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Risk factors associated with postpartum glucose intolerance in gestational diabetes mellitus patients: A meta-analysis study

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Abstract: Women, especially those with a history of gestational diabetes mellitus (GDM), are at increased risk for abnormal glucose tolerance during and after pregnancy. Identifying the risk factors for postpartum glucose intolerance is crucial for effective prevention. This meta-analysis reviewed 8 relevant studies to identify key factors associated with postpartum glucose intolerance in women with GDM. The analysis found that a history of GDM, elevated body mass index (BMI), and insulin use during pregnancy are significant risk factors for postpartum glucose intolerance. Specifically, the odds ratio for GDM history was 0.877 (95% *CI:* 0.122, 1.633; $P = 0.023$), for BMI it was 1.083 (95% *CI:* 1.039, 1.128; $P < 0.0001$), and for insulin use during pregnancy it was 2.704 (95% *CI:* 1.156, 4.251; $P = 0.001$). Our findings emphasize the importance of monitoring women with high BMI or those who used insulin during pregnancy for postpartum glucose intolerance. These factors should be considered in strategies aimed at preventing the progression to type 2 diabetes.

Keywords: Pregnancy complications, BMI, diabetes and pregnancy, meta-analysis, type 2 diabetes

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INTRODUCTION

In China, Gestational diabetes mellitus (GDM) has become an epidemic condition, resulting in significant health and economic burdens (Juan and Yang, 2020). Adverse outcomes associated with GDM include postpartum hemorrhage, macrosomia, and neonatal hypoglycemia, which have a serious impact on the health of both mother and infant (Yogev, Chen *et al.*, 2010).

GDM is a common condition influencing many pregnancies. In 2013, a total of 3.4 million cases with hyperglycemia during pregnancy were screened from the Gulf and North Africa. Meanwhile, the age-adjusted prevalence of GDM is 9.5% in Africa and 26.6% in South-East Asia (Wang, Li *et al.*, 2022). Notably, the laboratory indicators of part of GDM patients will return to normal range with the decrease of hormone level after delivery, but from a longer-term perspective, the risk of developing diabetes will remain high. Studies have shown that patients with gestational diabetes still have a high risk of developing diabetes 5–16 years after the onset of the disease, specifically 17%–63% (Sweeting, Wongs *et al.*, 2022; Sweeting, Hannah *et al.*, 2024). Studies have also shown that patients who have already developed gestational diabetes are much more likely to develop Hu *et al.*, 2021).

The transitional mechanisms from GDM to persistent glucose intolerance involve three interrelated pathological processes. First, the failure of postpartum β-cell mass adaptation plays a pivotal role. While pregnancy induces β-cell hyperplasia through placental lactogen signaling, GDM patients exhibit impaired proliferative capacity due to IRS-2 (insulin receptor substrate-2) phosphorylation defects (Wang, Wei *et al.*, 2021). Second, the vicious cycle between insulin resistance and chronic inflammation persists postpartum. Adipose tissue macrophage infiltration, particularly the M1/M2 macrophage ratio imbalance, sustains elevated TNF-α and IL-1β levels that impair insulin signaling through JNK pathway activation (Kawai, Autieri *et al.*, 2021). Third, emerging evidence implicates epigenetic reprogramming during pregnancy. DNA methylation alterations at the *PPARGC1A* promoter region (cg19693031 site) have been identified as molecular predictors of postpartum β-cell dysfunction, with hypermethylation patterns correlating with 2.3-fold increased diabetes risk (95% CI 1.4–3.8) (Sun, Wang *et al.*, 2024). These mechanisms collectively drive the progression from transient gestational hyperglycemia to sustained metabolic dysregulation.

Women may experience postpartum glucose intolerance after childbirth (Champion, Battarbee *et al.*, 2022). Identifying the risk factors for postpartum glucose intolerance is a critical step in reducing the prevalence of type 2 diabetes. However, for women who have had gestational diabetes, the research results on the risk factors for postpartum glucose intolerance are inconsistent. Champion *et al.* found that there is a strong correlation between a history of gestational diabetes (GDM) and the development of postpartum glucose intolerance (Champion, Battarbee *et al.*, 2022). In contrast, according to the observations of Bhavadharini B *et al.*, a history of gestational diabetes is not necessarily a result of postpartum glucose intolerance (Bhavadharini, Anjana *et al.*, 2016). While prepregnancy obesity (BMI ≥30 kg/m²) was strongly associated with glucose intolerance in European cohorts (Ciba, Dahlbom *et al.*, 2024), Asian studies emphasize postpartum weight retention (ΔBMI >2

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kg/m²: OR 4.7 vs 1.9 in Caucasians) (Zhang, Yue *et al.*, 2023). Belsti *et al.* specifically identified advanced maternal age (>35 years) as an independent predictor in Mediterranean populations, whereas Latin American cohorts found no such association (Belsti, Moran *et al.*, 2023). The predictive value of third-trimester HbA1c remains contentious. Bhavadharini B *et al.* reported significant correlation in Indian women (AUC 0.71), contrasting with null findings in African Americans (AUC 0.62) (Hannah, Bhavadharini *et al.*, 2022). These contradictions may result from methodological heterogeneity in diagnostic criteria, duration of follow-up, and cutoff values for ethnic adjustment.

Previous studies on the risk factors of postpartum glucose intolerance in GDM patients are inconsistent and have limitations. This study aims to conduct a comprehensive meta-analysis to systematically review and integrate relevant research findings. By doing so, we can accurately identify the key risk factors, clarify the differences in risk factor profiles among different populations, and provide more reliable evidence-based guidance for the prevention and management of postpartum glucose intolerance in GDM patients.

MATERIALS AND METHODS

Search strategy

The databases selected for this study include WOS, Medline, PubMed, and Cochrane Library. The search was conducted by Naijun Chen starting on January 2000 and was completed by February 2024. The keywords include postpartum glucose tolerance, gestational diabetes, abnormal glucose metabolism, etc., and finally the literature that meets the requirements was screened out. The search time was set from January 2000 to February 2024. This time frame was chosen to obtain the latest research findings while ensuring that a sufficient number of studies were included to guarantee the reliability of the results. Studies conducted before 2000 have limited reference value for this study due to differences in research methods, diagnostic criteria, etc. Considering the time cost and the workload of literature screening, this time range was determined after comprehensive consideration.

Study selection

The PICO framework is a tool widely used in evidence - based medicine to formulating research questions and establishing study inclusion criteria. PICO stands for Population, Intervention, Comparison, and Outcome respectively. In this study, the "Population" consisted of women with Gestational Diabetes Mellitus (GDM). The "Intervention" referred to the factors under investigation as potential risk factors for postpartum glucose intolerance. The "Comparison" was represented by the control group. The "Outcome" is postpartum glucose intolerance or abnormal postpartum glucose metabolism.

We set the study selection criteria according to the PICO framework: (1) The search time was up to February 2024, and the search abstracts were risk factors for abnormal postpartum glucose metabolism. (2) The subjects in the literature were all diagnosed with GDM. (3) The samples in the control group of the literature excluded patients with abnormal postpartum glucose metabolism. (4) The statistical data in the literature were complete. All literature was limited to English articles (Zhang, Huang *et al*., 2021).

Literature quality evaluation and data extraction

In case of disagreement, a third reviewer was invited to vote by raising hands. The collected data should include the number of cases, results, author information, and publication date. The following aspects were considered in the assessment: comprehensiveness of the case definition, typicality of case selection, selection of the control group, representative definition of the control group, selection of exposure factors, consistency in the identification of cases and controls, and the presence or absence of response rates.

STATISTICAL ANALYSIS

We used Stata version 11.0 software in this study. OR and 95% CI were used to combine effect estimates, and the assessment of risk factors for postpartum glucose tolerance was assessed by using *OR* and 95% *CI*. The heterogeneity between the two was tested by Q test and I^2 test. We set the heterogeneity to be minimal when $P>0.1$ and $I^2<50\%$. When there is a large heterogeneity, a random effects model is required. Sensitivity analysis is required to determine whether the research results are reliable. In order to show the intuitiveness of the results, we used Stata 11.0 software to generate funnel plots and forest plots.

RESULTS

Study characteristics and quality assessment

After determining the inclusion and exclusion criteria, 82 articles were selected for study. This study finally selected 8 clinical studies (Bhavadharini, Anjana *et al*.,2016, Prados, Flores-Le Roux *et al*., 2019, Nouhjah, Shahbazian *et al*., 2017, Weinert, Mastella *et al*., 2014, Capula, Chiefari *et al*., 2014, Reyes-López, Perez-Luque *et al*., 2019, Hung, Chuang *et al*., 2021, Ghamri, 2019), including a total of 988 patients with postpartum glucose intolerance and 2326 controls. These studies have evaluated the relationship between risk factors and postpartum glucose intolerance. The selection process of the literature is shown in fig. 1, based on the basic information of the literature sources listed in table 1. The Newcastle Ottawa Scale was used to evaluate the quality of the studies, and the results showed that the quality of the included studies was at a medium level, with a score between 6 and 7 points. The evaluation results of the specific included literature are shown in table 2.

Table 1: Basic information of the research subjects

First author& year	Country	Sample size(n) Control	Postpartum glucose tolerance	Study design
Prados M 2019	Spain	177	128	Cohort study
Bhavadharini B 2016	India	162	41	Cohort study
Nouhjah S 2017	Iran	137	39	Cohort study
Weinert LS 2014	Brazil	82	26	Cohort study
Capula C 2014	Italy	290	164	Case control study
Reyes-López R 2019	Mexico	83	70	Case control study
Hung TH 2021	Taiwan	1155	493	Case control study
Ghamri K 2019	Saudi Arabia	240	27	Case control study

Table 2: Assessment of study quality using the Newcastle Ottawa Scale

Author, Year	Selection				Comparability of Cases and Controls on Basis of Design of Analysis	Outcome			
	Adequate Case Definition	Representative of Cases	Selection of Controls	Definition of Controls		Ascertainment of Exposure	Same Method of Ascertainment for Cases and Controls	Non-Response Rate	Score
Prados M 2019	Yes	Yes	Yes	Yes	Yes	No	Yes	No	6
Bhavadharini B 2016	Yes	Yes	Yes	Yes	Yes	No	Yes	No	6
Nouhjah S 2017	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
Weinert LS 2014	Yes	Yes	Yes	Yes	Yes	No	Yes	No	6
Capula C 2014	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	7
Reyes-López R 2019	Yes	Yes	Yes	Yes	Yes	No	Yes	No	6
Hung TH 2021	Yes	Yes	Yes	Yes	Yes	No	Yes	No	6
Ghamri K 2019	Yes	Yes	Yes	Yes	Yes	No	Yes	No	6

Heterogeneity testing and effect estimation

The heterogeneity test for the correlation between postpartum glucose intolerance and GDM history was (Q=4.39, *P*=0.222, I^2=31.7%). This result shows that the heterogeneity between studies is large. In this case, a random effects model is needed for analysis. The estimated value of the combined effect is [*OR*=0.877, 95% *CI* (0.122, 1.633); *P*=0.023]. See fig. 2. The heterogeneity test result for the effect of body mass index (BMI) during pregnancy on postpartum glucose intolerance was (Q=2.16, *P*=0.339, I^2=7.6%), indicating little heterogeneity among the studies. Therefore, a random effect model was applied to the analysis. The combined effect estimate was [OR=1.083, 95% CI (1.039, 1.128); *P*=0.000]. The forest plot is depicted in fig. 3.

The heterogeneity test result of the influence of using insulin during pregnancy on postpartum glucose intolerance was (Q=2.15, *P*=0.543, I^2=0.00%). To avoid significant heterogeneity among studies, a random effects model was used for analysis. The estimated combined effect size was [*OR*=2.704, 95% *CI* (1.156, 4.251); *P*=0.001]. Fig. 4 displays the corresponding forest plot.

Sensitivity analysis

This study conducted a sensitivity analysis on the stability of the results of the impact of history of gestational diabetes on postpartum glucose tolerance. The results showed that none of the studies had a significant impact on the overall conclusion. Therefore, this shows that the results of this meta-analysis can withstand scrutiny (see fig. 5).

After a sensitivity analysis, we assessed the stability of the results as a result of the impact of BMI and insulin use during pregnancy on postpartum glucose intolerance. The findings showed that none of the studies had a significant impact on the overall conclusions (fig. 6 and 7).

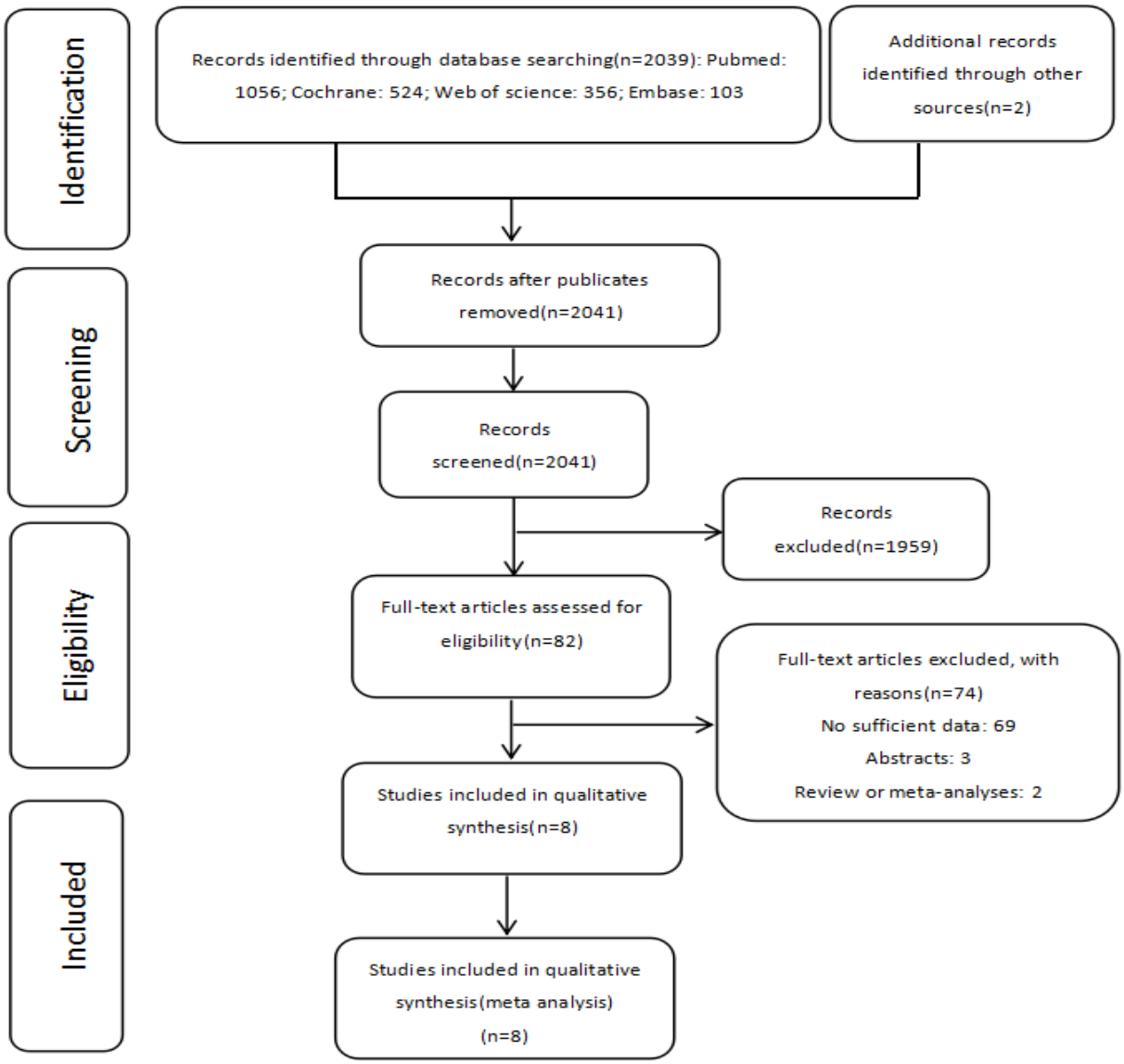

Fig. 1: Flow diagram depicting the literature search and selection of studies

Bias analysis

According to the results shown in the funnel plot, the distribution of all data points is uniform and symmetrical, and no publication bias was found by Egger's test ($P > 0.05$). Therefore, we can believe in the reliability of the results. For more details, please refer to fig. 8, 9 and 10.

DISCUSSION

Our meta-analysis identified three significant independent risk factors for postpartum glucose intolerance among women with a history of gestational diabetes mellitus (GDM). Firstly, a prior GDM history, elevated BMI during pregnancy, and insulin use during pregnancy were all found to be closely associated with postpartum glucose intolerance. Notably, for GDM history, the odds ratio was 0.877 (95% *CI* 0.122, 1.633; $P = 0.023$), suggesting it may be a risk factor, although further exploration of the unexpected OR value is warranted. The odds ratio for BMI was 1.083 (95% *CI* 1.039, 1.128; $P < 0.0001$), indicating that an increase in BMI during pregnancy significantly raises the likelihood of postpartum glucose intolerance. For insulin use during pregnancy, the odds ratio was 2.704 (95% *CI* 1.156, 4.251; $P = 0.001$), highlighting its strong association with the outcome. From a methodological perspective, our study demonstrated high rigor. The heterogeneity tests revealed a moderate degree of variability among studies regarding GDM history ($I^2 = 31.7\%$), while the variability was low for BMI ($I^2 = 7.6\%$) and insulin use ($I^2 = 0\%$). These results justified the use of random - effects models in data analysis, enhancing the reliability of our findings. Moreover, bias analyses, including Egger's test and funnel plots, indicated no significant publication bias ($P > 0.05$), further validating the robustness of our results.

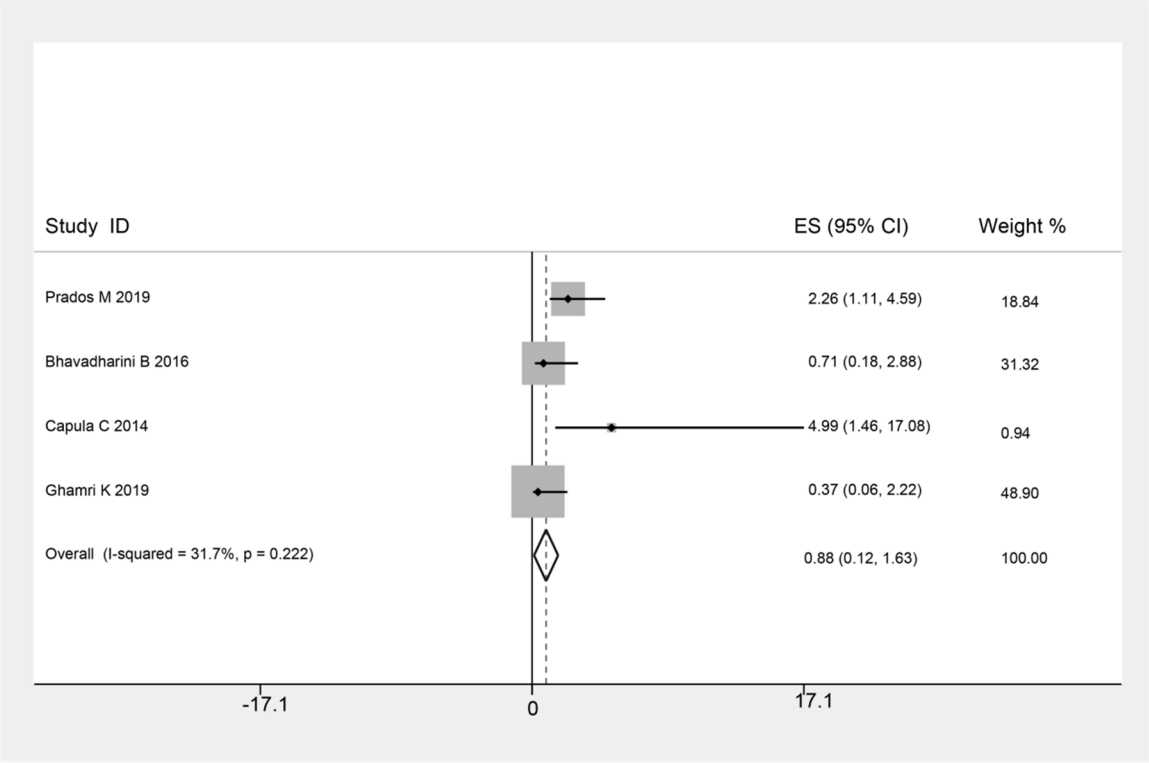

Fig. 2: The forest plot of the association between postpartum glucose intolerance and history of GDM. The heterogeneity test yielded the following results: Q = 4.39, P = 0.222, I^2 = 31.7%. The pooled estimate of the effect size was [OR=0.877, 95% CI (0.122, 1.633); P=0.023].

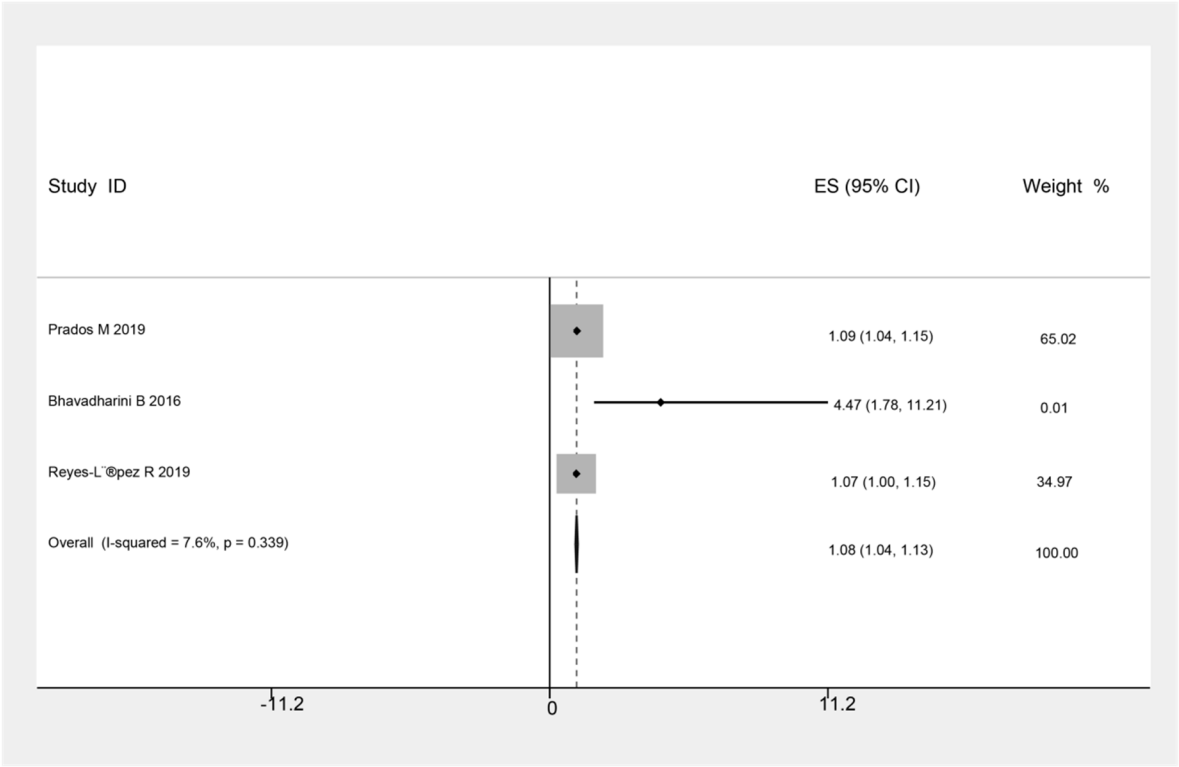

Fig. 3: The forest plot of the association between BMI during pregnancy and postpartum glucose intolerance. The result of the heterogeneity test was calculated as (Q=2.16, P=0.339, I^2=7.6%). The aggregated effect size was calculated as [OR=1.083, 95% CI (1.039, 1.128); P=0.000].

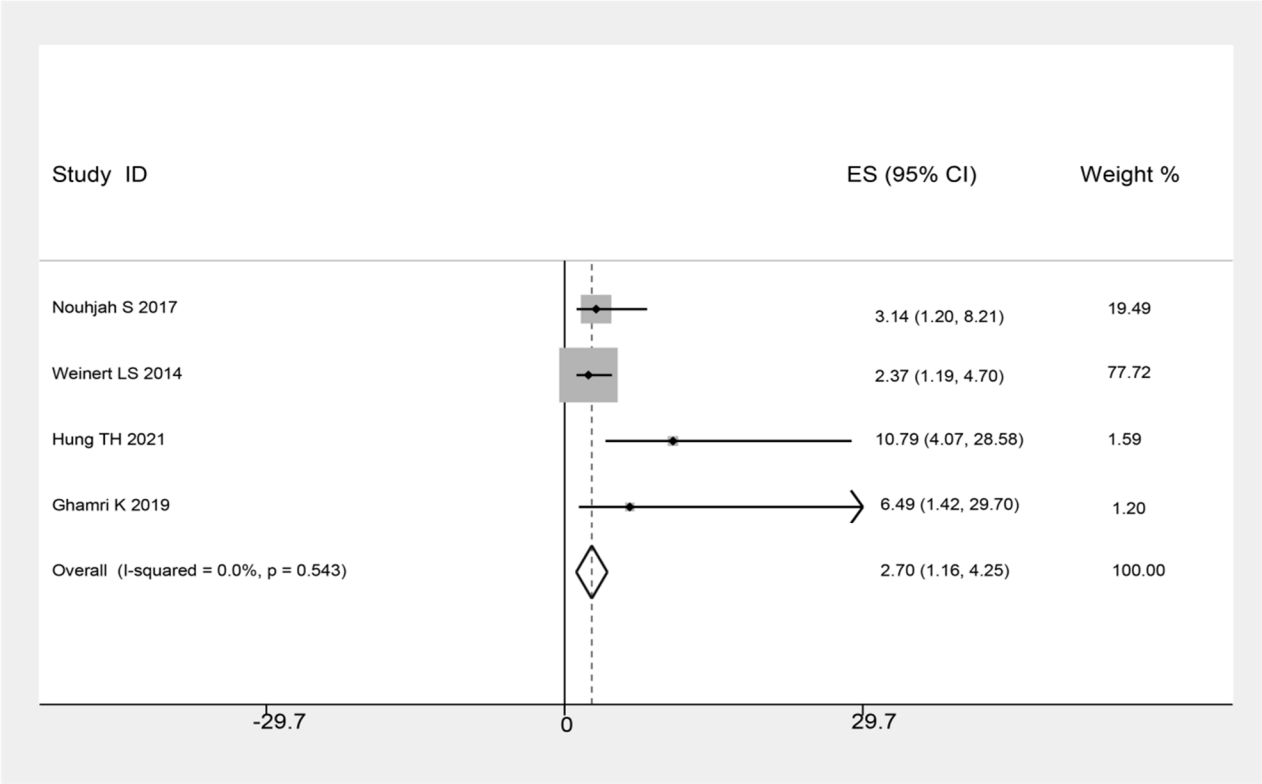

Fig. 4: The forest plot of the association between using isulin and postpartum glucose intolerance. The heterogeneity test result was (Q=2.15, P=0.543, I^2=0.00%). The combined value of the estimated effect was [OR=2.704, 95% CI (1.156, 4.251); P=0.001].

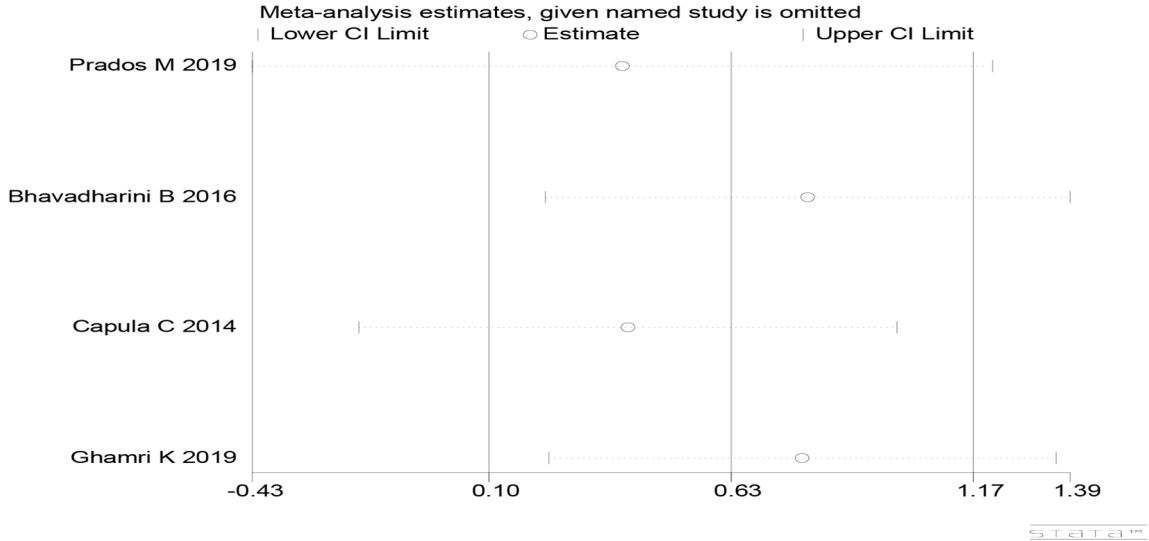

Fig. 5: The sensitivity analysis of the association between postpartum glucose intolerance and history of GDM. The results of the pooled effect regarding primary outcomes were notably unaffected by the findings of any single study.

This meta-analysis revealed that a history of GDM, an elevated BMI during pregnancy, and insulin use are important independent risk factors for postpartum glucose intolerance. Studies have shown that BMI has an impact on the risk of type 2 diabetes. Patients with a BMI greater than 30 kg/m2 during pregnancy have a higher probability of developing type 2 diabetes after delivery(Ghamri, 2019) An excessively high BMI can exacerbate insulin resistance. The increase in adipose tissue, especially the accumulation of abdominal fat, can affect the action of insulin, reducing the uptake and utilization of glucose and leading to an increase in blood glucose levels.

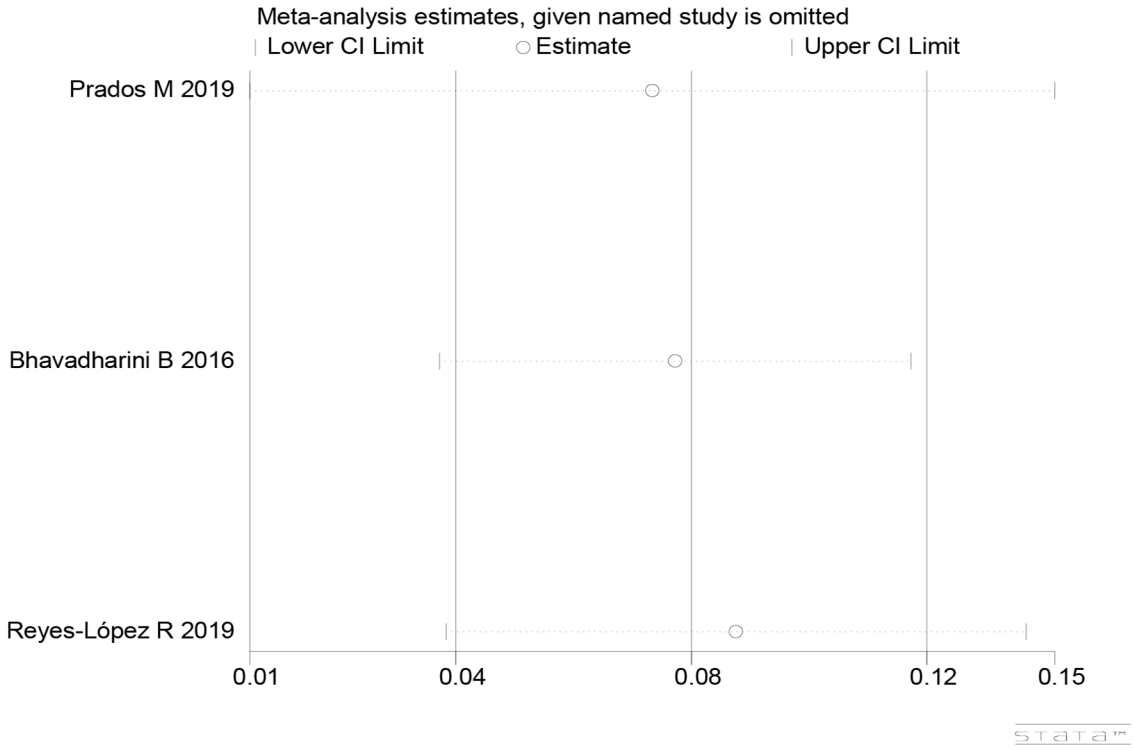

Fig. 6: The sensitivity analysis of the association between BMI during pregnancy and postpartum glucose intolerance. No study demonstrated a noteworthy impact on the pooled effect pertaining to the primary outcomes.

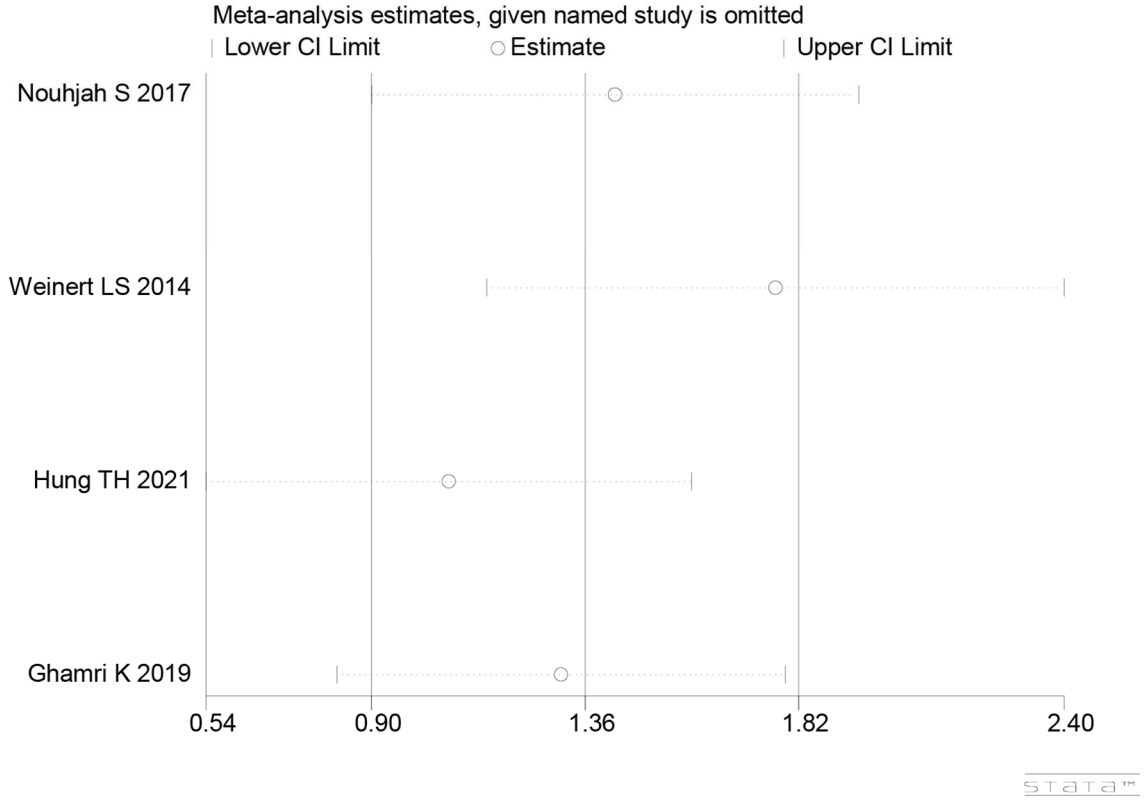

Fig. 7: The sensitivity analysis of the association between using isulin and postpartum glucose intolerance. The results of the pooled effect regarding primary outcomes were not significantly influenced by any single study.

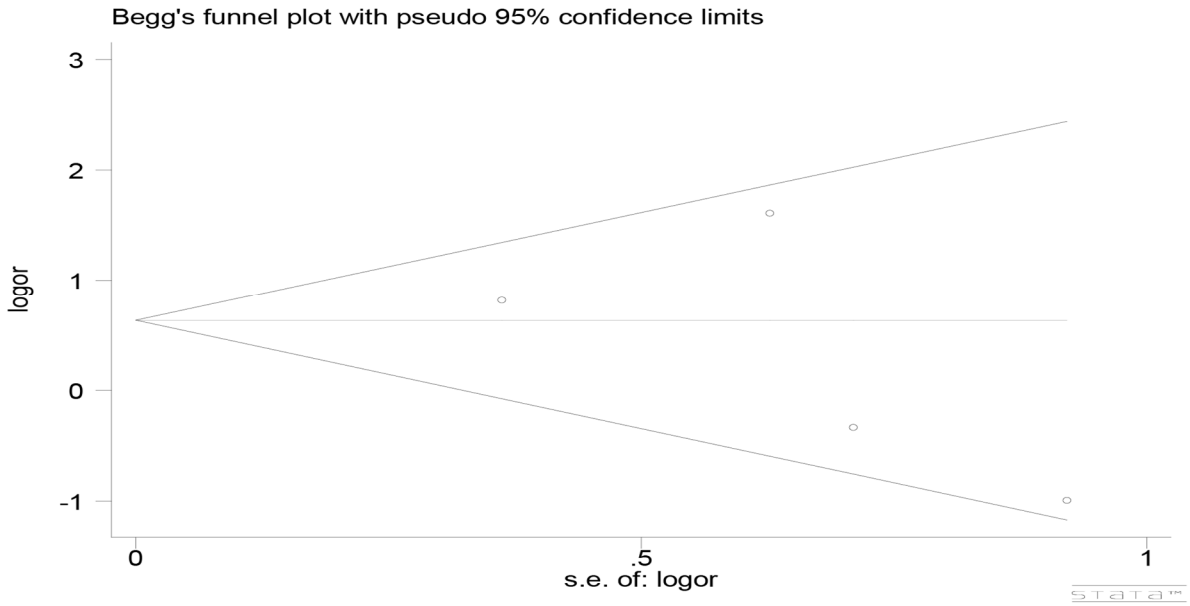

Fig. 8: The funnel plot shows the relationship between a history of GDM and postpartum glucose intolerance.

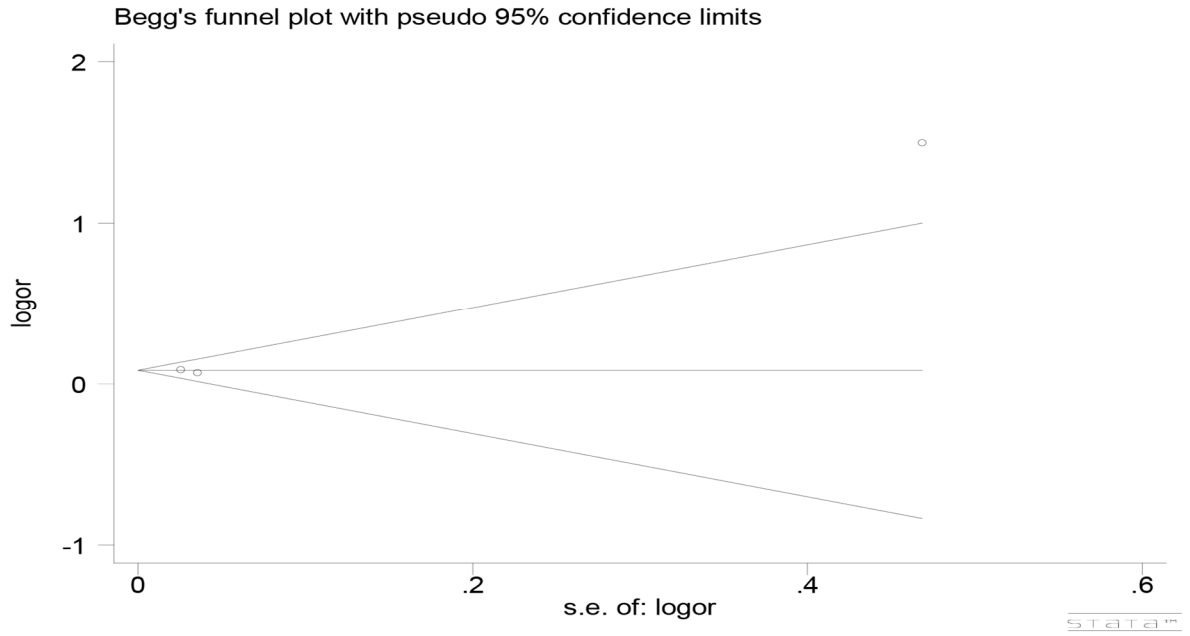

Fig. 9: The funnel plot depicts the correlation between BMI during pregnancy and postpartum glucose intolerance.

Studies have shown that in obese patients, insulin receptor signaling is blocked, and the secretion of inflammatory factors is increased, further exacerbating insulin resistance (Park, Kang *et al.,* 2022). In addition, obesity can also reduce the insulin secretion function by increasing the pressure on pancreatic β-cells from adipose tissue, resulting in abnormal blood glucose metabolism (Laget, Vigor *et al*.,2022).

In our study, the correlation between an increase in BMI and postpartum glucose intolerance was also confirmed, with an OR of 1.083 (95% CI 1.039, 1.128; $P < 0.0001$), indicating that each increase in BMI during pregnancy significantly increases the risk of postpartum glucose intolerance. Karcz *et al* (Karcz, Gaweł *et al.,*2024) also pointed out in their study that there is a significant association between weight gain during pregnancy and postpartum glucose metabolism disorders, which is consistent with our findings. However, Dashti *et al.* (Dashti, Miranda *et al.,*2022) believed that the effect of BMI may be modulated by other factors, such as genetic background and lifestyle. We believe that this difference

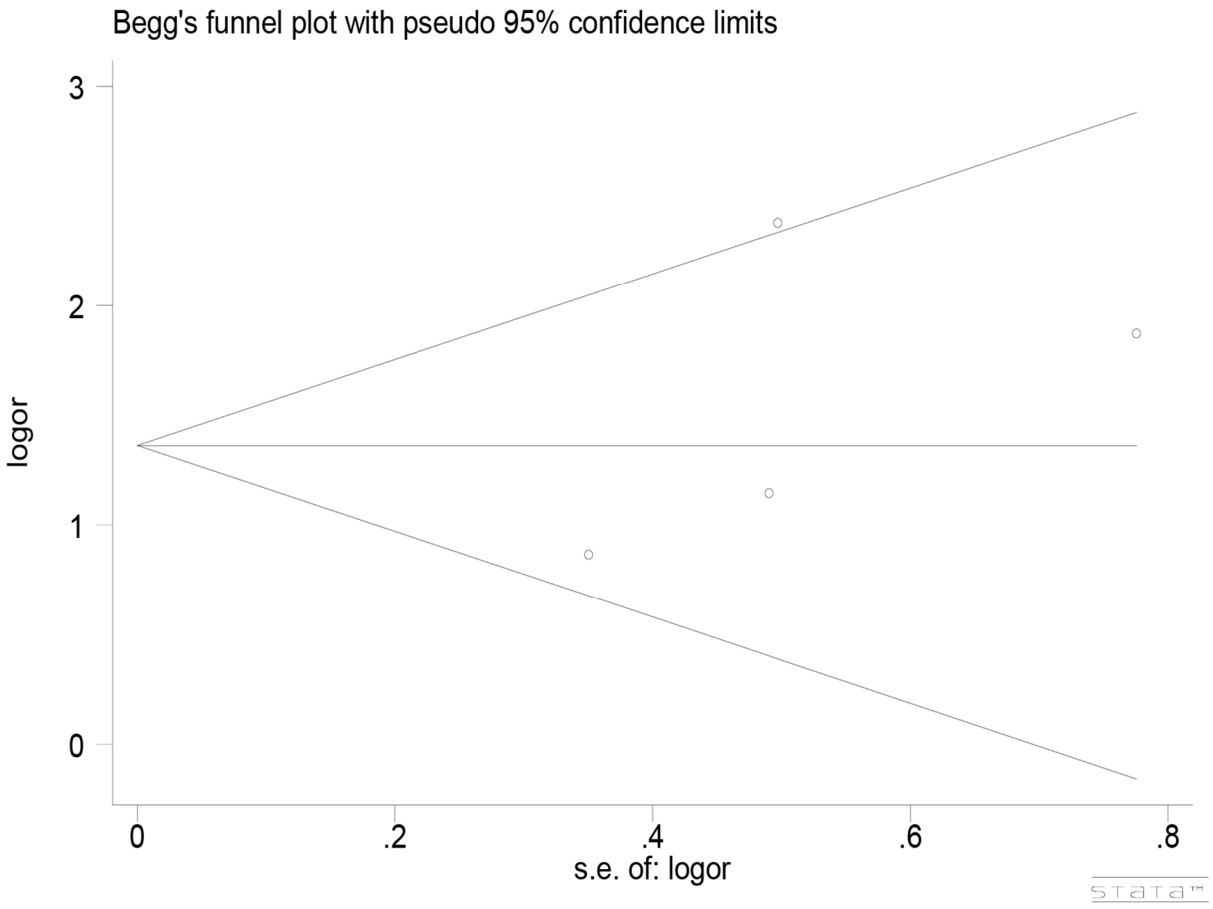

Fig. 10: The funnel plot illustrates the relationship between insulin use and postpartum glucose intolerance.

may stem from the heterogeneity of the study populations and the differences in intervention measures.

In addition, insulin use, as a treatment method for controlling blood sugar during pregnancy, was also confirmed as a powerful risk factor in our study, with an odds ratio (*OR*) of 2.704 (95% *CI* 1.156, 4.251; $P = 0.001$). The use of insulin reflects the functional defect of pancreatic β - cells in patients during pregnancy, which means that patients have a relatively severe deficiency in insulin secretion ability, leading to an increased risk of abnormal glucose metabolism postpartum. Nabi *et al*. (Nabi, Rafiq *et al.,* 2021) also pointed out that women who require insulin treatment during pregnancy have a significantly higher likelihood of developing type 2 diabetes postpartum. Our study further supports this view. Insulin treatment is not only a means of blood sugar control but is more likely to be an early indicator of metabolic disorders.

Numerous studies have indicated that in women with GDM during pregnancy, the function of pancreatic β - cells may be impaired to some extent. Pancreatic β - cells in GDM patients show an insufficient insulin - secretion response, making them more prone to insulin resistance during pregnancy (Hill, Smith *et al*., 2023). When the metabolic demands increase during pregnancy, pancreatic β - cells usually need to secrete more insulin to overcome insulin resistance. However, if the compensatory capacity of pancreatic β - cells under metabolic stress is insufficient, it may lead to abnormal glucose metabolism during pregnancy and postpartum (Ruiz-Otero, Tessem *et al*., 2024). This mechanism explains why patients with a history of GDM are prone to glucose intolerance postpartum. Even if their blood glucose returns to normal in the short - term after delivery, in the long - term, they still face a high risk of diabetes. The results of this study are consistent with the existing literature, emphasizing that a history of GDM is an independent risk factor for postpartum abnormal glucose metabolism. Sundarapperuma *et al* (Sundarapperuma, Hettiarachchi *et al.,* 2024) pointed out that a history of GDM is significantly associated with the risk of developing postpartum diabetes, which is consistent with our findings.

Based on the findings of this study, we suggest that for GDM patients with a high body mass index (BMI) or those who used insulin during pregnancy, postpartum glucose

tolerance monitoring should be enhanced. In particular, for pregnant women with a high BMI, it is recommended to initiate weight management and exercise interventions as early as possible after childbirth to reduce the risk of developing diabetes. Additionally, patients who used insulin during pregnancy should continue to receive blood glucose monitoring postpartum and undergo further interventions according to their specific conditions to reduce the incidence of diabetes.

Although this meta-analysis has revealed the significant impact of BMI and insulin use on postpartum glucose intolerance, there are still some limitations. Firstly, the sample size of the studies included in this research is relatively small, and the quality of some studies is low, which may lead to biases in the results. Secondly, this study failed to consider other potential risk factors such as family history and HbA1c, and these factors may affect our conclusions. Therefore, future large-scale prospective studies should take these factors into account and explore the differences in the roles of different risk factors among various groups. Further research should also focus on evaluating the effectiveness of different intervention measures in improving postpartum glucose tolerance, and clarifying the specific mechanisms of action of different risk factors in different populations. Such research will provide more reliable evidence for individualized intervention strategies and offer more guiding policy recommendations for clinical practice.

CONCLUSION

In summary, this meta-analysis identified three significant independent risk factors for postpartum glucose intolerance in women with a history of gestational diabetes mellitus (GDM). These factors include a history of GDM, elevated BMI during pregnancy, and insulin use during pregnancy. Given these findings, there is an urgent need for enhanced postpartum glucose monitoring for women with high BMI or insulin use during pregnancy. Immediate interventions such as weight management and lifestyle changes should be prioritized to reduce the risk of type 2 diabetes. Future studies should explore strategies to improve postpartum glucose metabolism, focusing on effective weight management and evaluating the role of other factors, such as genetic predisposition and HbA1c levels, in predicting postpartum glucose intolerance.

Conflict of interest

There is no conflict of interest.

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