidance regarding exercise for these women is extrapolated from non-pregnant individuals with type 1 or type 2 diabetes and women with GDM, although the unique metabolic milieu of preexisting diabetes during pregnancy certainly warrants more targeted investigation and recommendations.

At this time, we cannot recommend a specific "dose" of exercise for women with diabetes during pregnancy that may most effectively improve glycemic control without increasing the risk of hypoglycemia or maternal and neonatal complications. Furthermore, the safety and efficacy of a higher intensity or higher volume of exercise is not established, and whether targeting reductions in sedentary behavior instead of or in combination with structured exercise benefits pregnant women with diabetes has not been studied. In addition, considering the increase in insulin resistance as pregnancy progresses, the timing of exercise during gestation may also influence its effects, and trimester-specific recommendations would help target exercise interventions. Of note, women with GDM are typically diagnosed between weeks 24 to 28 of gestation, offering a limited window of opportunity to intervene. Whether a more intensive exercise intervention at the time of GDM diagnosis could safely help avoid or delay insulin requirements would be of interest. For women with preexisting diabetes, preconception care is exceedingly important [70], although it is not currently known if an earlier increase in physical activity could potentiate the benefits of an exercise intervention.

Finally, proving the feasibility of exercise for women with diabetes during pregnancy is imperative, as several barriers to exercise could limit adherence. Inclusion of objective measurement of exercise using devices validated for pregnancy [71] in combination with assessment of perceived exertion could confirm acceptability of an intervention. Furthermore, several technologies are currently available that could help pregnant women with diabetes to safely engage in exercise and optimize potential benefits in the real-world setting. Activity monitors are useful for enhancing adherence to exercise goals, and these devices may serve as a source of motivation for women to improve physical activity levels [72]. In addition, supervised exercise may be more beneficial than independent exercise for improving glycemic outcomes, as has been observed for exercise interventions in type 2 diabetes [73] and in pregnant women without diabetes [50•]. Moreover, diabetes-specific advances such as CGM, flash glucose monitoring, continuous subcutaneous insulin infusion, and closed-loop insulin delivery systems may have benefits for the maintenance of glycemic excursions and prevention of hypoglycemia among pregnant women with diabetes [74–77], although evidence of the utility of these technologies in combination with exercise for pregnant women with diabetes is lacking.

In conclusion, pregnancy is a challenging time for women with diabetes, but is also a period when motivation for health behavior change is high. It is reasonable for pregnant women with diabetes without contraindications to exercise at similar levels as pregnant women without diabetes. Accordingly, the 2019 Canadian guidelines for physical activity during pregnancy give a weak recommendation that women with GDM engage in exercise during pregnancy [29•]. In addition, the American Diabetes Association recommends that women with GDM exercise 20–30 min on most days for glycemic control and management of GWG and suggests that women with preexisting diabetes participate in "regular physical activity prior to and during pregnancy" [64]. Yet, as described above, the evidence base for these recommendations is limited, particularly for women with preexisting diabetes. Future studies of sufficient size and duration should investigate the effects of well-defined exercise interventions in controlled settings at various gestational timepoints and in distinct populations of pregnant women with diabetes (i.e., GDM with fasting hyperglycemia, GDM with postprandial hyperglycemia, type 1 or type 2 diabetes). Further evaluation of whether exercise has distinct effects depending on prepregnancy body weight, fitness level, or insulin use and investigation of the impact of emerging technologies will also provide additional insight regarding the benefits of exercise in pregnant women with diabetes.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Appendix

Table 2 Recent systematic reviews and intervention studies of exercise during pregnancy for women with (a) gestational diabetes mellitus, (b) type 2 diabetes, and (c) type 1 diabetes

	Components of exercise interventions				Effect of exercise on specified outcomes			
	Type (control group)	Frequency	Intensity	Timing and duration	Glycemic control	Insulin dose and/or requirement	Maternal	Fetal/neonatal
(a) Gestational diabetes								
Brown, 2017 [51••] (Cochrane review)	Aerobic, resistance, and combined aerobic + resistance (vs standard GDM care)	Various	Various	Various	Lower PPG (3 RCTs) Lower FBG (4 RCTs) No difference in maternal hypoglycemia (1 RCT)	No difference in the use of additional pharmacotherapy (4 RCTs)	No differences: gestational weight gain (2 RCTs) Preeclampsia (2 RCTs) C-section (5 RCTs) induction of labor (1 RCT)	No perinatal mortality events (1 RCT) No differences: morbidity/mortality composite (2 RCTs); neonatal hypoglycemia (1 RCT); stillbirth (1 RCT); gestational age (4 RCTs); preterm birth (5 RCTs); APGAR scores (1 RCT); macrosomia (1 RCT); birthweight (6 RCTs)
Davenport, 2018 [50•] (systematic review and meta-analysis, includes GDM studies only)	Acute; chronic (vs non-exercise control)	Various	Various	Various	Acute: Decreased post-exercise glucose (5 studies) Chronic: lower FPG (1 RCT) No difference in hypoglycemia (5 studies)	Lower insulin dose (3 RCTs) No difference in insulin requirement (10 RCTs)	N/A	N/A
Davenport, 2018 [34, 35•] (systematic review and meta-analysis, includes GDM studies only)	Any exercise or physical activity (vs non-exercise control)	Various	Various	Various	N/A	N/A	No differences: preterm labor (1 RCT); C-section (3 RCTs); total length of labor (1 RCT)	Lower birthweight (3 RCTs) No differences: macrosomia (1 RCT); preterm birth (2 RCTs); gestational age (3 RCTs); APGAR score at 1 min (2 RCTs); APGAR score at 5 min (1 RCT)
Cremona, 2018 [52•] (systematic review, includes GDM studies only)	Aerobic ($N = 3$); resistance training ($N = 2$); combined aerobic and resistance training ($N = 1$) (vs non-exercise control)	Various	Various	Various	Aerobic: lower BG (2 studies) Resistance: no difference in BG Combined: lower PPG,	Aerobic: lower insulin dose and fewer required insulin (2 studies); no difference in insulin (1 RCT)	N/A	N/A

Table 2 (continued)

	Components of exercise interventions				Effect of exercise on specified outcomes			
	Type (control group)	Frequency	Intensity	Timing and duration	Glycemic control	Insulin dose and/or requirement	Maternal	Fetal/neonatal
					no difference in FBG	Resistance: fewer required insulin (2 studies) Combined: N/A		
Kokic, 2018 [53•] (RCT, $N = 42$)	Combined aerobic, resistance, stretching (vs GDM diet)	Twice/week	Light-moderate (moderate: 65–75% maximum heart rate, 13–14 Borg scale)	50 min 6 weeks (recruited at ≤ 30 weeks of gestation)	Lower average PPG No difference in FBG	No insulin required	No differences: timing of birth; induction of labor; duration of labor; C-section	No differences: APGAR scores; ponderal index; neonatal complications
Kokic, 2018 [54] (pre-post intervention, $N = 18$)	Combined aerobic, resistance, stretching (no control; pre/post comparison)	Twice/week	Light-moderate (Moderate: 65–75% maximum heart rate, 13–14 Borg scale)	50 min 6 weeks (recruited at ≤ 30 weeks of gestation)	Lower post-exercise glucose	No insulin required	N/A	N/A
Coe, 2018 [55] (pre-post intervention, $N = 8$)	Postprandial treadmill walking (vs sitting)	Once daily	Moderate (3.3 METs, < 14 Borg scale)	30 min 2 days	No difference in overall average BG Lower PPG (CGM)	No insulin use (inclusion criteria)	N/A	N/A
Symons Downs, 2017 [56•] (RCT, $N = 65$)	Aerobic (in-person vs at home vs GDM diet)	Twice/week	Moderate	70 min 16 weeks (from 20 through 36 weeks of gestation)	No difference in FBG or PPG at 32 weeks Lower PPG at 36 weeks	No difference in insulin dose Later insulin initiation	N/A	N/A
(b) Type 2 diabetes								
E-Mekawy, 2012 [57•] (non-RCT, $N = 40$; BMI > 30 kg/m^2)	Cycling (vs normal daily activities)	Three/week	Moderate (60% maximum heart rate)	30 min 10 weeks (from 24 weeks of gestation)	Lower average BG	N/A All insulin-treated		Higher APGAR scores at 1-min No difference in APGAR scores at 5-min
(c) Type 1 diabetes								
Hollingsworth, 1987 [58•] (RCT, $N = 42$ type 1 diabetes; $N = 28$ non-diabetes)	Postprandial walking (vs usual care + pedometer)	Three/week	N/A	20 min 22–24 weeks (from 12 weeks of gestation	No differences: Glycemic control; hypoglycemia	No differences in insulin dose	No difference in gestational weight gain Decreased C-section	No differences: birth weight; BMI Decreased hypoglycemia, hypocalcemia,

Table 2 (continued)

	Components of exercise interventions				Effect of exercise on specified outcomes			
	Type (control group)	Frequency	Intensity	Timing and duration	Glycemic control	Insulin dose and/or requirement	Maternal	Fetal/neonatal
				through delivery)	Lower HbA1c and average glucose post-intervention		Increased preterm labor (NS)	hyperbilirubinemia, macrosomia
Kumareswaran, 2013 [59] (pre-post intervention, $N = 10$)	Walking (vs usual daily activity)	Five/day	Light-moderate (4.8 km/h, 2.6 km/h at 10% incline, 3.9 km/h; 7–15 Borg scale)	20 min × 3, 50 min × 2 Two days (average 20 weeks of gestation)	Lower average BG (CGM) Increased % time hypoglycemic (NS)	N/A All using closed-loop insulin pump		N/A

GDM gestational diabetes mellitus, *RCT* randomized controlled trial, *PPG* postprandial glucose, *FBG* fasting blood glucose, *N/A* no result available, *BG* blood glucose, *non-RCT* non-randomized trial, *BMI* body mass index, *HbA1c* hemoglobin A1c, *NS* not significant, *CGM* continuous glucose monitor

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Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

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