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MODERATE-INTENSITY PHYSICAL ACTIVITY IN PREGNANCY AS A STRATEGY FOR THE PREVENTION OF GESTATIONAL DIABETES MELLITUS: PATHOPHYSIOLOGIC RATIONALE AND CLINICAL EVIDENCE

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ABSTRACT

Gestational diabetes mellitus (GDM) is a common metabolic complication of pregnancy associated with significant short- and long-term consequences for both maternal and offspring health. Its development reflects progressive pregnancy-related insulin resistance driven by placental hormones and metabolic adaptations, which in some women is compounded by inadequate pancreatic β -cell compensation and inflammatory activation. Moderate-intensity physical activity has been proposed as a preventive strategy because it directly targets peripheral insulin sensitivity and glucose metabolism.

This review examines the pathophysiologic rationale and clinical evidence supporting moderate-intensity exercise during pregnancy as an approach to reduce GDM risk. Mechanistic data demonstrate that exercise enhances insulin-independent glucose uptake through GLUT4 translocation, improves mitochondrial efficiency, reduces pro-inflammatory cytokines, favorably alters adipokine profiles, and limits excessive gestational weight gain. Observational studies consistently report inverse associations between maternal physical activity and GDM incidence. Randomized controlled trials show more variable findings but suggest modest reductions in risk, particularly when interventions are initiated early and adequately supervised. Meta-analyses indicate relative risk reductions of approximately 20-30%, although heterogeneity in study design and adherence remains substantial.

Overall, moderate-intensity exercise represents a physiologically plausible, low-risk, and moderately effective strategy for GDM prevention and should be integrated into routine prenatal care.

KEYWORDS

Gestational Diabetes Mellitus, Physical Activity, Pregnancy

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1. Introduction

Gestational diabetes mellitus (GDM) is among the most common metabolic complications of pregnancy, affecting a substantial proportion of pregnancies worldwide and contributing significantly to global disease burden. Contemporary estimates indicate that hyperglycemia during gestation affects millions of women annually, with prevalence increasing across both high-income and low- and middle-income regions. [1] In parallel with rising rates of overweight and obesity, the incidence of GDM has demonstrated upward trends over recent decades, reflecting broader deterioration in metabolic health. [2]

The clinical importance of GDM extends beyond abnormal glucose screening values, as even modest elevations in maternal glycemia are associated with graded increases in adverse perinatal outcomes. Large multinational data demonstrate continuous relationships between maternal glucose concentrations and risks including fetal overgrowth, primary cesarean delivery, neonatal hypoglycemia, and hypertensive disorders of pregnancy. [3] Beyond immediate obstetric morbidity, GDM carries substantial long-term implications for maternal health and serves as a strong predictor of subsequent type 2 diabetes mellitus. Meta-analytic evidence indicates that women with prior GDM experience markedly higher rates of progression to type 2 diabetes compared with those without such history, underscoring pregnancy as an early marker of future cardiometabolic vulnerability. [4]

Given its rising prevalence and significant short- and long-term consequences, prevention of GDM has emerged as both a clinical imperative and a public health priority. [2] Physical activity, defined as planned and structured bodily movement undertaken to improve physical fitness, represents a modifiable behavioral factor with demonstrated safety in uncomplicated pregnancies. Observational evidence suggests that exercise during gestation is associated with lower rates of GDM, decreased operative delivery, and improved postpartum recovery. In the absence of obstetric or medical contraindications, professional guidelines support the continuation or initiation of moderate-intensity activity as a routine component of prenatal care. [5]

Accordingly, moderate-intensity physical activity during pregnancy represents a physiologically plausible and clinically supported strategy to attenuate gestational insulin resistance and reduce the risk of gestational diabetes mellitus. [2,5]

2. Pathophysiology of GDM: Why Exercise Should Work

Normal pregnancy is characterized by progressive insulin resistance that becomes most pronounced in the second and third trimesters. This physiologic adaptation facilitates increased nutrient availability to the developing fetus by reducing maternal peripheral glucose utilization. [6] Maternal insulin sensitivity declines substantially as gestation advances, necessitating compensatory increases in pancreatic insulin secretion to maintain euglycemia. [7]

The development of gestational diabetes mellitus occurs when this compensatory β -cell response is inadequate relative to the degree of insulin resistance. In such cases, pancreatic β -cells fail to expand functional mass or augment insulin secretion sufficiently, resulting in maternal hyperglycemia. [8] Thus, GDM reflects a mismatch between heightened insulin resistance and impaired β -cell adaptation rather than an isolated defect in glucose metabolism.

The progressive insulin resistance of pregnancy is driven in large part by placental endocrine activity. Human placental lactogen (hPL), progesterone, cortisol, and other placental hormones exert anti-insulin effects that promote lipolysis and decrease maternal insulin sensitivity. [9] Systematic evidence demonstrates associations between circulating hPL concentrations, maternal metabolic status, and fetal growth parameters, supporting its central role in metabolic adaptation during gestation. [10] The placenta also functions as an immunologically active organ, producing inflammatory mediators that further modulate insulin signaling pathways. [11]

Concomitant with hormonal changes, pregnancy is associated with increased maternal lipolysis and rising circulating free fatty acids. [9] Elevated free fatty acid levels contribute to peripheral insulin resistance by interfering with insulin-mediated glucose uptake in skeletal muscle and enhancing hepatic gluconeogenesis. [7] These metabolic shifts are physiologically adaptive under normal conditions but may exacerbate dysglycemia in susceptible individuals. [9]

Pre-existing obesity amplifies these processes through chronic low-grade inflammation and altered adipokine profiles. Increased concentrations of pro-inflammatory cytokines and dysregulated adipokines, including leptin and adiponectin, impair insulin signaling and further reduce insulin sensitivity. [12] Women entering pregnancy with higher adiposity therefore experience a compounded metabolic burden, increasing the likelihood that β -cell compensation will be insufficient. [7]

Taken together, GDM emerges from the interaction of hormonally mediated insulin resistance, enhanced lipolysis, inflammatory activation, and inadequate pancreatic adaptation. [9] Given that skeletal muscle constitutes the primary site of insulin-mediated glucose disposal, interventions that improve peripheral insulin sensitivity are physiologically compelling in the prevention of gestational dysglycemia. [7]

3. Mechanistic Effects of Moderate-Intensity Exercise

Moderate-intensity exercise exerts direct metabolic effects that counteract key pathophysiologic processes underlying gestational diabetes mellitus. Skeletal muscle contraction stimulates glucose uptake through mechanisms that are partially independent of insulin signaling. [13] During exercise, contraction-mediated pathways promote translocation of glucose transporter type 4 (GLUT4) to the muscle cell membrane, thereby increasing glucose disposal even in states of insulin resistance. Importantly, insulin- and contraction-induced GLUT4 trafficking occur through distinct yet complementary signaling cascades, allowing physical activity to enhance glucose uptake despite impaired insulin sensitivity. [14]

In the context of pregnancy, where progressive insulin resistance is physiologically mediated, this contraction-dependent glucose transport provides a biologically plausible means of mitigating hyperglycemia. By augmenting peripheral glucose utilization, exercise reduces circulating glucose concentrations and may lessen the secretory burden placed on pancreatic β -cells. [15] This mechanism is particularly relevant in women at risk for inadequate β -cell compensation, as improved skeletal muscle glucose disposal directly targets the primary site of insulin-mediated glucose uptake. [13]

Beyond acute effects on glucose transport, regular exercise induces structural and functional remodeling within skeletal muscle mitochondria. Exercise training enhances mitochondrial oxidative capacity, improves substrate utilization, and promotes greater metabolic flexibility. [16] In human skeletal muscle, physical

training shifts mitochondrial dynamics toward a more efficient and elongated phenotype, supporting improved oxidative metabolism. [17] Enhanced mitochondrial function reduces lipid accumulation within muscle fibers and contributes to improved insulin sensitivity. [16] These adaptations are clinically relevant in pregnancy, where elevated circulating lipids and free fatty acids contribute to insulin resistance. [15]

Exercise also exerts anti-inflammatory effects that may counteract the low-grade inflammatory milieu associated with obesity and gestational dysglycemia. Regular physical activity is associated with reductions in pro-inflammatory cytokines and improvements in oxidative stress markers in both type 2 diabetes and gestational diabetes populations. By attenuating systemic inflammation, exercise may improve insulin receptor signaling and reduce the inflammatory interference with glucose transport pathways. [18] This anti-inflammatory modulation provides an additional mechanism through which physical activity addresses the multifactorial drivers of gestational insulin resistance. [15]

Alterations in adipokine profiles further contribute to the metabolic benefits of exercise. Physical activity has been shown to increase adiponectin concentrations and reduce leptin levels, thereby promoting improved insulin sensitivity and more favorable metabolic regulation. Because dysregulated adipokines are implicated in the pathogenesis of gestational diabetes, exercise-induced normalization of these mediators offers another physiologically coherent preventive pathway. [19]

Finally, moderate-intensity exercise influences overall energy balance and gestational weight gain. Structured physical activity during pregnancy is associated with lower total weight gain and reduced risk of excessive gestational weight gain relative to recommended guidelines. Limiting excessive adipose accumulation may blunt the amplification of insulin resistance that accompanies increased adiposity. [20] Through its combined effects on glucose transport, mitochondrial efficiency, inflammatory signaling, adipokine regulation, and weight control, moderate-intensity exercise directly targets the principal mechanisms underlying gestational diabetes development. [15]

4. Clinical Evidence: What Do Trials Actually Show?

A. Observational Data

Prospective observational studies consistently demonstrate that habitual physical activity before conception is associated with a lower subsequent risk of gestational diabetes mellitus (GDM). A pooled meta-analysis of cohort studies reported that women engaging in higher levels of pre-pregnancy activity experienced a substantial reduction in GDM risk compared with sedentary counterparts, with risk reductions approaching 30-40% depending on exposure definitions.

Importantly, the protective association appears to extend into early gestation. Women who maintained moderate levels of activity during the first trimester demonstrated significantly lower GDM incidence relative to those reporting low activity levels. [21] This temporal relationship supports the concept that early metabolic conditioning may influence placental and peripheral insulin dynamics before peak insulin resistance develops.

Data from the Omega Study further refined this association by demonstrating that leisure-time physical activity in early pregnancy was inversely related to GDM risk in a dose-responsive manner, even after adjustment for age, adiposity, and other confounders. [22] These findings strengthen biological plausibility but must be interpreted cautiously given reliance on self-reported activity measures.

Similar associations have been observed in lower-income populations, where early gestational inactivity was associated with higher odds of glucose intolerance later in pregnancy. [23] This highlights both the potential preventive window in early gestation and the influence of socioeconomic barriers to exercise participation.

Preconception activity may also modify cardiovascular adaptation to pregnancy. Women reporting greater activity prior to conception demonstrated more favorable cardiovascular profiles, suggesting that baseline metabolic health may partially mediate later glycemic outcomes. [24] However, observational designs cannot eliminate residual confounding; physically active women often differ systematically in diet quality, healthcare engagement, and baseline metabolic status.

Collectively, observational evidence consistently supports an inverse relationship between maternal activity levels and GDM risk. Nevertheless, causality requires confirmation through randomized trials.

B. Randomized Controlled Trials

Randomized controlled trials (RCTs) evaluating structured exercise programs during pregnancy have yielded more heterogeneous results than observational studies.

The ETIP trial randomized overweight and obese women to supervised endurance and resistance training beginning between 12 and 18 weeks of gestation. Although no reduction in gestational weight gain was observed, the incidence of GDM defined by 2009 WHO criteria was lower in the intervention group compared with standard care. [25] Notably, the study was underpowered relative to its recruitment target and adherence was limited, with only half of participants meeting predefined compliance thresholds. These factors constrain confidence in effect estimates.

Similarly, Nobles and colleagues conducted a randomized trial in women at elevated risk for GDM and found no statistically significant reduction in GDM incidence with an exercise intervention. [26] The intervention began in the second trimester, and adherence varied, raising the possibility that later initiation may limit preventive efficacy given that insulin resistance is already increasing substantially by mid-pregnancy.

More recently, an online supervised exercise program initiated early in pregnancy demonstrated a lower rate of GDM among healthy pregnant women during the COVID-19 pandemic. [27] The digital delivery model improved feasibility but still required structured participation, underscoring that program implementation affects outcomes as much as physiological potential.

Across trials, several themes emerge. First, timing appears critical; earlier initiation may better counteract progressive gestational insulin resistance. Second, adherence significantly influences effect size, and per-protocol analyses frequently demonstrate stronger associations than intention-to-treat results. Third, many studies are modest in sample size and may lack statistical power to detect clinically meaningful differences in GDM incidence, particularly when baseline risk is low.

In overweight and obese populations specifically, exercise alone has not consistently reduced gestational weight gain, suggesting that glycemic effects may occur independently of large changes in total weight. [25] This distinction is clinically relevant, as metabolic improvements can occur without dramatic shifts on the scale.

Overall, RCT data suggest potential benefit, but effect magnitude varies and statistical certainty is often limited by under-recruitment and imperfect adherence.

C. Meta-Analyses and Systematic Reviews

Aggregated analyses provide broader context. An umbrella review and updated meta-analysis of randomized trials concluded that structured prenatal exercise reduces the risk of GDM, with pooled relative risk reductions generally in the range of 20-30%. [28] Importantly, heterogeneity across studies was moderate, reflecting variability in intervention type, intensity, frequency, and population characteristics.

A recent systematic review focusing on healthy pregnant women similarly demonstrated that exercise interventions were associated with lower GDM risk without increasing adverse obstetric outcomes. [29] However, subgroup analyses revealed that program supervision, earlier initiation, and consistent moderate intensity were associated with stronger preventive effects.

Network meta-analytic approaches comparing exercise modalities suggest that aerobic and combined aerobic–resistance programs may provide greater protection than low-intensity or unsupervised regimens. [30] These findings support the concept that sufficient metabolic stimulus is required to meaningfully alter insulin sensitivity.

In women with overweight or obesity, pooled analyses indicate a trend toward benefit, although effect sizes are sometimes attenuated and confidence intervals widen due to smaller trial numbers. [31] Higher baseline BMI may confer greater absolute risk reduction, yet these populations also face greater barriers to sustained participation, complicating translation into routine care.

Across meta-analyses, several limitations recur: small individual trial sizes, inconsistent diagnostic criteria for GDM, and reliance on self-reported activity in some interventions. Moreover, few studies report number needed to treat, and variability in baseline risk makes absolute effect estimation challenging. Nonetheless, the directionality of evidence is remarkably consistent in favor of structured moderate-intensity exercise.

Synthesis

Collectively, observational studies demonstrate a consistent inverse association between maternal physical activity and GDM risk. [21-24] Randomized trials yield more heterogeneous findings but suggest that supervised, adequately dosed, and early-initiated exercise interventions may reduce GDM incidence, particularly among higher-risk populations. [25-27] Meta-analyses report modest but statistically significant relative risk reductions, although methodological variability and trial limitations temper certainty. [28-31]

From a clinical standpoint, exercise cannot be considered a definitive preventive therapy; however, given its safety profile and potential metabolic and cardiovascular benefits, structured moderate-intensity activity represents a rational component of comprehensive prenatal care.

Current Clinical Recommendations

Professional organizations uniformly endorse physical activity during uncomplicated pregnancy as safe and beneficial. The American College of Obstetricians and Gynecologists (ACOG) recommends that pregnant individuals without obstetric or medical contraindications engage in regular aerobic and strength-conditioning exercise as part of routine prenatal care. ACOG emphasizes that physical activity is associated with reduced risk of gestational diabetes mellitus (GDM), lower rates of cesarean delivery, and improved postpartum recovery, and encourages continuation of pre-pregnancy exercise habits with appropriate modifications. [5]

Similarly, the World Health Organization (WHO) recommends that pregnant women without contraindications accumulate at least 150 minutes of moderate-intensity aerobic physical activity per week. Activities should be distributed throughout the week and may include walking, swimming, or other low-impact modalities. The WHO further advises minimizing sedentary time and incorporating muscle-strengthening activities when feasible. [32] These recommendations align closely with U.S. guidance and reflect global consensus that moderate-intensity activity confers more benefit than risk in normal pregnancies.

The 2019 Canadian guideline provides additional specificity, recommending a combination of aerobic and resistance training performed at moderate intensity for at least 150 minutes weekly, ideally across three or more days. Importantly, this guideline outlines both absolute and relative contraindications, including significant cardiovascular disease, restrictive lung disease, incompetent cervix, persistent second- or third-trimester bleeding, placenta previa after mid-pregnancy, preeclampsia, and severe anemia. [33] Such structured contraindication frameworks assist clinicians in individualized counseling.

Across guidelines, safety considerations are consistent: exercise should avoid supine positioning after the first trimester, high-risk contact sports, activities with risk of abdominal trauma, and environments associated with overheating or dehydration. [5,33] Patients are advised to discontinue activity if they experience warning symptoms such as vaginal bleeding, dyspnea prior to exertion, chest pain, uterine contractions, or decreased fetal movement. [5]

While guidelines endorse exercise as a preventive strategy for GDM, they also recognize that physical activity alone may not fully mitigate risk in all populations. [5] Meta-analytic data demonstrate modest relative risk reductions, generally in the range of 20-30%, but substantial heterogeneity persists across trials. [28-31] Women with obesity or additional metabolic risk factors may require multimodal interventions, including nutritional counseling and weight management strategies, to achieve clinically meaningful reductions in GDM incidence. [27,31]

Overall, contemporary clinical guidelines are well aligned with available evidence. They recommend moderate-intensity exercise as a foundational component of prenatal care, acknowledge contraindications and safety parameters, and appropriately avoid overstating preventive efficacy. The convergence of international guidance with randomized and pooled trial data supports incorporation of structured physical activity counseling into standard obstetric practice.

Clinical Implications and Gaps

The available evidence carries important implications for clinical practice. Counseling regarding physical activity should begin at the earliest stages of prenatal care, ideally during the first antenatal visit. The World Health Organization's recommendations for antenatal care emphasize early risk assessment and preventive health promotion as core components of a positive pregnancy experience, providing a structured framework within which exercise counseling can be routinely incorporated. [34] Given that insulin resistance progressively intensifies as gestation advances, initiation of moderate-intensity activity in the first trimester- or earlier-may offer greater preventive benefit than programs introduced later in pregnancy. [25]

Preconception care represents an additional, and often underutilized, opportunity. Observational data indicate that higher levels of physical activity prior to conception are associated with lower subsequent risk of GDM. [21] Framing pregnancy as a metabolic stress test highlights the importance of optimizing cardiometabolic health before conception, particularly among women with elevated body mass index or prior glucose intolerance. Integrating physical activity counseling into preconception visits may therefore yield benefits that extend beyond a single pregnancy.

Despite supportive guidelines, implementation barriers remain substantial, particularly in higher-risk populations. Women with overweight or obesity, limited financial resources, or restricted access to safe environments for exercise may encounter structural obstacles that hinder sustained participation. [23] Randomized trials frequently report variable adherence to prescribed exercise regimens, attenuating observed effect sizes and underscoring the gap between controlled intervention efficacy and real-world feasibility. [27] Digital and home-based models may improve accessibility, but long-term engagement and scalability require further evaluation. [26]

From a research standpoint, methodological heterogeneity continues to limit definitive conclusions. Exercise interventions differ widely in timing, intensity, supervision, and modality, while diagnostic criteria for GDM vary across studies. [28-31] Few trials are powered specifically for GDM incidence as a primary endpoint, and reporting of adherence and dose-response relationships is inconsistent. [25,27] Standardized intervention protocols and harmonized outcome definitions would enhance comparability and strengthen future meta-analytic estimates.

Moreover, there remains a relative paucity of large-scale trials conducted in racially, ethnically, and socioeconomically diverse populations, despite disproportionate GDM prevalence in these groups. Expanding representation and addressing social determinants of health are essential to ensuring equitable implementation of exercise-based prevention strategies.

Taken together, moderate-intensity exercise represents a rational and evidence-informed preventive approach; however, translating physiologic plausibility and trial data into routine practice requires earlier counseling, improved accessibility, standardized research methodology, and greater inclusivity.

Conclusions

Gestational diabetes mellitus represents the convergence of progressive pregnancy-related insulin resistance, placental hormonal influences, inflammatory activation, and inadequate pancreatic β -cell compensation. The physiologic mechanisms underlying its development provide a compelling rationale for interventions that enhance peripheral glucose uptake and improve metabolic flexibility. Moderate-intensity physical activity directly targets these pathways through contraction-mediated glucose transport, mitochondrial adaptation, inflammatory modulation, and regulation of gestational weight gain.

Clinical evidence supports this biologic plausibility. Observational studies consistently demonstrate lower GDM risk among women who are physically active before and during pregnancy, while randomized trials and pooled analyses suggest modest but reproducible reductions in incidence with structured exercise programs. Although heterogeneity in study design and adherence tempers certainty regarding effect magnitude, the direction of evidence remains remarkably consistent.

Importantly, moderate-intensity exercise is a low-cost, accessible intervention with minimal risk in uncomplicated pregnancies and well-established cardiovascular and metabolic benefits beyond glycemic control. Even if absolute reductions in GDM risk are moderate, the population-level implications are substantial given the rising global prevalence of metabolic disease in reproductive-aged women.

Despite guideline endorsement and physiologic rationale, structured exercise counseling remains underutilized in routine prenatal care. Bridging the gap between evidence and implementation-through early counseling, improved access, and standardized intervention strategies-represents a meaningful opportunity to reduce the burden of gestational diabetes. In this context, moderate-intensity physical activity should be viewed not as an adjunctive recommendation, but as a foundational component of preventive obstetric care.

Author's contribution:

Conceptualization, Antonina Gaj-Hunter, and Alicja Ruzik; methodology, Monika Rajs; software, Sandra Terpiłowska; check, Patrycja Przebieradło, Kaja Stolarska and Katarzyna Żurek; formal analysis, Sandra Żak; investigation, Monika Kowalska; resources, Patrycja Rędziniak; data curation, Alicja Ruzik; writing - rough preparation, Kaja Stolarska; writing - review and editing, Patrycja Przebieradło; visualization, Katarzyna Żurek; supervision, Antonina Gaj-Hunter; project administration, Monika Kowalska;

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