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Impact of Physical Activity on Reducing Blood Glucose and Insulin in Gestational Diabetes: A Meta-Analysis

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Abstract
Gestational diabetes mellitus is a pregnancy complication characterized by elevated blood glucose levels, which can affect the health of both the mother and fetus. This study aims to evaluate the impact of physical exercise on blood glucose levels in pregnant women with gestational diabetes mellitus. We reviewed studies published over the past ten years from PubMed, Cochrane, and Science Direct. Our analysis includes randomized controlled trials exploring the role of physical activity in blood glucose management among gestational diabetes mellitus patients, examining both aerobic and anaerobic exercise interventions. We extracted data on maternal characteristics, intervention details, and outcomes post-intervention. Fasting and postprandial blood glucose levels were our primary results. Diabetes mellitus is a complication during pregnancy marked by high blood glucose levels, which can impact both the mother and the unborn child. This study finds that physical exercise positively influences metabolism in women with gestational diabetes mellitus, particularly in controlling and reducing blood glucose levels. Exercise significantly affected postprandial blood glucose levels.

Keywords: Fasting Blood Glucose Level, Gestational Diabetes Mellitus, Insulin, Physical Activity, Postprandial Glucose Level

1. Introduction

The hallmark of diabetes mellitus is high blood glucose levels due to either an insulin secretion deficiency or biological dysfunction in humans (Xia et al., 2021). Diabetes complications are a significant contributor to the high mortality rates of this illness, which is third on the list of "silent killers" after cancer and cardiovascular diseases (Kodikonda & Naik, 2017). Diabetes mellitus is a multifactorial metabolic disease defined by chronic hyperglycemia and altered carbohydrate, lipid, and protein metabolism resulting from insulin production abnormalities (Beyuo et al., 2015). According to their causes, diabetes mellitus can be divided into two main categories: An immune system attack on the pancreatic islet cells' proteins causes type 1 diabetes. In addition to genetics, which can cause members of the family to have issues with insulin secretion, type 2 diabetes is also a result of environmental factors like stress, obesity, overeating, and inactivity (Ozougwu, 2013). Another special kind of diabetes that is different from Type 1 and Type 2 is gestational diabetes (GDM). GDM frequently improves after birth, giving those affected optimism even though its symptoms and treatment approaches may be comparable. This implies that diabetes mellitus can strike anyone, including expecting moms. Although its symptoms and therapeutic strategies may be similar, GDM often improves after delivery, offering hope to those affected. This suggests that anyone, including expectant mothers, can get diabetes mellitus. (Woodside & Bradford, 2021).

Pregnancy involves normal physiological variations that lead to a pseudodiabetogenic state, marked by increased insulin resistance and decreased insulin sensitivity. This mechanism helps ensure sufficient nutrient supply to the fetus (Mottola & Artal, 2016). Consequently, the prevalence of diabetes mellitus, including Type 1, Type 2, and GDM, increases during pregnancy (Murphy et al., 2017). GDM is a common complication during pregnancy (Ming et al., 2018), characterized by elevated glucose levels exceeding the normal range during pregnancy and associated with high health risks for both mother and child (Kim et al., 2021).

With an estimated median prevalence of 12.9%, ranging from 8.4% to 24.5%, the Middle East and North Africa have the most significant prevalence of gestational diabetes mellitus (GDM) worldwide. Southeast Asia and the Western Pacific are next, with a median prevalence of 11.7%, then South and Central America (11.2%), Africa (8.9%), North America, and the Caribbean (7.0%). The lowest prevalence is in Europe, where the median incidence is 5.8% (1.8% to 22.3%) (Zhu et al., 2019).

Among the risk factors that contribute to the development of GDM include maternal age, obesity, a history of GDM, a family history of diabetes, and a previous history of macrosomia (Kouhkan et al., 2021). Even though diet and exercise are effective therapy and preventative strategies, being overweight or obese is a substantial risk factor for GDM. Numerous studies have examined how well these medications manage or prevent GDM (Chiefari et al., 2017).

Physical activity has several advantages for general well-being and is essential for maintaining a healthy lifestyle. Numerous chronic diseases can be effectively prevented and treated with exercise (Hegde, 2018). Frequent exercise is crucial for managing and maintaining metabolic syndrome, which is characterized by the co-occurrence of many risk factors for atherosclerosis. Significant factors include glucose intolerance, impaired fasting glucose, obesity, dyslipidemia, and hypertension (Ko et al., 2016). Exercise and other physical activity also have significant positive health effects on expectant mothers.

2. Methods

2.1 Research Methodology

We presented the results of our systematic review and meta-analysis following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards.

2.2 Search Strategy

We looked for papers published between February 2014 and February 2024 using ScienceDirect, PubMed, and the Cochrane Library. The search used a combination of the following keywords: ('activit*' OR 'exercise' OR 'physical activit*' OR 'physical exercise') AND ('pregnancy' OR 'wom*') AND ('GDM' OR 'gestational diabetes mellitus' OR 'Gestational diabetes') AND ('insulin level' OR 'postprandial blood glucose level' OR 'fasting blood glucose level'). To find further research that might have gone unnoticed, we also looked through the reference lists of pertinent publications.

2.3 Study Selection

These requirements had to be met by the included research: 1) they were randomized controlled trials (RCTs); 2) the interventions involved at least one type of exercise; and 3) participants in both the intervention and control groups were pregnant women with GDM. Publications were excluded if they: 1) were published more than 10 years ago; 2) were not in English; 3) were literature reviews, case reports, or protocols; 4) only published abstracts or conference content; or 5) did not provide specific data.

2.4 Data Extraction

Each of the three authors searched the literature and retrieved information from relevant studies. All participating writers conducted a thorough review and discussion to settle any differences in data extraction. The following information was among the extracted data: 1) study attributes (authors, year of publication, nation, sample size, and gestation period); 2) type, frequency, duration, and intensity of exercise intervention; and 3) blood glucose and insulin change outcomes (fasting, postprandial, and insulin levels). A reduction in fasting blood glucose was the primary result, with reductions in postprandial blood glucose and insulin levels being secondary results.

2.5 Risk of Bias Assessment

The Cochrane Guide for Systematic Reviews of Interventions. recommendations were adhered to during the quality assessment process. We evaluated the selected RCTs' quality using the Risk of Bias Tool version 2 (RoB2) for randomized trials, focusing on five areas: 1) bias in the process of randomization; 2) bias arising from deviations from deliberate interventions; 3) bias arising from incomplete outcome data; 4) bias in the measurement of outcomes; and 5) bias in the selection of results that were presented.

2.6 Data Synthesis

Review Manager version 5.4.1 (RevMan 5.4.1) was used for data analysis. To evaluate the total effect magnitude, a 95% CI and a mean difference (MD) were computed. For continuous outcomes such as postprandial blood glucose levels and fasting, the mean difference was provided. Heterogeneity was evaluated using Cochran's Q-statistic ($P < 0.1$), and the level of heterogeneity was quantified using the Higgins I^2 statistic. A p-value of less than 0.05 in this two-tailed test indicated statistical significance.

3. Results

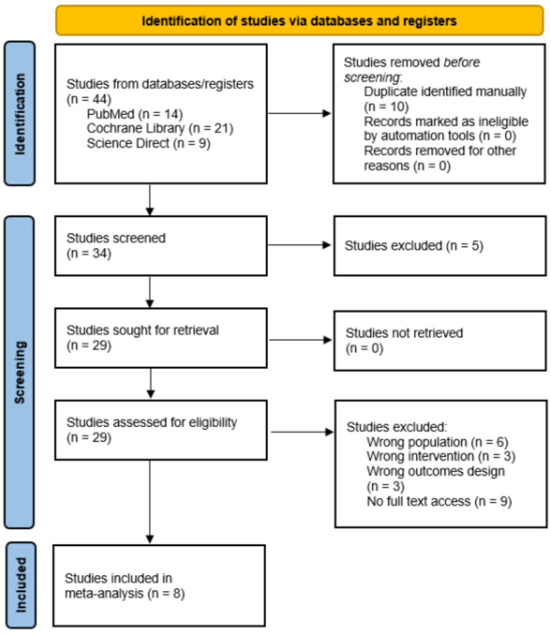
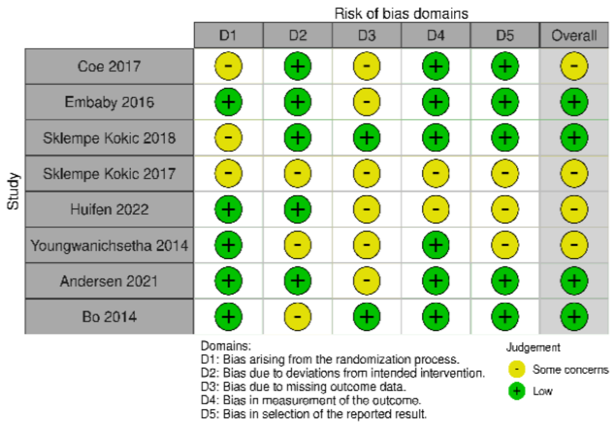


Figure 1: PRISMA Flow Diagram

Table 1: Randomized Control Trial Assessment Bias



Study	D1	D2	D3	D4	D5	Overall
Coe 2017	-	+	-	+	+	-
Embaby 2016	+	+	-	+	+	+
Sklempe Kokic 2018	-	+	+	+	+	+
Sklempe Kokic 2017	-	-	-	-	-	-
Huifen 2022	+	+	-	-	-	-
Youngwanichsetha 2014	+	-	-	+	-	-
Andersen 2021	+	+	-	+	+	+
Bo 2014	+	-	+	+	+	+

After conducting the literature search, we identified 44 studies relevant to the topic and filtered them based on the publication date within the past ten years. As shown in Figure 1, the 44 studies were evaluated based on specific inclusion and exclusion criteria, ultimately resulting in eight studies that met the inclusion criteria (Bo et al., 2014; Dawn Coe, Scott Conger, Jo Kendrick, Bobby Howard, Dixie Thompson, David Bassett, 2017; Embaby et al., 2016; I. Sklempe Kokic et al., 2018; Iva Sklempe Kokic et al., 2018; Xie et al., 2022; Youngwanichsetha et al., 2014). Of these eight studies, two were from Croatia, while the others originated from the United States, Saudi Arabia, China, Thailand, Denmark, and Italy. The general characteristics of each included study are detailed in Table 2.

Overall, the bias assessment domains outlined in Table 1 showed that four studies had a low risk of bias (Andersen et al., 2021; Bo et al., 2014; Embaby et al., 2016; I. Sklempe Kokic et al., 2018), while the remaining four raised some concerns but were not at high risk of bias (Dawn Coe, Scott Conger, Jo Kendrick, Bobby Howard, Dixie Thompson, David Bassett, 2017; Iva Sklempe Kokic et al., 2018; Xie et al., 2022). Among the included studies, none exhibited high risk in any specific bias domain. In the randomization process domain, five studies demonstrated a low risk of bias (Andersen et al., 2021; Bo et al., 2014; Embaby et al., 2016; Xie et al., 2022; Youngwanichsetha et al., 2014). Likewise, five studies showed low risk for deviations from intended interventions (15) (Andersen et al., 2021; Embaby et al., 2016; I. Sklempe Kokic et al., 2018; Xie et al., 2022). For missing outcome data, two studies exhibited the lowest risk of bias (Bo et al., 2014; I. Sklempe Kokic et al., 2018). In the outcome selection domain, five studies had a low risk of bias (Andersen et al., 2021; Bo et al., 2014; Dawn Coe, Scott Conger, Jo Kendrick, Bobby Howard, Dixie Thompson, David Bassett, 2017; Embaby et al., 2016; I. Sklempe Kokic et al., 2018). Finally, in the outcome measurement domain, six studies had a low risk of bias, with two studies presenting some concerns (Andersen et al., 2021; Bo et al., 2014; Dawn Coe, Scott Conger, Jo Kendrick, Bobby Howard, Dixie Thompson, David Bassett, 2017; Embaby et al., 2016; I. Sklempe Kokic et al., 2018; Youngwanichsetha et al., 2014).

The included studies encompassed 488 participants in total, 244 in the intervention groups and 248 in the control groups. One study utilized a crossover design, resulting in 14 participants in both intervention and control groups (Andersen et al., 2021).

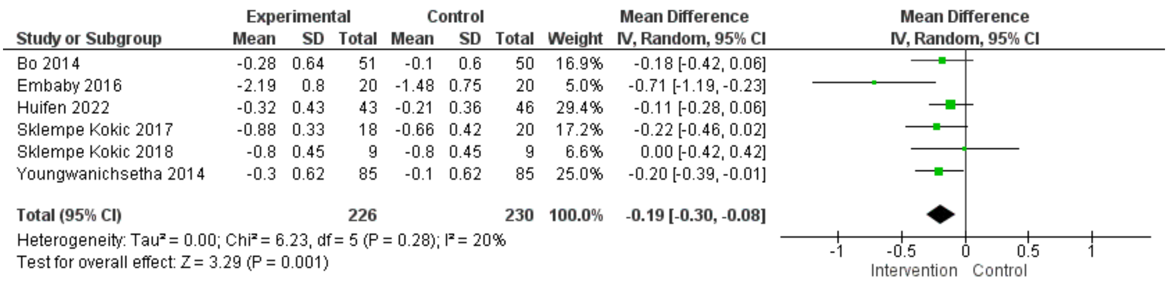


Figure 2: Meta-Analysis of Changes in Fasting Blood Glucose Levels

This review and meta-analysis were divided into subgroups to obtain more specific data based on the desired outcomes. Six of the eight studies were grouped in the first subgroup as they provided data on fasting blood glucose levels (FBG) before and after the intervention (Bo et al., 2014; Embaby et al., 2016; I. Sklempe Kokic et al., 2018; Iva Sklempe Kokic et al., 2018; Xie et al., 2022; Youngwanichsetha et al., 2014). The meta-analysis revealed a more significant reduction in FBG in the intervention group (MD = -0.19; 95% CI [-0.30, -0.08]; P=0.28; I2= 20%) (Figure 2). In this subgroup, the study by Huifen et al. (Xie et al., 2022) held the most significant weight at 29.4%, though its FBG reduction (-0.11 [-0.28, 0.06]) was not more significant than those of other studies.

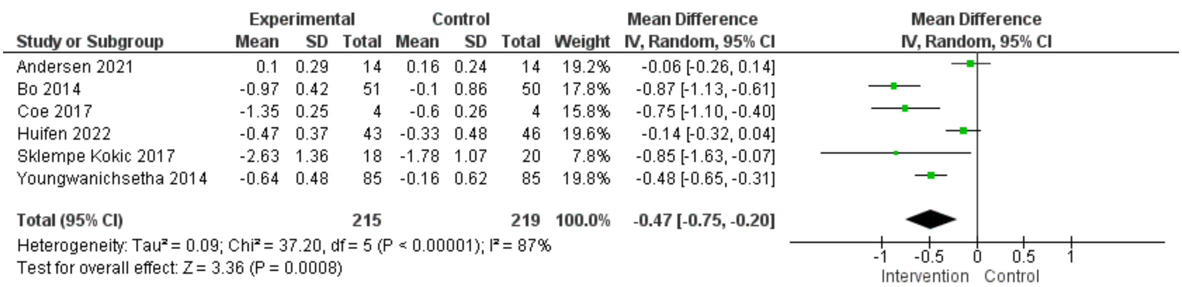


Figure 3: Meta-Analysis of Changes in Postprandial Blood Glucose Levels

The following subgroup analysis focused on the impact of exercise on changes in postprandial blood glucose levels (PPBG). Six studies provided PPBG data (Andersen et al., 2021; Bo et al., 2014; Dawn Coe et al., 2017; Iva Sklempe Kokic et al., 2018; Xie et al., 2022; Youngwanichsetha et al., 2014). The meta-analysis showed a significant reduction in PPBG, with the intervention group exhibiting a more significant decrease compared to the control group (MD = -0.47; 95% CI [-0.75, -0.20]; P < 0.00001; I2 = 87%) (Figure 3). Study weights in this subgroup ranged from 15.8% to 19.8%, with the study by Sklempe Kokic et al. (Iva Sklempe Kokic et al., 2018) in 2017 holding the most negligible weight at 7.8% yet yielding the second-largest significant reduction at -0.85 [-1.63, 0.07].

In the second half of pregnancy, skeletal muscle and adipose tissue become insulin-resistant. Given the metabolic effects of exercise, it proves to be an effective approach to preventing or managing GDM (Hamidreza Sheikhi, Mojtaba Jahromi, Alireza Sheikhi, 2017). Both aerobic exercise and resistance training, or a combination of the two, can be effective in improving fitness (Laredo-Aguilera et al., 2020). Physical activity increases glucose uptake by muscles, thereby requiring less insulin, which can help reduce PPBG (ACOG Practice Bulletins, 2018). Additionally, exercise improves insulin sensitivity by modifying adipokine parameters or lowering intermediate intramuscular lipid concentrations, such as various ceramides and diacylglycerols, which otherwise disrupt insulin signaling (Gu et al., 2022).

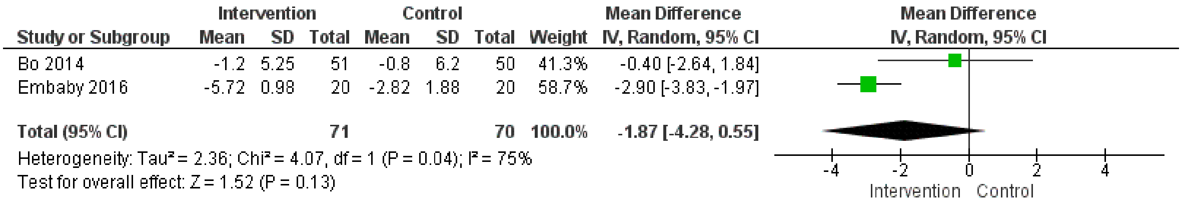


Figure 4: Meta-Analysis of Changes in Insulin Levels in the Blood

The final subgroup meta-analysis assessed the effect of exercise on insulin levels in the blood, comparing the intervention and control groups. Only two studies provided eligible data for this outcome (Bo et al., 2014; Embaby et al., 2016). Results showed a reduction in insulin usage as a metabolic function, particularly in the intervention group (MD = -1.87; 95% CI [-4.28, 0.55]; P = 0.04; I2= 75%) (Figure 4). Of the two studies, Embaby et al. (Embaby et al., 2016) had the largest weight at 58.7% and reported a change of -2.90 [-3.83, -1.97], which had a substantial impact on the overall results.

Table 2: Data Extraction

Author, Year	**Country**	**Subject**			**Description of Intervention**					**Results**
		Total		**Pregnancy Duration (Weeks)**	**Intervention Type**	**Interval**	**Duration (minutes /day)**	**Frequency (days /weeks)**	**Intensity**	
		Intervention	**Control**							
Anderson et al., 2021	Denmark	14	14	30.5–33.1	Interval walking after meals	4 days	3 x 20	4	Moderate	Postprandial interval walking effectively controls postprandial blood glucose
Bo et al., 2014	Italy	51	50	24-26	Brisk walking	Up to 38 weeks of gestation	20	7	Moderate	Exercise can reduce postprandial blood glucose but is not significant for fasting blood glucose
Coe et al., 2017	United States	4	4	24-35	Walking on a treadmill	Once	30	1	Moderate	The reduction in postprandial blood glucose levels is greater in the intervention group
Embaby et al., 2016	Saudi Arabia	20	20	20-24	Walking on a treadmill	Up to 37 weeks of gestation	45	3	Moderate	Fasting blood glucose levels decreased significantly in the intervention group

Huifen et al., 2022	China	46	46	24-31	Resistance training	Up to 37 weeks of gestation	50-60	3	Moderate	After the exercise period, blood glucose levels in the intervention group were lower than in the control group
Skelmpe Kokic et al., 2017	Croasia	20	20	≤30	Resistance, aerobic, and stretching exercises	6 weeks	50-55	2	Moderate	Postprandial blood glucose in the intervention group was lower, while the difference in fasting blood glucose was not significant
Skelmpe Kokic et al., 2018	Croasia	9	9	Not stated	Resistance, aerobic, and stretching exercises	Up to 36 weeks of gestation	50-55	2	Moderate	There was a reduction in blood glucose levels in both groups with a less significant difference
Youngwanichsetha et al., 2014	Thailand	85	85	24-30	Yoga exercises	8 weeks	15-20	5	Mild	The intervention group showed a significant reduction in both fasting and postprandial blood glucose levels

4. Discussion

These findings are consistent with several studies indicating that women who tend to be less active at the beginning of pregnancy may increase their risk of developing gestational diabetes mellitus (GDM) (do Nascimento et al., 2019). Research in China also showed that increased physical activity during pregnancy is associated with a reduced risk of GDM, whereas a sedentary lifestyle is associated with an increased risk of GDM among pregnant women (Leng et al., 2016).

For more than a decade, healthcare professionals have focused on exercise for overweight/obese women during pregnancy in relation to GDM, although a substantial proportion of women with GDM have a normal pre-pregnancy BMI (Ming et al., 2018). Moderate-intensity physical activity can lower fasting blood glucose levels in mothers with GDM and is recommended as part of the treatment plan for GDM patients. Common activities such as walking for 10-15 minutes are also recommended to control fasting blood glucose (ACOG Practice Bulletins, 2018).

Exercise may influence adipokine profiles by increasing adiponectin, a protein that enhances cellular sensitivity to insulin (Wang et al., 2016). It also raises the expression of GLUT4, a glucose transporter that moves glucose from the bloodstream into cells, lowering blood glucose and reducing insulin resistance, thus alleviating pancreatic strain on the mother. Additionally, exercise boosts antioxidant levels, countering oxidative stress, a contributor to GDM, and decreases inflammatory markers linked to insulin resistance, potentially reducing GDM risk by decreasing maternal insulin resistance (Wang et al., 2016).

Based on data extraction results, the study by Youngwanichsetha et al. (Youngwanichsetha et al., 2014), with the highest sample size of 85 participants in both groups, showed significant reductions in FBG and PPBG. This study's intervention involved exercise sessions of 15–20 minutes, five times a week, over eight weeks, resulting in a longer intervention period than other studies. Conversely, Bo et al. (Bo et al., 2014) provided a 20-minute daily exercise session until 38 weeks of gestation. Although this study showed a significant reduction in PPBG in the intervention group, the FBG reduction was less pronounced.

5. Conclusion

This study demonstrates that pregnant women with gestational diabetes mellitus (GDM) can engage in light to moderate-intensity physical exercise, including resistance training, aerobic exercises, or yoga. Physical exercise positively influences metabolism in women with GDM, particularly in controlling and reducing blood glucose levels. Exercise significantly affected postprandial blood glucose levels (PPBG) compared to fasting blood glucose levels (FBG). Additionally, it may help regulate insulin levels, further supporting glucose control.

Moderate-intensity exercises, such as walking, and low-intensity activities like yoga, yielded notable benefits. Exercises that do not strain the mother excessively and promote relaxation are well-suited for managing blood glucose levels. An essential factor in exercising for pregnant women with GDM is to engage in regular, well-measured activity under supervision to ensure both safety and effectiveness.

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