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Original Research

Delivery Mode and Risk of Neonatal Hypoglycemia in Gestational Diabetes Mellitus: A Retrospective Study

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Abstract

Background: Neonatal hypoglycemia (NH) is a common metabolic complication among infants born to mothers with gestational diabetes mellitus (GDM) and may adversely affect neurodevelopment. Delivery mode, particularly cesarean section (CS), has been proposed as a potential risk factor for NH; however, existing evidence remains inconsistent. This study aimed to evaluate the association between delivery mode and the risk of NH in pregnancies complicated by GDM. **Methods**: This retrospective study included women with GDM who delivered at ≥35 weeks of gestation at Anhui No.2 Provincial People's Hospital between January 2024 and December 2024. NH was defined as any blood glucose measurement <2.6 mmol/L within the first 24 hours of life, consistent with American Academy of Pediatrics guidelines. Maternal and neonatal characteristics were compared between the NH and non-NH groups. Independent risk factors for NH were identified using multivariable logistic regression. The predictive performance of CS for NH was evaluated by calculating sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). **Results**: Among 201 women with GDM who met the inclusion criteria, 44 neonates (21.89%) developed NH. The rate of CS was significantly higher in the NH group compared with the non-NH group (81.82% vs. 39.49%, $p < 0.001$). After adjustment for potential confounders, CS remained an independent risk factor for NH (adjusted odds ratio [OR] = 4.48, 95% confidence interval [CI]: 1.56–12.87; $p = 0.005$). CS was associated with a sensitivity of 81.8%, a specificity of 60.5%, a PPV of 36.7%, and an NPV of 92.2% for NH. **Conclusions**: CS independently increases the risk of NH in infants born to mothers with GDM. Delivery mode should be considered in perinatal management strategies to improve early identification and prevention of NH.

Keywords: gestational diabetes mellitus; neonatal hypoglycemia; cesarean section; delivery mode; risk factor

1. Introduction

Gestational diabetes mellitus (GDM) is the most prevalent metabolic disorder during pregnancy, affecting approximately 7%–14% of pregnancies worldwide [1,2]. In mainland China, a systematic review and meta-analysis of studies that used the IADPSG criteria reported a pooled GDM prevalence of 14.8%. This rate exceeds that reported in many Western populations and may reflect genetic susceptibility, dietary patterns, and increasing maternal age [3]. GDM not only increases the risk for pregnant women, such as gestational hypertension and elevated cesarean section (CS) rates, but also contributes to adverse neonatal outcomes, including unstable blood glucose, macrosomia, and respiratory distress syndrome [4,5]. Neonatal hypoglycemia (NH) is one of the most common metabolic disturbances in the early neonatal period, and its incidence is markedly higher among infants with established risk factors such as maternal diabetes, growth restriction, or prematurity [6]. In this study, NH was defined as any blood glucose concentration below 2.6 mmol/L within the first 24 hours of life, consistent with widely used operational thresholds for at-risk late preterm and term infants [7]. If not promptly identified and managed, neonatal hypoglycemia can result in acute brain injury that predominantly affects the posterior cerebral regions, as demonstrated by magnetic resonance imaging studies [8,9]. Long-term follow-up neuroimaging study has revealed that NH is associated with smaller volumes of deep gray matter structures, including the caudate nucleus and thalamus, which persist into mid-childhood [8]. Consequently, timely identification of risk factors is crucial for prevention and early intervention.

Beyond its occurrence, NH exhibits a dose-dependent relationship with subsequent neurodevelopmental outcomes. Data from the Children with Hypoglycemia and Their Later Development (CHYLD) prospective cohort demonstrated that more severe NH (blood glucose <2.0 mmol/L), prolonged episodes, or recurrent events (≥3 episodes) were associated with diminished executive function and visual-motor performance at 4.5 years of age, whereas mild or transient episodes were not associated with these outcomes [10]. In a later follow-up of the same cohort, neuroimaging assessments at 9–10 years of age suggested that NH was associated with structural brain alterations, including smaller caudate volume, which in turn was related to emotional and behavioral outcomes in mid-childhood [11]. Neuroimaging study further corroborates this gradient of risk, with severe NH linked to reduced deep gray matter volume persisting into mid-childhood [8]. Ad-

ditional systematic reviews suggest that severe or recurrent NH poses greater long-term neurodevelopmental risk than milder forms, although the evidence base remains heterogeneous [12]. Overall, these findings underscore that both the occurrence and severity of hypoglycemic exposure influence subsequent neurodevelopment.

Delivery mode represents an important perinatal factor that may influence neonatal metabolic adaptation, particularly in pregnancies complicated by GDM. CS can mitigate certain obstetric risks, such as dystocia and severe perineal trauma in cases of suspected macrosomia; however, it may also delay the onset of breastfeeding, alter early neonatal stress responses, and increase the likelihood of maternal postoperative complications and impaired early mother–infant contact [13]. In contrast, vaginal delivery (VD) is accompanied by labor-associated hormonal surges and catecholamine release, which may facilitate neonatal glucose homeostasis. These physiological differences have led to ongoing debate regarding whether delivery mode independently contributes to NH risk in infants born to mothers with GDM.

The approach to GDM management may also modify the relationship between maternal diabetes and neonatal outcomes. A recent systematic review and meta-analysis of 18 randomized controlled trials demonstrated that lifestyle intervention, including diet and physical activity, reduced the risk of NH by 27% (relative risk [RR] = 0.73, 95% confidence interval [CI]: 0.54–0.98), with the greatest effect when intervention was initiated before the third-trimester [14]. Furthermore, pharmacologic management with metformin, compared with insulin, has been associated with a 35% lower rate of NH (RR = 0.65, 95% CI: 0.52–0.81), although the underlying mechanisms remain under investigation [15]. These findings suggest that both lifestyle and pharmacologic interventions may attenuate neonatal metabolic risk in pregnancies complicated by GDM.

Several observational studies have examined factors associated with NH in pregnancies complicated by GDM, suggesting that maternal glycemic control, a history of uterine scarring, and delivery mode may influence neonatal glucose instability [16,17]. In particular, more stringent management of maternal blood glucose has been associated with a lower incidence of NH in some cohorts, implying a potential protective effect of optimized glycemic control [18]. However, these findings are often limited by heterogeneous study populations, variable definitions and timing of hypoglycemia assessment, and incomplete adjustment for key confounders, including maternal body mass index (BMI), diabetes treatment modality (dietary management versus insulin or oral hypoglycemic agents), and the timing of glucose measurements. Previous observational study has suggested that CS may be associated with NH and related early clinical consequences, particularly in the context of adverse maternal or perinatal metabolic conditions [19]. Moreover, the distinction between diet-controlled and pharmacologically treated GDM, both of which may independently influence neonatal glucose homeostasis, has often been overlooked. These limitations underscore the need for more rigorous evaluation of delivery mode as a potential determinant of NH in well-characterized GDM cohorts.

Recent systematic reviews and meta-analyses have further elucidated risk factors for NH in pregnancies complicated by GDM. A 2024 meta-analysis by Wang *et al.* [20], synthesizing 12 case-control studies encompassing 991 neonates with NH and 4388 controls, found that CS was associated with nearly twofold higher odds of NH (odds ratio [OR] = 1.90, 95% CI: 1.23–2.92). Other identified risk factors included gestational diabetes itself (OR = 1.65), gestational hypertension (OR = 2.79), and small-for-gestational-age status (OR = 2.88). These findings indicate that both maternal characteristics and perinatal factors contribute to neonatal glucose instability.

Despite these robust meta-analytic findings, several knowledge gaps remain. Most previous studies included mixed populations (GDM and non-GDM) or did not comprehensively adjust for key confounders such as uterine scarring, maternal age, gestational age, maternal BMI, and gravidity, factors that are particularly relevant in Asian cohorts with high CS rates. In China, the CS rate remains notably elevated. A recent national analysis of more than 7.6 million births reported an overall rate of 44.5% in 2020, with rates of about 40% even among low-risk term singleton vertex deliveries [21]. Furthermore, few studies have quantified the predictive performance of delivery mode as a standalone risk factor in well-characterized GDM populations. Therefore, in a retrospective study of 201 women with GDM from a tertiary center in China, the present study aimed to: (1) determine whether CS remains independently associated with NH after adjustment for key confounders, and (2) assess its clinical predictive value using sensitivity, specificity, PPV, and NPV.

2. Materials and Methods

2.1 Study Design and Population

This retrospective study included clinical records of all singleton pregnancies complicate by GDM that met the inclusion criteria and delivered in the Department of Obstetrics of Anhui No.2 Provincial People's Hospital from January 2024 to December 2024. The study was approved by the Ethics Committee of Anhui No.2 Provincial People's Hospital (Approval No: (R) 2025-107) and was conducted in accordance with the Declaration of Helsinki. The ethics committee waived the requirement for informed consent due to the retrospective design and use of anonymize data.

Inclusion criteria were as follows: (1) diagnosis of GDM based on the criteria recommended by the International Federation of Gynecology and Obstetrics (FIGO), confirmed by a 75 g oral glucose tolerance test (OGTT)

[22]; (2) singleton pregnancy; and (3) gestational age ≥35 weeks.

Exclusion criteria were as follows: (1) pre-existing diagnosis of type 1 or type 2 diabetes before pregnancy; (2) multiple pregnancy; (3) severe comorbid conditions, such as cardiac, hepatic, or renal disorders; (4) known severe structural or genetic abnormalities in the fetus; and (5) severely incomplete clinical data.

2.2 Data Collection

The following maternal and infant data were obtained from the hospital electronic medical record system:

(1) Maternal general characteristics: age, pre-pregnancy height, weight, and BMI (BMI = weight (kg) / height $(m)^2$).

(2) Obstetric-related information: gravidity, parity, gestational age (days), delivery mode (vaginal or cesarean), presence of uterine scar, and other pregnancy complications. Results of the 75 g OGTT. including fasting, 1-hour, and 2-hour plasma glucose levels, were extracted directly from the electronic medical record system.

(3) Laboratory tests: fasting blood glucose levels at GDM diagnosis.

(4) Neonatal information: gender, birth weight (grams), presence of macrosomia (birth weight ≥4000 grams), neonatal blood glucose level within 2 hours after birth, and admission to the neonatal intensive care unit (NICU).

2.3 Management of GDM

All patients with GDM were managed according to FIGO and American Diabetes Association (ADA) guidelines. Initial treatment consisted of medical nutrition therapy and physical activity. Pharmacologic therapy (metformin or insulin) was initiated if glycemic targets were not achieved within 1–2 weeks [23,24]. Glycemic targets were defined as follows: fasting plasma glucose ≤5.3 mmol/L, 1-h postprandial ≤7.8 mmol/L, and 2-h postprandial ≤6.7 mmol/L [24].

2.4 Relevant Definitions

NH was defined based on widely applied operational thresholds in previous neonatal studies. Any blood glucose value <2.6 mmol/L within the first 24 hours was considered hypoglycemia, and a value ≤2.0 mmol/L was classified as severe hypoglycemia for analyses of severity [6,11,12].

Delivery mode: categorized as VD, including spontaneous VD and forceps or vacuum-assisted VD, or CS, including elective and emergency procedures.

Scarred uterus: defined as a history of uterine surgery, such as myomectomy, uterine rupture repair, or previous CS [25].

2.5 Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and R software (R Foundation for Statistical Computing, Vienna, Austria; version 4.3.0). Quantitative variables were first assessed for normality. Normally distributed data are presented as mean ± standard deviation (SD), and comparisons between groups were conducted using the independent-samples *t*-test. Non-normally distributed data are presented as median (interquartile range, IQR) [M (Q1, Q3)], and comparisons between groups were performed using the Mann-Whitney U test. Categorical variables are expressed as counts and percentages [n (%)], and comparisons between groups were conducted using the chi-square (χ^2) test or Fisher exact test, as appropriate.

Variables with a p-value < 0.1 in univariate analyses were entered into a multivariate binary logistic regression model to identify independent risk factors for NH, using a purposeful selection approach to avoid premature exclusion of potential confounders [26]. Prior to final model construction, multicollinearity among candidate variables was assessed using variance inflation factors (VIF), and no significant multicollinearity was detected (**Supplementary Table 1**). Results of the regression analyses are reported as ORs with corresponding 95% CIs.

The predictive performance of delivery mode for NH was evaluated using sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

3. Results

3.1 General Characteristics of the Study Population

A total of 201 pregnant women with GDM met the inclusion criteria. Among them, 44 (21.89%) neonates developed NH, whereas 157 (78.11%) did not. Table 1 summarizes the maternal and neonatal characteristics of the hypoglycemia and non-hypoglycemia groups. Maternal age and gestational age differed significantly between the two groups. The mean maternal age was higher in the hypoglycemia group than the non-hypoglycemia group (32.50 vs. 30.57 years, $p = 0.004$), whereas the gestational period was slightly shorter (270.61 vs. 273.20 days, $p = 0.028$). When expressed in weeks, the mean gestational age was 38.9 ± 1.0 weeks overall, with 39.0 ± 0.9 weeks in the non-NH group vs. 38.7 ± 1.2 weeks in the NH group. Notably, the proportion of CSs was significantly higher in the hypoglycemia group than in the non-hypoglycemia group (81.82% vs. 39.49%, $p < 0.001$). Similarly, a history of uterine scarring, indicative of previous CS, was more common in the hypoglycemia group (59.09% vs. 24.20%, $p < 0.001$). Other variables, including pre-pregnancy BMI, fasting blood glucose, neona-

Table 1. Maternal and neonatal characteristics of GDM pregnancies with and without neonatal hypoglycemia.

Variables	Total (n = 201)	Non-NH (n = 157)	NH (n = 44)	Statistic	*p*-value
Age (mean ± SD), years	31.00 ± 3.97	30.57 ± 3.86	32.50 ± 4.07	$t = -2.90$	0.004
Gestational age (mean ± SD), days	272.64 ± 6.95	273.20 ± 6.47	270.61 ± 8.20	$t = 2.21$	0.028
Gestational age (mean ± SD), weeks	38.95 ± 0.99	39.03 ± 0.92	38.66 ± 1.17	$t = 2.21$	0.028
Height (mean ± SD), cm	161.75 ± 4.45	161.94 ± 4.40	161.05 ± 4.60	$t = 1.18$	0.238
Weight (mean ± SD), kg	74.98 ± 10.36	74.82 ± 10.45	75.55 ± 10.14	$t = -0.41$	0.679
BMI (mean ± SD), kg/m²	28.84 ± 4.32	28.75 ± 4.42	29.16 ± 3.97	$t = -0.56$	0.574
Fasting blood glucose (mean ± SD), mmol/L	5.08 ± 0.56	5.07 ± 0.52	5.14 ± 0.69	$t = -0.73$	0.465
Primipara, n (%)				$\chi^2 = 2.09$	0.149
No	118 (58.71)	88 (56.05)	30 (68.18)		
Yes	83 (41.29)	69 (43.95)	14 (31.82)		
Gravidity, n (%)				$\chi^2 = 3.26$	0.071
<2	124 (61.69)	102 (64.97)	22 (50.00)		
≥2	77 (38.31)	55 (35.03)	22 (50.00)		
Delivery mode, n (%)				$\chi^2 = 24.65$	<0.001
VD	103 (51.24)	95 (60.51)	8 (18.18)		
CS	98 (48.76)	62 (39.49)	36 (81.82)		
Scarred uterus, n (%)				$\chi^2 = 19.27$	<0.001
No	137 (68.16)	119 (75.80)	18 (40.91)		
Yes	64 (31.84)	38 (24.20)	26 (59.09)		
Comorbidities, n (%)				$\chi^2 = 0.02$	0.896
No	61 (30.35)	48 (30.57)	13 (29.55)		
Yes	140 (69.65)	109 (69.43)	31 (70.45)		
Hypothyroidism, n (%)				$\chi^2 = 0.02$	0.894
No	177 (88.06)	138 (87.90)	39 (88.64)		
Yes	24 (11.94)	19 (12.10)	5 (11.36)		
Neonatal gender, n (%)				$\chi^2 = 2.52$	0.112
Male	108 (53.73)	89 (56.69)	19 (43.18)		
Female	93 (46.27)	68 (43.31)	25 (56.82)		
Birth weight, g, M (Q1, Q3)	3450.00 (3200.00, 3780.00)	3460.00 (3150.00, 3800.00)	3400.00 (3327.50, 3772.50)	$Z = -0.17$	0.865
Initial neonatal blood glucose (mean ± SD), mmol/L	3.72 ± 1.25	4.13 ± 1.04	2.24 ± 0.66	$t = 14.57$	<0.001
Macrosomia, n (%)				$\chi^2 = 1.51$	0.219
No	171 (85.07)	131 (83.44)	40 (90.91)		
Yes	30 (14.93)	26 (16.56)	4 (9.09)		
NICU admission, n (%)				$\chi^2 = 1.42$	0.233
No	179 (89.05)	142 (90.45)	37 (84.09)		
Yes	22 (10.95)	15 (9.55)	7 (15.91)		

t: *t*-test, Z: Mann-Whitney test, χ^2: Chi-square test, SD: standard deviation, M: Median, Q_1: 1st Quartile, Q_3: 3rd Quartile. VD, vaginal delivery; CS, cesarean section; NH, neonatal hypoglycemia; GDM, gestational diabetes mellitus; BMI, body mass index; NICU, neonatal intensive care unit.

tal sex, and birth weight, showed no significant differences between groups.

3.2 Logistic Regression Analysis of Risk Factors for NH

Variables with $p < 0.1$ in univariate analysis, including maternal age, gestational age, gravidity, delivery mode, and scarred uterus, were included in the logistic regression model. Univariate logistic regression analysis showed that CS vs. VD (OR = 6.90, 95% CI: 3.01–15.82, $p < 0.001$), scarred uterus (OR = 4.52, 95% CI: 2.24–9.14, $p < 0.001$), maternal age (OR = 1.13, 95% CI: 1.04–1.23, $p = 0.005$), and gestational age (OR = 0.95, 95% CI: 0.91–0.99, $p = 0.033$) were associated with NH.

As shown in Table 2, multivariate analysis demonstrated that only delivery mode remained an independent predictor of NH. Compared with VD, CS significantly increased the risk of NH, with an adjusted OR of 4.48 (95% CI: 1.56–12.87, $p = 0.005$). Maternal age, gestational age,

Table 2. Univariate and multivariate logistic regression analyses of risk factors for NH.

Variables	Univariate					Multivariate				
	β	S.E	Wald	*p*-value	OR (95% CI)	β	S.E	Wald	*p*-value	OR (95% CI)
Scarred uterus										
No					1.00 (Reference)					1.00 (Reference)
Yes	1.51	0.36	17.72	<0.001	4.52 (2.24–9.14)	0.39	0.55	0.52	0.472	1.48 (0.51–4.32)
Delivery mode										
VD					1.00 (Reference)					1.00 (Reference)
CS	1.93	0.42	20.79	<0.001	6.90 (3.01–15.82)	1.50	0.54	7.73	0.005	4.48 (1.56–12.87)
Age	0.12	0.04	7.78	0.005	1.13 (1.04–1.23)	0.05	0.05	1.00	0.318	1.05 (0.95–1.16)
Gestational age	–0.05	0.02	4.58	0.033	0.95 (0.91–0.99)	–0.02	0.03	0.46	0.497	0.98 (0.93–1.04)
Gravidity										
<2					1.00 (Reference)					1.00 (Reference)
≥2	0.62	0.34	3.20	0.073	1.85 (0.94–3.65)	–0.13	0.46	0.07	0.783	0.88 (0.36–2.16)

OR, odds ratio; CI, confidence interval.

Table 3. Diagnostic performance of CS for predicting NH.

AUC (95% CI)	Specificity (95% CI)	Sensitivity (95% CI)	NPV (95% CI)	PPV (95% CI)
0.712 (0.642–0.781)	0.605 (0.529–0.682)	0.818 (0.704–0.932)	0.922 (0.871–0.974)	0.367 (0.272–0.463)

AUC, area under the curve; NPV, negative predictive value; PPV, positive predictive value.

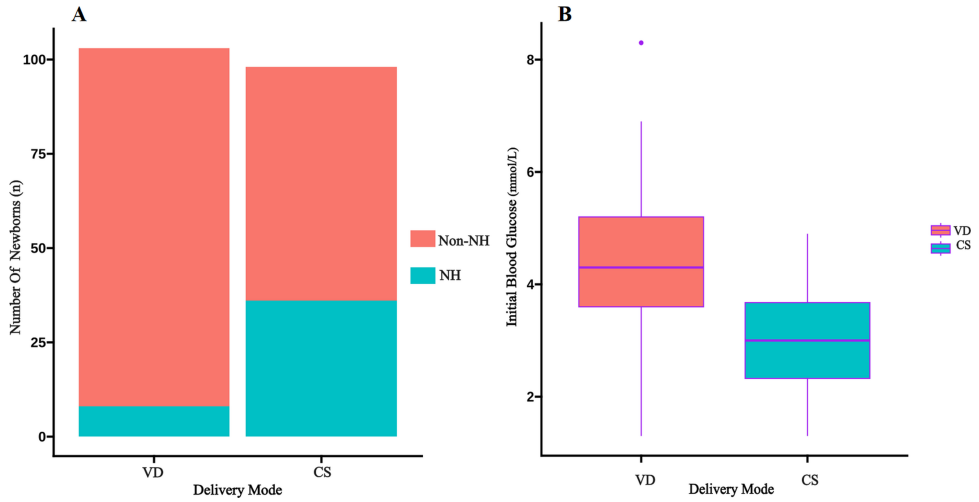

Fig. 1. Association between delivery mode and neonatal hypoglycemia. (A) Stacked bar chart of NH event counts by delivery mode. (B) Box plot of initial neonatal blood glucose by delivery mode, this point represents an outlier in the box plot (beyond 1.5×IQR) and reflects an actual observation.

gravidity, and uterine scarring were not significantly associated with NH in the multivariate model (all $p > 0.05$).

3.3 Predictive Value of Delivery Mode for NH

CS showed a sensitivity of 81.8%, specificity of 60.5%, PPV of 36.7%, and NPV of 92.2% for NH (Table 3). These results indicate that although CS is characterized by a relatively low PPV, VD is associated with a high NPV (92.2%) for the occurrence of NH in pregnancies complicated by GDM. Fig. 1A illustrates the distribution of NH according to delivery mode, and Fig. 1B shows that initial neonatal blood glucose levels were significantly lower in the CS group than in the VD group.

4. Discussion

This retrospective study evaluated the association between delivery mode and NH among 201 pregnancies complicated by GDM. After adjustment for maternal age, gestational age, gravidity, and a history of uterine scarring, CS remained independently associated with an increased risk of NH, with an adjusted OR of 4.48 compared with VD. In addition, analysis of predictive metrics showed that VD was associated with a high NPV (92.2%), which indicates that neonates delivered vaginally were unlikely to develop hypoglycemia, whereas the PPV of CS was relatively modest. These findings suggest that delivery mode may contribute to early neonatal metabolic risk stratification and should be

considered in perinatal monitoring strategies for pregnancies complicated by GDM.

Our findings are consistent with previous studies reporting an association between CS and NH. A 2024 meta-analysis by Wang *et al*. [20] showed that the odds of hypoglycemia were nearly twice as high in infants delivered by CS compared with those delivered vaginally (OR = 1.90, 95% CI: 1.23–2.92). Similarly, a cohort study by Ogunyemi *et al*. [19] reported that NH in term infants was associated with several obstetric and perinatal factors, including mode of delivery, highlighting the potential role of CS in neonatal glucose instability. Another study of 4602 infants reported that CS was associated with an increased likelihood of requiring glucose infusion (OR = 1.4, 95% CI: 1.1–1.9), with earlier onset of hypoglycemia particularly evident among infants of obese mothers [16]. Our study extends these observations by focusing specifically on pregnancies complicated by GDM, in which we observed a higher OR associated with CS. This stronger association may reflect the unique metabolic environment of GDM: chronic *in utero* hyperglycemia, persistent neonatal hyperinsulinemia, absence of labor-induced counterregulatory hormonal surges, and delayed initiation of feeding may collectively heighten the risk of hypoglycemia in this subgroup [27–29]. Previous studies have reported that cesarean delivery is more frequent among neonates with hypoglycemia; however, it may not remain an independent predictor after adjustment for confounding factors, with maternal obesity and glycemic control playing more prominent roles in neonatal glucose regulation [16,18]. The larger effect size observed in our study population may be attributable to differences in the definition of hypoglycemia, the higher incidence of NH in our population, or variations in confounder adjustment and population characteristics.

The high CS rate observed in our study (48.76% overall) reflects broader trends in China. A 2023 analysis of 7.6 million deliveries across 4359 hospitals reported an overall CS rate of 44.5%, approximately three times the World Health Organization recommended maximum of 15% [21]. Multiple factors have been proposed to contribute to the elevated CS rate in China, including maternal preference, often related to fear of labor pain, provider- and system-level drivers, a high prevalence of repeat CSs, and variation in obstetric practice and capacity across hospitals [30]. In pregnancies complicated by GDM, CS may be indicated more frequently due to concerns about macrosomia, shoulder dystocia, and labor dystocia. Given the association between CS and NH observed in our study, these high CS rates may amplify the population-level burden of neonatal metabolic complications in China.

The increased susceptibility to NH after CS in GDM pregnancies may be explained by several disruptions in perinatal glucose regulation. In GDM, chronic maternal hyperglycemia enhances placental glucose transfer and induces fetal β-cell hyperplasia, which results in persistent neonatal hyperinsulinemia after birth and impaired activation of gluconeogenesis, glycogenolysis, and ketogenesis [31]. CS may further exacerbate this vulnerability through several mechanisms. Preoperative fasting reduces maternal glucose availability and may limit fetal hepatic glycogen reserves [32]. Delayed skin-to-skin contact and postponed initiation of breastfeeding may reduce early exogenous glucose intake in the immediate postnatal period [29,33]. From a mechanistic perspective, the absence of labor-related birth signaling hormone surges following CS has been proposed to influence neonatal physiological adaptation [34]. Consistent with this concept, compared with VD, elective CS has been associated with differences in neonatal stress exposure and immediate metabolic adaptation [35]. In addition, differences in early thermal responses between VD and CSs may further contribute to neonatal metabolic stress in the immediate postnatal period [36]. These mechanisms collectively provide a plausible physiological basis for the lower initial glucose concentrations observed in infants delivered by CS in our study population.

Our study has several strengths. It incorporated a comprehensive set of maternal and neonatal characteristics, which enabled a more thorough assessment of risk factors and reduced the likelihood of residual confounding. By adjusting for key variables, including uterine scarring, gestational age, gravidity, and maternal age, the multivariate model provided a more accurate estimate of the independent association between CS and NH. Clinically, these findings have important implications for perinatal care. First, delivery mode should be incorporated into risk stratification algorithms for identification of neonates at elevated risk of hypoglycemia. Second, when CS is indicated in GDM pregnancies, enhanced monitoring protocols should be implemented, including earlier and more frequent glucose measurements. Third, interventions known to reduce NH risk, such as maintaining maternal glucose stability preoperatively, ensuring early skin-to-skin contact, and promoting early breastfeeding, should be prioritized. Individualized delivery decisions should be made through multidisciplinary collaboration, with assessment of maternal glycemic control, estimated fetal weight, and available delivery resources.

Limitations

This study has several limitations that warrant acknowledgment. First, as a single-center retrospective study, residual selection bias cannot be fully excluded, and the observational design does not allow causal inference regarding the relationship between delivery mode and NH. Second, because infants delivered before 35 weeks were excluded to limit confounding from prematurity, our findings may not generalize to moderately or late preterm GDM pregnancies, which constitute an important high-risk subgroup. Third, several potentially relevant maternal variables, including the distinction between elective and emer-

gency CS, diabetes treatment modality (dietary management vs. insulin or oral hypoglycemic agents), and physical activity or dietary patterns, were not consistently documented in the medical record system and therefore could not be incorporated into the multivariate model. Fourth, mechanistic indicators such as continuous maternal glucose profiles, neonatal cord blood insulin or counterregulatory hormones (e.g., cortisol, catecholamines), and markers of metabolic adaptation were unavailable, which limited our ability to explore physiological pathways linking delivery mode to neonatal glucose instability. Fifth, this study focused only on early NH and did not include longitudinal assessment of neurodevelopment, cognitive function, or behavioral outcomes, which limits evaluation of the long-term consequences of hypoglycemia. Finally, as the study was conducted in a single maternity center in China, the applicability of these findings to other healthcare systems, including international or resource-limited settings, warrants further validation through multicenter prospective studies.

5. Conclusions

CS is an independent risk factor for NH in infants born to mothers with GDM. In clinical practice, clinicians should ensure maternal and fetal safety, consider glycemic control and labor-related risks, select the delivery mode accordingly, and strengthen postpartum neonatal blood glucose monitoring to reduce adverse outcomes associated with hypoglycemia.

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

QL contributed to study conception, data collection, and initial drafting of the manuscript. FW contributed to data analysis, interpretation, and critical revision. SZ contributed to methodology design, statistical analysis, and data curation. BD contributed to overall supervision, final approval of the version to be published, and accountability for all aspects of the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Anhui No.2 Provincial People's Hospital (Approval No. (R) 2025-107). Because the study used de-identified retrospective data, the requirement for informed consent was waived by the ethics committee.

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Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.31083/CEOG47854.

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