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Maternal pre-pregnancy body mass index, hemoglobin concentration, and gestational diabetes as predictors of neonatal macrosomia: A retrospective study in Kenitra, Morocco

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Abstract

Neonatal macrosomia is a major perinatal complication associated with maternal metabolic disorders. This study aimed to assess whether hemoglobin concentration and gestational diabetes mediate the association between pre-pregnancy body mass index and neonatal macrosomia. A retrospective analysis was conducted among 700 singleton full-term pregnancies at El Idrissi Provincial Hospital, Kenitra, Morocco. Macrosomia was defined as birth weight ≥ 4000 g, and elevated hemoglobin as ≥ 12.5 g/dL. Gestational diabetes was diagnosed using fasting glucose or a 75-g oral glucose tolerance test. Mediation analysis using the Karlson–Holm–Breen method was adjusted for maternal age, parity, gestational hypertension, and infant sex. The prevalence of gestational diabetes was 11.9%, and macrosomia occurred in 14.7% of cases. Overweight and obesity were significantly associated with macrosomia, and 71.86% (overweight) and 67.52% (obesity) of these associations were jointly explained by hemoglobin concentration and gestational diabetes, mainly through gestational diabetes. Early metabolic screening during pregnancy may reduce the risk of adverse birth outcomes. (*Afr J Reprod Health* 2026; 30 [18]: 87-99).

Keywords: overweight; obesity; hemoglobin; gestational diabetes; macrosomia

Résumé

La macrosomie néonatale est une complication périnatale majeure associée aux troubles métaboliques maternels. Cette étude visait à évaluer si la concentration d'hémoglobine et le diabète gestationnel médient l'association entre l'indice de masse corporelle préconceptionnel et la macrosomie néonatale. Une analyse rétrospective a été réalisée sur 700 grossesses uniques à terme à l'Hôpital Provincial El Idrissi de Kénitra, Maroc. La macrosomie a été définie par un poids de naissance ≥ 4000 g, et l'hémoglobine élevée par $\geq 12,5$ g/dL. Le diabète gestationnel a été diagnostiqué à l'aide de la glycémie à jeun ou d'un test d'hyperglycémie provoquée par voie orale avec 75 g de glucose. L'analyse de médiation utilisant la méthode de Karlson–Holm–Breen a été ajustée sur l'âge maternel, la parité, l'hypertension gravidique et le sexe du nouveau-né. La prévalence du diabète gestationnel était de 11,9 %, et la macrosomie était observée dans 14,7 % des cas. Le surpoids et l'obésité étaient significativement associés à la macrosomie, et 71,86 % (surpoids) et 67,52 % (obésité) de ces associations étaient expliqués conjointement par la concentration d'hémoglobine et le diabète gestationnel, principalement par le diabète gestationnel. Un dépistage métabolique précoce pendant la grossesse pourrait réduire le risque d'issues néonatales défavorables. (*Afr J Reprod Health* 2026; 30 [18]: 87-99).

Mots-clés: Surpoids ; obésité ; hémoglobine ; diabète gestationnel ; macrosomie.

Introduction

The growing burden of obesity among women of reproductive age has significantly contributed to the increase in obesity-related conditions and complications during pregnancy.¹ Maternal and

neonatal complications have increasingly been linked to higher pre-pregnancy body mass index (BMI), particularly through mechanisms involving elevated hemoglobin levels and gestational diabetes,² as well as fetal macrosomia.³ Neonatal macrosomia, usually defined as birth weight of

4000 g or more, is associated with increased risks of shoulder dystocia, birth trauma, asphyxia, and perinatal mortality.⁴ Macrosomic infants are also at increased risk of later-life hypertension, type 2 diabetes, and obesity.⁵ Fetal growth is closely linked to maternal nutrition and the hormonal environment and is influenced by placental transport mechanisms.⁶ Evidence also suggests that higher blood glucose levels during pregnancy, even below the conventional diabetes threshold, contribute to increased birth weight.⁷

In real-world obstetric settings, women often present with overlapping risk factors such as gestational hypertension, pre-pregnancy overweight or obesity, and gestational diabetes. High maternal BMI may contribute to the development of gestational diabetes, and both factors may jointly increase the likelihood of delivering a macrosomic infant.² In addition, high-dose iron supplementation may contribute to the development of gestational diabetes.⁸

Elevated first-trimester hemoglobin (Hb) levels and gestational diabetes have commonly been observed among women with pre-pregnancy BMI ≥ 25 kg/m².² Women who develop gestational diabetes have also been shown to have significantly higher first-trimester hemoglobin levels than controls.² Similarly, gestational diabetes is a well-established risk factor for macrosomia.⁹

Taken together, these findings suggest that high first-trimester hemoglobin levels and gestational diabetes may act as mediators in the pathway linking pre-pregnancy BMI to neonatal macrosomia. Previous research has shown that gestational diabetes may mediate the relationship between pre-pregnancy BMI and macrosomia.¹⁰ From an epidemiological perspective, this study developed a serial mediation model to examine: (a) the effect of pre-pregnancy BMI on first-trimester hemoglobin levels, gestational diabetes, and macrosomia; (b) the mediating effects of first-trimester hemoglobin levels and gestational diabetes; and (c) whether these two mediators sequentially explain the BMI-macrosomia association.

Using this theory-driven approach, the present retrospective study aimed to assess the extent to which the relationship between maternal

pre-pregnancy overweight or obesity and the risk of macrosomia in full-term singleton pregnancies is mediated by elevated first-trimester hemoglobin levels and gestational diabetes, with the ultimate goal of informing strategies to reduce adverse perinatal outcomes.

Methods

Study setting and design

Located in north-west Morocco, the Rabat–Salé–Kénitra region covers 17,570 km² and had a legal population of 5,132,639 according to the 2024 General Population and Housing Census. The provinces of Kenitra, Sidi Kacem, and Sidi Slimane together cover 7,990 km² and had 2,180,955 inhabitants in 2024, of whom 58.9% lived in Kenitra province, 25.0% in Sidi Kacem, and 16.1% in Sidi Slimane. These provinces include 10 municipalities and 53 rural communes.¹¹

This retrospective study was conducted in the maternity ward of El Idrissi Provincial Hospital, Kenitra, Morocco, from April 2021 to October 2021. The source population comprised 7,200 pregnant women who received prenatal care at El Idrissi Provincial Hospital during the study period. For the present analysis, 700 women with singleton full-term pregnancies and available prenatal records were included.

Sample size determination. Because this was a retrospective study, the analysis was based on the final set of records that met the eligibility criteria and passed data-completeness and validity checks. The adequacy of the sample was verified using the single-proportion formula $n = Z^2p(1-p)/d^2$, assuming a 95% confidence level, an expected macrosomia prevalence of approximately 15% based on prior local clinical estimates and published macrosomia frequencies, and an absolute precision of 3%. This calculation yielded a minimum of approximately 545 participants. After allowing for at least 10% incomplete or non-valid records, the required sample was approximately 600 participants. The final analytic sample of 700 women therefore exceeded the minimum requirement and provided adequate precision for estimating macrosomia prevalence, as well as sufficient outcome events for adjusted logistic and mediation analyses.

Eligibility criteria and measurements

This study included women in the first trimester of pregnancy who were at least 17 years old and attended El Idrissi Provincial Hospital in Kenitra between April and October 2021. Participants with a prior diagnosis of type 1 or type 2 diabetes before pregnancy were excluded, along with those with multiple gestations. Pregnancies achieved through assisted or non-natural conception methods and those that did not result in full-term delivery were also excluded from the analysis.

At the initial prenatal visit (6–8 weeks of gestation), mothers provided information regarding their pre-pregnancy weight and height, which was recorded by healthcare professionals. Height was assessed with a stadiometer graduated up to 2 m and measured with a precision of 0.1 cm. Women were measured barefoot, with heels together, arms at their sides, shoulders and buttocks touching the stadiometer, and the lower edge of the eye sockets in the Frankfurt plane. They were also asked to remove headscarves before measurement.

Weight was measured using a portable SECA-type scale with a maximum load of 150 kg and a minimum load of 10 kg, with readings taken to the nearest 0.5 kg. Women were weighed with as little clothing as possible while standing upright with arms in line with the body. The scale was calibrated regularly during each session.

Exposure

Pre-pregnancy BMI was calculated as weight divided by height squared. According to WHO classification criteria, participants were categorized into four groups: underweight (BMI <18.5 kg/m²), normal weight (18.5–24.9 kg/m²), overweight (25.0–29.9 kg/m²), and obese (≥30.0 kg/m²).¹²

Outcome

Neonatal macrosomia was defined as birth weight ≥4000 g, regardless of gestational age. Only term pregnancies (37–41 weeks of gestation) were included.

Potential mediators

This study considered hemoglobin levels and gestational diabetes as potential mediators in the

association between maternal BMI and fetal macrosomia risk. These variables were selected based on previous studies demonstrating their links with both BMI and macrosomia.^{13–15} Gestational diabetes is defined by the World Health Organization as hyperglycemia first identified during pregnancy.¹⁶

A fasting capillary glucose test was performed at the first prenatal visit (positive fasting glucose ≥0.92 and ≤1.25 g/L). Women were invited to return at 24–28 weeks of gestation to undergo a 75-g oral glucose tolerance test (positive result: fasting glucose ≥0.92 g/L, or 1-h glucose ≥1.8 g/L, or 2-h glucose ≥1.53 g/L).¹⁷ At the first prenatal screening, participants also underwent a complete blood count to determine hemoglobin levels.

Covariates

Based on an extended literature review,^{18,19} maternal age, gestational hypertension (yes/no), parity (primiparous/multiparous), and infant sex were treated as covariates because of their potential confounding relationships with pre-pregnancy BMI, hemoglobin levels, gestational diabetes, and fetal macrosomia.

Data accuracy and validity

To strengthen data accuracy and validity, information was abstracted from standardized prenatal and delivery records by trained health personnel. Anthropometric measurements were performed using calibrated equipment and standardized procedures. Gestational diabetes and hemoglobin status were based on documented laboratory or point-of-care results recorded during routine antenatal follow-up. Before statistical analysis, the database was checked for completeness, implausible values, duplicated records, inconsistencies between antenatal and delivery files, and eligibility criteria. Ambiguous or incomplete records were rechecked against the original hospital register whenever possible; records that could not be validated were excluded from the final analytic dataset.

Data analysis

Data analysis was performed using SPSS version 25 and Stata version 14. Descriptive analysis was used to characterize the distribution of pregnant women

and newborns according to hemoglobin levels, gestational diabetes, and macrosomia. The prevalence of elevated hemoglobin levels, gestational diabetes, and macrosomia was estimated for each BMI group with 95% confidence intervals.

Mediation analysis was conducted in a regression-based causal mediation framework informed by Baron and Kenny's approach.²⁰ Hayes' PROCESS macro version 4.2, Model 6, was used to perform serial mediation analyses,²¹ with 10,000 bootstrap samples as recommended by Hayes.²² In the hypothetical model, pre-pregnancy BMI was the independent variable, macrosomia the dependent variable, and hemoglobin levels and gestational diabetes the first and second mediators, respectively (Figure 1)

The total effect was divided into direct and indirect effects. Because the dependent variable was dichotomous, the mediated proportion and total effect model were not available with Hayes PROCESS Model 6. Therefore, the Karlson-Holm-Breen (KHB) method was applied for non-linear probability models, such as logistic regression.^{23,24} The KHB method decomposes the total effect of a variable into direct and indirect components in an unbiased manner and allows adjustment for confounding factors (Figure 1). This method has been widely used for mediation analysis in logistic regression.²⁵ The user-written Stata khb command was used to implement the decomposition.²⁶ Results are expressed as odds ratios with 95% confidence intervals for direct, indirect, and total effects. The mediation percentage was calculated by dividing the mediating effect by the total effect.

Ethical considerations

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and its subsequent amendments. Ethical approval was obtained from the competent institutional review board under approval No. 342. Formal authorization to access and use medical records was granted by the Ministry of Health, Rabat, Morocco, and the Directorate of El Idrissi Provincial Hospital, Kenitra. Given the retrospective design of the study, the requirement for informed consent was waived by the ethics committee. All data were fully

anonymized before analysis, and strict confidentiality was maintained throughout the study.

Results

Baseline characteristics of the study population

A total of 700 singleton full-term pregnancies were analyzed across different pre-pregnancy BMI categories. The characteristics of mothers and newborns according to hemoglobin levels, gestational diabetes, and macrosomia are presented in Table 1. Overall, 14.7% of births involved macrosomia, 11.9% of women had gestational diabetes, and 14.6% had hemoglobin levels ≥ 12.5 g/dL. Normal pre-pregnancy BMI was observed in 42.1% of women, whereas 26.0% were overweight and 16.1% were obese. Most participants were multiparous, and 50.9% of newborns were male. Gestational hypertension was documented in 7.9% of women.

Prevalence of hemoglobin concentration, gestational diabetes, and macrosomia by BMI group

The prevalence of hemoglobin ≥ 12.5 g/dL, gestational diabetes, and macrosomia by BMI category is presented in Table 2. Elevated hemoglobin was more frequent among women with overweight (18.68%) and obesity (29.20%) than among normal-weight (10.17%) or underweight women (4.55%). A similar gradient was observed for gestational diabetes, which increased from 4.55% among underweight women to 23.01% among women with obesity. Macrosomia was also most prevalent among infants of women with obesity (34.51%), followed by overweight (18.13%), normal-weight (8.81%), and underweight women (4.55%).

Serial multiple mediation analysis using KHB and Hayes PROCESS Model 6

Multiple regression analyses were performed to examine the serial mediation model, and the corresponding results are reported in Table 3. The total effect represents the overall contribution of pre-pregnancy BMI to the risk of fetal macrosomia.

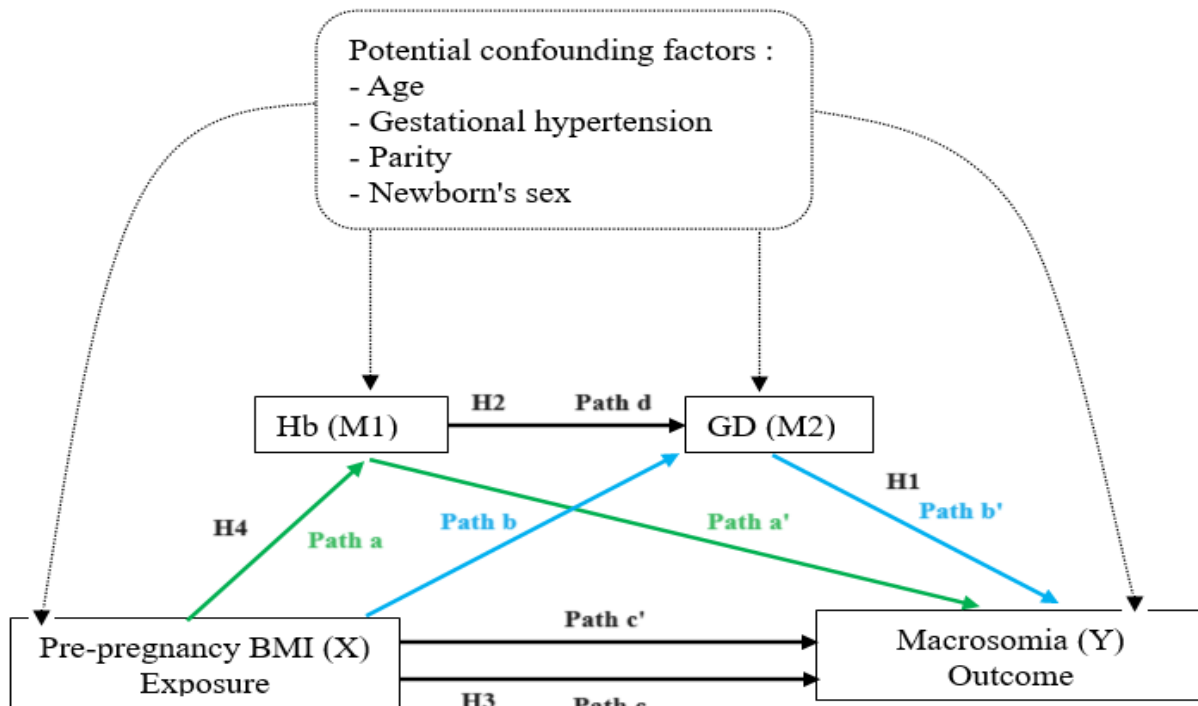


Figure 1: Illustration of the total effect (path c), the direct effect (path c'), and the indirect effects (paths a, a', b, b', and d) linking exposure (X) to outcome (Y) through mediators M1 and M2.

Abbreviations: Hb (M1) = hemoglobin concentration levels; GD (M2) = gestational diabetes

Table 1: Characteristics of the women and newborns according to hemoglobin concentration, gestational diabetes, and macrosomia.

Characteristics	Total Births, n (%)	Hb ≥ 12.5 g/dL n (%)	GD, n (%)	Macrosomia n (%)
	n = 700	102 (14.6%)	83 (11.9)	103 (15)
Pre-pregnancy body mass index				
Underweight	110 (15.7)	5 (4.9)	5 (6.0)	5 (4.9)
Normal	295 (42.1)	30 (29.4)	23 (27.7)	26 (25.2)
Overweight	182 (26.0)	34 (33.3)	29 (34.9)	33 (32.0)
Obesity	113 (16.1)	33 (32.4)	26 (31.3)	39 (37.9)
Age (years)				
<25	233 (33.3)	32 (31.4)	31 (37.3)	34 (33.0)
25–29	193 (27.6)	30 (29.4)	23 (27.7)	27 (26.2)
30–34	152 (21.7)	19 (18.6)	15 (18.1)	26 (25.2)
≥ 35	122 (17.4)	21 (20.6)	14 (16.9)	16 (15.5)
Parity				
Multipara	446 (63.7)	53 (52.0)	52 (62.7)	66 (64.1)
Primipara	254 (36.3)	49 (48.0)	31 (37.3)	37 (35.9)
Infant sex				
Male	356 (50.9)	53 (52.0)	44 (53.0)	49 (47.0)
Female	344 (49.1)	49 (48.0)	39 (47.0)	54 (52.4)
Gestational hypertension				
No	645 (92.1)	93 (91.2)	73 (88.0)	92 (89.3)
Yes	55 (7.9)	9 (8.8)	10 (12.0)	11 (10.7)

Table 2: Prevalence of hemoglobin concentration, gestational diabetes, and macrosomia by BMI category.

BMI category kg/m ²	Hb ≥12.5 g/dL % (95% CI)	GD % (95% CI)	Macrosomia % (95% CI)
Underweight (<18.5)	4.55 (1.96–10.20)	4.55 (1.96–10.20)	4.55 (1.96–10.20)
Normal (18.5–24.9)	10.17 (7.22–14.15)	7.80 (5.25–11.43)	8.81 (6.09–12.60)
Overweight (25.0–29.9)	18.68 (13.69–24.97)	15.93 (11.33–21.95)	18.13 (13.21–24.37)
Obese (≥30.0)	29.20 (21.61–38.16)	23.01 (16.21–31.58)	34.51 (26.39–43.66)

Table 3: Mediating roles of hemoglobin levels and gestational diabetes, individually and jointly, in the relationship between BMI and macrosomia

Effect type	Effect	95% CI
Path a: Pre-pregnancy BMI → Hb levels		
Underweight	−0.5807	(−0.8682, −0.2933) ***
Overweight	0.3880	(0.1419, 0.6341) **
Obesity	1.3444	(1.0584, 1.6304) ***
Path b: Pre-pregnancy BMI → GD		
Underweight	−0.1201	(−0.1383, −0.1018) ***
Overweight	0.0323	(0.0167, 0.0479) ***
Obesity	0.0237	(0.0047, 0.0428) *
Path d: Hb levels → GD		
	0.0356	(0.0309, 0.0403) ***
Path a': Hb levels → Macrosomia		
	0.0699	(−0.2044, 0.3443) NS
Path b': GD → Macrosomia		
	18.0406	(10.5190, 25.5622) ***
Relative indirect effect: BMI → Hb → Macrosomia		
Underweight	−0.0406	(−0.2801, 0.1587) NS
Overweight	0.0271	(−0.1003, 0.1847) NS
Obesity	0.0940	(−0.3469, 0.5910) NS
Relative indirect effect: BMI → GD → Macrosomia		
Underweight	−2.1662	(−4.0385, −0.9487) S
Overweight	0.5828	(0.2805, 1.0062) S
Obesity	0.4284	(0.1578, 0.8775) S
Relative indirect effect: BMI → Hb → GD → Macrosomia		
Underweight	−0.3733	(−0.7362, −0.1367) S
Overweight	0.2494	(0.0851, 0.5263) S
Obesity	0.8641	(0.3739, 1.6418) S

Note: Adjusted for maternal age, gestational hypertension, newborn sex, and parity. The significance of indirect effects was evaluated using bootstrapped 95% confidence intervals; no p-values were calculated for indirect effects. CI = confidence interval; NS = not significant; S = significant; *p < 0.05, **p < 0.01, ***p < 0.001.

Table 4: Simultaneous mediating roles of hemoglobin concentration and gestational diabetes in the link between pre-pregnancy BMI and fetal macrosomia.

Key variable	β (SE)	OR (95% CI)	Adjusted β (SE)	Adjusted OR (95% CI)
Overweight vs normal				
Total effect	1.22(0.30) ***	3.38 (1.86–6.09) ***	1.20 (0.31) ***	3.31 (1.82–6.01) ***
Direct effect	0.33(0.29) NS	1.39 (0.77–2.48) NS	0.34 (0.30) NS	1.40 (0.78–2.52) NS
Indirect effect	0.88 (0.36) *	2.43 (1.20–4.88) *	0.86 (0.35) *	2.36 (1.18–4.74) *
Obesity vs normal				
Total effect	2.06 (0.33) ***	7.90 (4.11–15.2) ***	2.05 (0.34) ***	7.80 (4.04–15.0) ***
Direct effect	0.66 (0.33) *	1.94 (1.01–3.74) *	0.67 (0.34) *	1.95 (1.01–3.77) *
Indirect effect	1.40 (0.39) ***	4.07 (1.88–8.77) ***	1.39 (0.39) ***	4.00 (1.86–8.60) ***
% mediated: overweight via hemoglobin levels	1.81		2.27	
% mediated: overweight via gestational diabetes	71.02		69.59	
% total mediated: overweight	72.83		71.86	
% mediated: obesity via hemoglobin levels	3.76		4.58	
% mediated: obesity via gestational diabetes	64.10		62.94	
% total mediated: obesity	67.85		67.52	

Note: Adjusted for age, infant sex, gestational hypertension, and parity. The mediated proportion represents the proportion of the total effect attributable to the respective mediator.

The mediation analysis showed that gestational diabetes was a strong positive predictor of fetal macrosomia, whereas hemoglobin concentration alone did not significantly mediate the relationship between BMI and macrosomia. However, hemoglobin concentration was significantly associated with gestational diabetes and contributed to a statistically significant serial pathway from pre-pregnancy BMI to hemoglobin concentration, then to gestational diabetes, and then to macrosomia. The pathway through gestational diabetes alone was significant among overweight and obese women, and the sequential pathway through hemoglobin concentration and gestational diabetes was also significant in these groups. Underweight before pregnancy showed a protective association with macrosomia through the same mediation structure.

The KHB decomposition further clarified the magnitude of mediation. Among overweight women, 71.86% of the association with macrosomia was explained by the mediators, with 2.27% attributable to hemoglobin concentration and 69.59% to gestational diabetes. Among obese women, 67.52% of the association with macrosomia was explained by the mediators, with 4.58% attributable to hemoglobin concentration and 62.94% to gestational diabetes. These results indicate that gestational diabetes was the dominant mediator, whereas elevated hemoglobin had a smaller direct mediating contribution but remained relevant in the sequential pathway leading to gestational diabetes and macrosomia.

Path a, representing the effect of pre-pregnancy BMI on hemoglobin levels, was statistically significant for underweight, overweight, and obesity. Hemoglobin levels were not significantly associated with fetal macrosomia ($b=0.0699$, $p=0.6174$), whereas gestational diabetes showed a significant positive association with macrosomia ($b=18.0406$, $p<0.001$).

Discussion

The present study found that increased pre-pregnancy BMI was linked to a higher risk of gestational diabetes and elevated first-trimester hemoglobin levels. High hemoglobin levels (≥ 12.5 g/dL) were associated with gestational diabetes, which in turn increased the occurrence of fetal macrosomia. Although elevated hemoglobin alone did not significantly mediate the BMI-macrosomia association, gestational diabetes alone and the combined pathway involving hemoglobin and gestational diabetes explained a substantial proportion of the association between pre-pregnancy overweight or obesity and fetal macrosomia.

These findings are consistent with research on 21,577 singleton pregnancies showing that elevated pre-pregnancy BMI was associated with increased first-trimester hemoglobin concentrations.² Data from a Finnish multicenter observational case-control study similarly confirmed that high pre-pregnancy BMI is associated with higher first-trimester hemoglobin levels.²⁸ Conversely, low BMI during early pregnancy may reflect insufficient nutritional intake of micronutrients essential for hematopoiesis,²⁸ or chronic conditions such as tuberculosis and parasitic infections, which can contribute to low hemoglobin levels.²⁹

After adjustment for potential confounders, the serial mediation analysis did not show a significant independent mediating role of elevated hemoglobin levels in the link between BMI and macrosomia. Previous cohort and observational studies have reported heterogeneous associations between maternal hemoglobin concentrations and birth weight, with some studies suggesting associations with fetal growth and others reporting

weaker or non-significant relationships.^{30–32} This inconsistency may be explained by the complexity of hemoglobin dynamics during pregnancy.

Maternal hemoglobin status varies across gestation because physiological hemodilution occurs as plasma volume expands more markedly than red blood cell mass.³¹ Very high maternal hemoglobin concentrations may reflect inadequate plasma volume expansion, hemoconcentration, increased blood viscosity, and vascular resistance, potentially affecting placental exchange.³⁴ Because the present study measured hemoglobin only during early pregnancy, the lack of serial hemoglobin measurements may have limited the ability to capture the full relationship between hemoglobin status and neonatal growth.

Consistent with previous evidence, elevated BMI was independently associated with the risk of macrosomia.³⁵ Maternal adiposity may influence fetal growth through insulin resistance, altered lipid metabolism, and increased availability of nutrients to the fetus. Maternal lipid accumulation and hyperlipidemia are physiological features of pregnancy,³⁵ but elevated triglyceride concentrations during later pregnancy have been associated with large-for-gestational-age delivery.³⁶ Placental trophoblasts can facilitate the transfer of lipid-derived substrates, including free fatty acids, to the fetus, supporting fetal energy requirements and adipose tissue accretion.³⁷

The dominant mediating role of gestational diabetes in the present analysis is biologically plausible. In the HAPO study, macrosomia was substantially more common among women with gestational diabetes than among women without gestational diabetes, and the combination of maternal obesity and gestational diabetes produced the highest macrosomia prevalence.³⁸ Gestational diabetes may mediate the impact of maternal BMI on fetal growth because obesity promotes insulin resistance, dyslipidemia, and lower adiponectin levels, all of which contribute to glucose intolerance during pregnancy.¹⁴ Maternal hyperglycemia increases transplacental glucose transfer, stimulating fetal insulin production and promoting excessive fetal growth.

Recent efforts to improve gestational diabetes management have shown that controlling

blood glucose levels can reduce excessive fetal growth.³⁹ Differences in fetal size between women with and without gestational diabetes may become evident between the 20th and 28th weeks of pregnancy,⁴⁰ which supports timely diagnosis and early intervention. Nevertheless, macrosomia can still occur in women without gestational diabetes,⁴² indicating that fetal growth is influenced by multiple factors, including maternal age, parity, infant sex, and seasonal or environmental factors.^{18, 42, 43}

An important contribution of this study is the demonstration that hemoglobin levels may act together with gestational diabetes in a serial pathway. Other studies have reported associations between elevated first-trimester hemoglobin levels and increased gestational diabetes risk.^{44, 45} High hemoglobin in early pregnancy has also been associated with gestational diabetes in settings of high iron intake.⁴⁶ Excess iron may promote oxidative stress in pancreatic β -cells and impair insulin function,⁴⁷ providing a potential mechanism linking elevated hemoglobin, altered glucose regulation, and fetal overgrowth. Recent placental research also suggests that hyperglycemia may stimulate placental signaling molecules and vascular markers that enhance nutrient transfer to the fetus.^{48, 49}

Overall, these results highlight a complex pathway in which pre-pregnancy overweight and obesity may increase the risk of macrosomia mainly through gestational diabetes, while elevated hemoglobin appears to contribute more modestly and indirectly through its relationship with gestational diabetes. Further prospective studies with repeated hemoglobin, glucose, insulin, lipid, and placental biomarker measurements are needed to confirm the temporal sequence and biological mechanisms involved.

Implications for policy and practice

The findings have several implications for maternal and child health policy and clinical practice. First, preconception and early-pregnancy counseling should prioritize healthy weight before pregnancy, particularly among women with overweight or obesity. Second, early metabolic risk assessment should be integrated into antenatal care so that women at high risk for gestational diabetes can be

identified before excessive fetal growth becomes established. Third, hemoglobin monitoring should not be limited to the detection of anemia; high hemoglobin levels in early pregnancy may also help identify women requiring closer metabolic surveillance, especially when iron supplementation is used. Finally, prenatal programs in Morocco and similar low- and middle-income settings should combine nutritional counseling, appropriate iron supplementation, gestational diabetes screening, and follow-up of fetal growth to reduce macrosomia and related perinatal complications.

Study limitations and future directions

The results of this study should be interpreted in light of several limitations. First, although participants came from rural and urban areas, women from more affluent socioeconomic groups may have attended private clinics; therefore, replication in other Moroccan settings is needed. Second, newborn glucose profiles were not collected, and hemoglobin levels were not measured across all trimesters, which limited the ability to fully explain the proposed relationship between maternal hemoglobin levels, gestational diabetes, and macrosomia. Third, the study did not include detailed follow-up data on interventions offered to women with gestational diabetes, such as weight management, nutritional changes, physical activity, glycemic monitoring, and treatment. Fourth, the retrospective design limits causal interpretation even though the analysis was guided by a theory-driven mediation framework. Future prospective cohort studies should include repeated metabolic measurements, standardized follow-up of gestational diabetes management, and placental biomarkers to better clarify causal mechanisms.

Strengths

This study provides novel data on perinatal epidemiology in Morocco and highlights the combined mediating role of gestational diabetes and hemoglobin levels in the association between pre-pregnancy BMI and neonatal macrosomia. Using advanced statistical methods, including Hayes PROCESS Model 6 and the Karlson–Holm–Breen method, the study analyzed complex interactions among maternal metabolic factors. The

findings emphasize the importance of preventing pre-pregnancy obesity, screening for gestational diabetes, and monitoring hemoglobin, underscoring the clinical relevance and public health value of targeted prenatal programs.

Conclusion

High hemoglobin levels and gestational diabetes were important mediators in the relationship between pre-pregnancy BMI and the risk of neonatal macrosomia. Gestational diabetes was the dominant mediator, whereas hemoglobin levels contributed mainly through a sequential pathway involving gestational diabetes. These findings support early metabolic screening, appropriate hemoglobin monitoring, and weight-related counseling before and during pregnancy to reduce the risk of macrosomia and associated adverse outcomes.

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Authors' contributions

MD, MEB, AQ, and MLO conceptualized the study. MD, MZ, NAO, KH, ME, AK, YN, and AA contributed to data collection and data verification. MD, MEB, YL, AQ, and MLO contributed to statistical analysis and interpretation of results. MD drafted the initial manuscript. MEB, AQ, and MLO critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Availability of data and materials

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

Consent for publication

Not applicable. No identifiable personal data are presented in this manuscript.

Conflicts of interest

The authors declare that they have no competing interests.

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