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Whole-grain intake frequency in late pregnancy and small-for-gestational-age birth: a secondary analysis of two prospective birth cohorts in China

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Abstract

Introduction: Whole-grain consumption has been associated with favorable maternal metabolic profiles, but evidence regarding the relationship between whole-grain intake frequency during pregnancy and small-for-gestational-age birth remains limited, particularly in Asian populations.

Methods: This study was a secondary analysis of prospectively collected data from two birth cohorts in China. A total of 524 women with linked late-pregnancy dietary data and delivery records were included. Whole-grain intake frequency at approximately 28–32 weeks of gestation was assessed using a food-frequency questionnaire and classified as never or rarely, 1–3 times per week, or at least 4 times per week. Multivariable logistic regression was used to estimate odds ratios and 95% confidence intervals for SGA. Effect modification by maternal pregnancy complications was examined using stratified analyses and a multiplicative interaction term.

Results: Among 524 participants, 35 infants were classified as SGA. Each one-point increase in the whole-grain intake-frequency score was associated with lower odds of SGA after covariate adjustment (adjusted OR=0.49, 95% CI: 0.27–0.87).

Compared with women who never or rarely consumed whole grains, those reporting intake at least 4 times per week had lower odds of SGA (adjusted OR=0.25, 95% CI: 0.05–0.81). The association was stronger among women with recorded pregnancy complications, although statistical evidence for interaction was limited (P for interaction=0.050).

Conclusion: Higher reported whole-grain intake frequency during late pregnancy was associated with lower odds of SGA in this cohort. The association may differ according to maternal complication status, but the interaction and complication-specific findings should be interpreted cautiously because of the limited number of SGA events. Larger prospective studies with quantitative dietary assessment and more comprehensive confounder control are needed.

Keywords: Pregnancy complications, Small for gestational age, Effect modification, Whole grains

1 Introduction

Small for gestational age (SGA) is commonly defined as birth weight below the 10th percentile for gestational age and infant sex [1, 2]. Although SGA is frequently used as a proxy for impaired fetal growth, it is not synonymous with fetal growth restriction (FGR), which refers to a fetus that fails to achieve its biological growth potential [2, 5]. SGA infants are at increased risk of adverse neonatal outcomes and may also experience long-term developmental and cardiometabolic consequences [3, 4]. The etiology of impaired fetal growth is multifactorial, involving an intricate interplay of placental insufficiency, maternal constitutional factors, and gestational nutrition [5]. Given that vascular remodeling and placental perfusion are sensitive to maternal metabolic states [6], identifying modifiable dietary factors during pregnancy is of clinical significance for supporting fetal growth.

Maternal grain intake represents a foundational energy source during pregnancy; however, the nutritional quality of carbohydrate sources varies substantially [7, 8]. Whole grains retain the bran, germ, and endosperm, providing dietary fiber, micronutrients, and bioactive compounds [9]. Previous cohort studies and systematic reviews have reported associations between higher-quality maternal dietary patterns and lower risks of adverse birth outcomes [10, 11]. However, because these overall dietary patterns include multiple correlated food groups, the independent contribution of whole-grain consumption remains uncertain [12, 13]. Furthermore, much of the existing evidence originates from Western cohorts, whereas evidence regarding whole-grain consumption in Asian pregnant populations remains limited [16].

The association between whole-grain intake and fetal growth may differ according to maternal metabolic and obstetric status [17]. Women with gestational diabetes mellitus (GDM) or vascular complications may experience altered glucose metabolism, systemic inflammation, or impaired placental perfusion, which could modify the relationship between carbohydrate quality and fetal growth [14, 15, 18, 19]. However, evidence for such effect modification remains limited.

In this secondary analysis of prospectively collected data from two birth cohorts in China, we aimed to examine the association between whole-grain intake frequency during late pregnancy and SGA birth and, secondarily, to explore whether this association differed according to the presence of maternal pregnancy complications.

2 Methods

2.1 Study Design and Data Source

This study was a secondary analysis of prospectively collected data from two longitudinal birth cohorts conducted in China. In the original source cohorts, pregnant women were recruited during early pregnancy ($\leq$ 12 weeks of gestation) and followed prospectively through delivery. For the present analysis, late-pregnancy dietary questionnaire data were linked with obstetric and neonatal records from the delivery databases using deterministic record linkage based on individual identifiers.

Because participants were derived from two distinct source cohorts, cohort membership was included as a covariate in the primary regression models to account for potential unmeasured baseline differences between the study sites.

2.2 Study Population and Selection Flow

Participants were eligible for inclusion if they had: (1) a singleton live birth; (2) completed the late-pregnancy dietary assessment; (3) available neonatal birth weight, gestational age, and infant sex; and (4) sufficient identifiers for deterministic record linkage. Participants were excluded if they had multiple gestation, stillbirth, major congenital anomalies, missing key dietary or neonatal outcome data, or duplicate delivery records.

The initial source databases comprised 1,911 delivery records and 738 late-pregnancy dietary questionnaires. Prior to linkage, a duplication check was performed on the delivery outcome database. Duplicate records were defined based on identical identifiers, and only the chronological first entry was retained, resulting in the exclusion of 105 redundant records and yielding 1,806 unique delivery records.

Subsequently, a deterministic record linkage was implemented to merge the dietary and obstetric registries using maternal names, delivery dates, and basic demographic attributes. This matching process yielded a final analytical sample of 524 successfully linked participants. A total of 1,282 delivery records and 214 dietary surveys failed the linkage protocol, primarily due to variations in transcription formats between the distinct electronic modules, and were consequently excluded.

The detailed flow of participant screening and selection is structurally delineated in Figure 1.

2.3 Variable Definitions and Measurements

Maternal dietary intake during late gestation (approximately 28–32 weeks of gestation) was assessed using a food-frequency questionnaire (FFQ) used in the source cohorts. The questionnaire included a range of commonly consumed whole-grain foods, including whole-wheat bread, oats, brown rice, millet, buckwheat, and corn. Participants

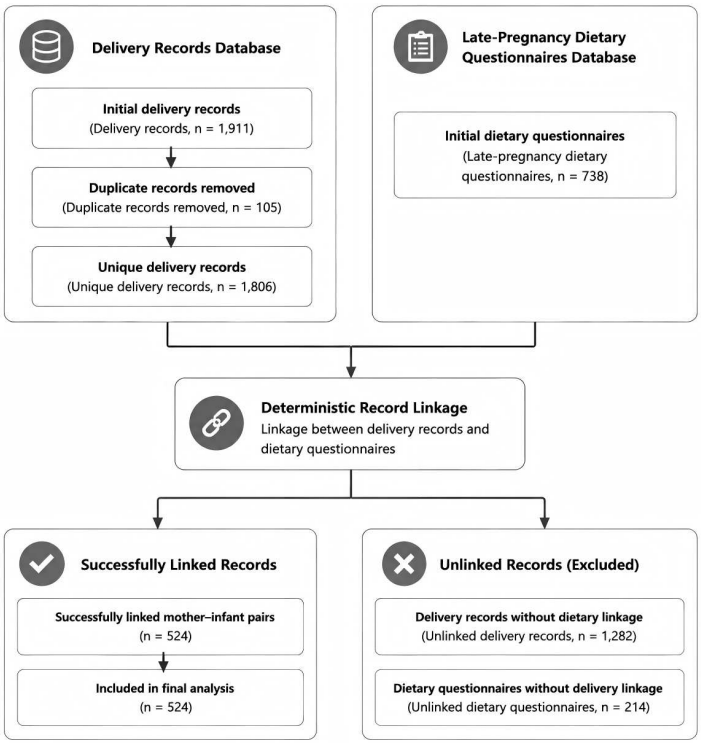


Fig. 1 Flowchart showing participant selection, record linkage, and inclusion in the final analysis.

reported their overall consumption frequencies using predefined response categories. For the primary analysis, reported whole-grain intake frequency was recoded into three ordinal categories: 0 (never or rarely), 1 (low frequency, 1–3 times per week), and 2 (moderate-to-high frequency, ≥ 4 times per week). Because relatively few participants reported daily consumption (9.2%), the highest-frequency categories were combined to avoid sparse cells and improve interpretability. The exact response categories included in each recoded group are provided in Supplementary Table S1.

The primary outcome was small-for-gestational-age (SGA). Neonatal birth weight and gestational age at delivery were obtained directly from verified electronic hospital medical records. In accordance with standard obstetric clinical practice, gestational age was routinely determined based on the reliable date of the last menstrual period (LMP) and confirmed or adjusted by crown-rump length (CRL) measurement obtained via first-trimester ultrasonography ($\leq 12^{+6}$ weeks of gestation). If a discrepancy of more than 5–7 days existed between LMP and ultrasound estimates, the early ultrasound measurement was prioritized to establish the definitive gestational age.

SGA was defined according to the updated Weight Standards for Newborns of Different Gestational Ages in China (2022 Edition). Infants whose birth weight was below the sex- and gestational-age-specific 10th percentile reference standard were classified as SGA (coded as 1), whereas those at or above the 10th percentile were classified as non-SGA (coded as 0).

Information regarding maternal clinical and obstetric conditions was extracted from the "High-Risk Obstetric Indicators" section of the electronic health record system. A structured keyword-based text-parsing approach was used to identify and classify obstetric morbidities. The extracted conditions included metabolic complications, primarily gestational diabetes mellitus (GDM); hypertensive disorders of pregnancy, including gestational hypertension and preeclampsia; placental abnormalities; thyroid dysfunction; and gestational anemia. Assisted reproductive technology (ART) status was evaluated separately rather than being combined into the morbidity indicator. Only conditions diagnosed before or at the time of the late-pregnancy dietary assessment were considered as potential effect modifiers. For exploratory stratified analyses, a composite dichotomous indicator of recorded maternal conditions was created. Women with at least one documented condition were assigned to the "with conditions" group, whereas those without any recorded condition were assigned to the reference group. Because the included conditions were clinically heterogeneous, the composite condition variable was used primarily for exploratory stratification rather than as a single etiologically homogeneous disease category.

Potential confounding factors were selected based on biological plausibility and directed acyclic graph (DAG) considerations (Supplementary Figure S1). To minimize residual confounding while preserving model parsimony, all primary multivariable models were adjusted for maternal age at delivery (continuous, years), gravidity (continuous), parity (continuous), and cohort source. Gestational age at delivery was not adjusted for in the primary models because SGA is inherently defined according to gestational age.

2.4 Statistical Analysis

All statistical operations were performed using R software (version 4.2.0; R Foundation for Statistical Computing, Vienna, Austria), utilizing the `tableone`, `stats`, and `logistf` packages. All tests were two-tailed, and statistical significance was defined a priori at $P < 0.05$. Complete-case analysis was utilized because there were no missing data for the key exposure, outcome, and selected covariates in the linked analytical cohort.

Continuous variables were assessed for normality; normally distributed data were expressed as means ± standard deviations (SD) and compared using independent-samples t-tests for two-group comparisons and one-way analysis of variance (ANOVA) for comparisons across the three whole-grain intake groups. Categorical variables were presented as absolute frequencies and percentages, with cross-group differences evaluated using Pearson's Chi-square (χ^2) tests or Fisher's exact tests as appropriate.

The primary exposure was the ordinal whole-grain intake-frequency score, modeled continuously to estimate the association per one-category increase. Categorical models were conducted as secondary analyses, with the lowest intake group ("never or rarely") serving as the reference. Multivariable logistic regression was used to calculate adjusted odds ratios (ORs) and their corresponding 95% confidence intervals (CIs) for SGA. Because only 35 SGA events were observed, the number of covariates was restricted to reduce model overfitting.

Effect modification was evaluated by including a multiplicative interaction term between the continuous whole-grain intake-frequency score and maternal condition status in the fully adjusted model. The interaction coefficient, interaction OR, 95% CI, and Wald-test P value were reported. Stratified multivariable models were then executed within the sub-cohorts of women with and without recorded conditions. Analyses for specific complication types (e.g., GDM) were considered exploratory. No formal adjustment for multiple comparisons was performed; therefore, subgroup findings should be interpreted as hypothesis-generating. Due to sparse data in specific clinical sub-strata, Firth's penalized likelihood logistic regression (`logistf`) was utilized to provide unbiased and stable point estimations.

Finally, a series of sensitivity analyses were conducted to confirm the robustness of our primary findings: (1) utilizing Firth's penalized logistic regression for the primary model to account for the low number of overall SGA events; (2) restricting the analysis to term deliveries (gestational age ≥ 37 weeks) to assess whether the association was sensitive to the inclusion of preterm deliveries; and (3) re-running models utilizing the uncollapsed, original ordinal whole-grain score to guarantee that category collapsing did not introduce artifactual associations.

3 Results

3.1 Baseline Characteristics of the Study Population

A total of 524 pregnant women were included in the final analytical cohort. The mean maternal age at delivery was 31.2 ± 3.8 years. Primiparous women accounted for 54.8% (287/524) of the cohort. Whole-grain intake frequency during late pregnancy showed a skewed distribution toward low-frequency consumption. Specifically, 63.0% of participants reported low-frequency intake (1–3 times/week), whereas 17.9% reported moderate-to-high intake frequency (≥ 4 times/week) (Table 1).

Among the 524 participants included in the analysis, 35 infants were classified as SGA, corresponding to an overall incidence of 6.7%. Baseline characteristics stratified by neonatal SGA status are presented in Table 2.

Compared with women in the non-SGA group, those who delivered an SGA infant had significantly lower whole-grain intake-frequency scores during late pregnancy (0.74 ± 0.61 vs. 1.01 ± 0.61, $P = 0.013$). No statistically significant differences were observed between the two groups with respect to maternal age at delivery, gestational age at delivery, gravidity, parity, or maternal clinical and obstetric conditions (all $P > 0.05$).

3.2 Association Between Whole-Grain Intake Frequency and SGA

The associations between whole-grain intake frequency during late pregnancy and the odds of SGA are presented in Table 3.

After adjustment for maternal age at delivery, gravidity, parity, and cohort source, higher whole-grain intake frequency was significantly associated with lower odds of SGA.

Table 1 Baseline Characteristics of the Study Population According to Whole-Grain Intake Frequency

Variable ($N = 524$)	Overall ($n = 100$)	Never or rarely ($n = 330$)	Low frequency ($n = 94$)	Moderate-to-high	P value
Maternal age (years)	31.2 ± 3.8	30.6 ± 3.8	31.3 ± 3.9	31.4 ± 3.4	0.188
Gravidity (times)	2.1 ± 1.3	2.0 ± 1.2	2.1 ± 1.3	2.0 ± 1.1	0.546
Parity (times)	1.5 ± 0.6	1.4 ± 0.6	1.5 ± 0.6	1.5 ± 0.6	0.713
Primiparous, n (%)	287 (54.8)	56 (56.0)	181 (54.8)	50 (53.2)	0.692
Gestational age (weeks)	38.6 ± 1.3	38.5 ± 1.4	38.6 ± 1.2	38.4 ± 1.3	0.425
Maternal conditions, n (%)					
With recorded conditions	278 (53.1)	52 (52.0)	175 (53.0)	51 (54.3)	0.586
Gestational diabetes mellitus	67 (12.8)	11 (11.0)	42 (12.7)	14 (14.9)	0.077
Neonatal outcome, n (%)					
Small-for-gestational-age	35 (6.7)	11 (31.4)	20 (57.1)	4 (11.4)	0.037

Note: Continuous variables are presented as mean ± standard deviation (SD) and compared using analysis of variance (ANOVA). Categorical variables are presented as number (percentage) and compared using Pearson's chi-square test or Fisher's exact test. Low frequency: 1–3 times/week; Moderate-to-high frequency: ≥ 4 times/week.

Table 2 Baseline Characteristics of the Study Population According to Neonatal SGA Status

Variable	Total ($N = 524$)	Non-SGA ($n = 489$)	SGA ($n = 35$)	Statistic (χ^2/t)	P value
Maternal age (years)	31.2 ± 3.8	31.2 ± 3.8	30.8 ± 3.7	0.609	0.543
Gravidity (times)	2.1 ± 1.3	2.1 ± 1.3	1.9 ± 0.9	0.892	0.373
Parity (times)	1.5 ± 0.6	1.5 ± 0.6	1.4 ± 0.5	0.954	0.341
Primiparous, n (%)	287 (54.8)	266 (54.4)	21 (60.0)	0.414	0.520
Multiparous, n (%)	237 (45.2)	223 (45.6)	14 (40.0)		
Gestational age (weeks)	38.6 ± 1.3	38.6 ± 1.3	38.5 ± 1.4	0.435	0.664
Birth weight (g)[1]	3242.4 ± 431.1	3293.3 ± 380.1	2532.9 ± 386.0	—	—
Maternal conditions, n (%)				0.005	0.943
Without recorded	246 (46.9)	229 (46.8)	17 (48.6)		
With recorded	278 (53.1)	260 (53.2)	18 (51.4)		
Whole-grain score (0–2)	1.00 ± 0.61	1.01 ± 0.61	0.74 ± 0.61	2.502	0.013
Whole-grain frequency, n (%)				7.127	0.028
0: Never or rarely	100 (19.1)	89 (18.2)	11 (31.4)		
1: Low frequency	330 (63.0)	310 (63.4)	20 (57.1)		
2: Moderate-to-high	94 (17.9)	90 (18.4)	4 (11.4)		

Note: SGA = small-for-gestational-age. Continuous variables are presented as mean ± standard deviation (SD) and were compared using independent-samples t-tests. Categorical variables are presented as number (percentage) and were compared using Pearson's chi-square test or Fisher's exact test.
[1] Birth weight was not formally compared because it contributed directly to the definition of SGA.

Table 3 Multivariable Logistic Regression Analysis of Late-Gestational Whole-Grain Intake Frequency and Odds of SGA

Whole-grain intake	SGA / total	Crude OR (95% CI)	Adjusted OR (95% CI)[1]	*P* value
Continuous score	35 / 524	0.48 (0.27–0.84)	0.49 (0.27–0.87)	0.016
Categorical analysis				
0: Never or rarely	11 / 100	Reference	Reference	—
1: Low frequency	20 / 330	0.52 (0.24–1.12)	0.47 (0.22–1.03)	0.052
2: Moderate-to-high	4 / 94	0.36 (0.11–1.14)	0.25 (0.05–0.81)	0.036

[1] Adjusted for maternal age at delivery, gravidity, parity, and cohort source.

When the whole-grain intake-frequency score was analyzed continuously, each one-category increase in the score was associated with 51% lower odds of SGA (adjusted OR = 0.49, 95% CI: 0.27–0.87, $P = 0.016$).

When analyzed categorically, women with low-frequency intake (1–3 times/week) showed lower odds of SGA compared with women who rarely or never consumed whole grains, although the association did not reach statistical significance (adjusted OR = 0.47, 95% CI: 0.22–1.03, $P = 0.052$). Women with moderate-to-high intake frequency ($\geq$ 4 times/week) had significantly lower odds of SGA (adjusted OR = 0.25, 95% CI: 0.05–0.81, $P = 0.036$).

As shown in Figure 2, a graded inverse pattern was observed across increasing intake-frequency categories.

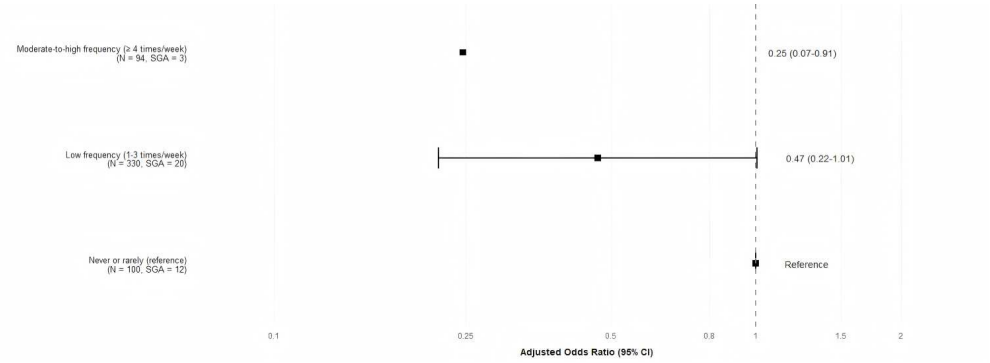


Fig. 2 Adjusted odds ratios for SGA according to whole-grain intake frequency

3.3 Effect Modification by Maternal Conditions

Stratified analyses according to maternal clinical and obstetric condition status are shown in Table 4.

Table 4 Stratified Analyses of the Association Between Whole-Grain Intake Frequency and Odds of SGA According to Maternal Condition Status

Strata / Phenotype	Sample (n)	SGA events	Adjusted OR (95% CI)[1]	P value	P for interaction[2]
Overall stratification					0.050
Without recorded conditions	246	17	0.79 (0.37–1.65)	0.527	
With recorded conditions	278	18	0.22 (0.09–0.58)	0.002	

[1] Adjusted for maternal age at delivery, gravidity, parity, and cohort source.
[2] The P for interaction was calculated by introducing a multiplicative interaction term into the fully adjusted logistic regression model.

Exploratory analyses suggested possible heterogeneity by maternal condition status, although the interaction estimate was imprecise (interaction OR = 0.28, 95% CI: 0.08–1.00, $P_{\text{interaction}} = 0.050$). Among women with recorded conditions ($n = 278$), each 1-point increase in whole-grain intake-frequency score was associated with lower odds of SGA (adjusted OR = 0.22, 95% CI: 0.09–0.58, $P = 0.002$). Among women without recorded conditions ($n = 246$), the estimate was closer to the null and imprecise (adjusted OR = 0.79, 95% CI: 0.37–1.65, $P = 0.527$).

Condition-specific analyses were exploratory and are presented in the Supplementary Materials because of the small number of SGA events within individual subgroups.

3.4 Sensitivity Analyses

Sensitivity analyses are presented in Table 5.

Table 5 Sensitivity Analyses of the Association Between Whole-Grain Intake Frequency and Odds of SGA

Sensitivity scenario	Analytical n	SGA events	Adjusted OR (95% CI)[1]	P value
Firth penalized logistic regression (Primary model)	524	35	0.49 (0.27–0.86)	0.014
Excluding preterm deliveries (< 37 weeks)	499	31	0.50 (0.27–0.93)	0.028
Using original uncollapsed 4-level score (0–3)	524	35	0.49 (0.29–0.85)	0.011

Note: OR, odds ratio; CI, confidence interval; SGA, small-for-gestational-age.
[1] Adjusted for maternal age at delivery, gravidity, parity, and cohort source.

Sensitivity analyses were conducted to evaluate the robustness of the association between whole-grain intake frequency and the odds of SGA. Specifically, three sensitivity scenarios were performed: (1) applying Firth's penalized likelihood logistic regression to the primary continuous model to account for the relatively low number of overall SGA events; (2) restricting the analysis to term deliveries (gestational age < 37 weeks) to assess whether the association was sensitive to the inclusion of preterm deliveries; and (3) modeling whole-grain intake using the original, uncollapsed

four-level score (0–3 points) to guarantee that category collapsing did not introduce artifactual associations. All sensitivity analyses were adjusted for maternal age at delivery, gravidity, parity, and cohort source.

When Firth penalized logistic regression was applied to the primary continuous score model, the inverse association remained statistically significant (adjusted OR = 0.49, 95% CI: 0.27–0.86, $P = 0.014$).

Similarly, after excluding preterm births (gestational age < 37 weeks), the results remained consistent (adjusted OR = 0.50, 95% CI: 0.27–0.93, $P = 0.028$).

When the analyses were repeated using the original uncollapsed whole-grain intake score, the findings were again consistent with the primary analysis (adjusted OR = 0.49, 95% CI: 0.29–0.85, $P = 0.011$).

Overall, the sensitivity analyses yielded effect estimates that were broadly consistent with the primary analysis.

The consistency of the effect estimates across sensitivity analyses is illustrated in Figure 3.

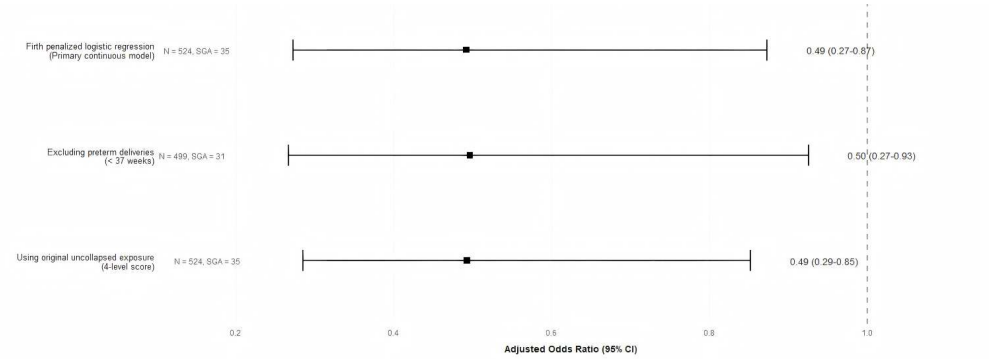


Fig. 3 Sensitivity analyses of the association between whole-grain intake-frequency score and SGA

4 Discussion

4.1 Main Findings

In this secondary analysis of two prospective birth cohorts, higher reported whole-grain intake frequency during late pregnancy was associated with lower odds of SGA in the overall sample. The estimates differed between women with and without recorded maternal pregnancy complications; however, the interaction test was borderline ($P = 0.050$) and the confidence intervals in the stratified analyses were wide. Therefore, the observed heterogeneity should be regarded as exploratory rather than confirmatory.

4.2 Comparison with Previous Studies and Potential Mechanisms

The inverse association between maternal whole-grain intake frequency and the odds of SGA observed in this study is broadly consistent with previous evidence linking higher-quality maternal diets to more favorable birth outcomes. Several cohort studies and systematic reviews have reported that dietary patterns characterized by higher consumption of whole grains, fruits, vegetables, and other nutrient-dense foods are associated with lower risks of adverse pregnancy outcomes. However, much of the existing literature has focused on overall dietary patterns rather than on specific dietary components. By examining whole-grain intake frequency as an individual dietary exposure, our findings provide additional observational evidence that whole-grain intake frequency may be associated with fetal growth during late pregnancy, a period characterized by rapid fetal development and increasing nutritional demands.

Several biological mechanisms may explain the observed association. One possible explanation is that whole-grain foods may contribute to more stable postprandial glucose responses because of their fiber-rich structure. More stable maternal glucose levels may facilitate more consistent nutrient delivery to the fetus and reduce metabolic stress on the placenta. Second, whole grains may influence fetal growth through pathways related to inflammation and vascular function. Fermentation of dietary fiber by the gut microbiota generates short-chain fatty acids, which have been shown to exert anti-inflammatory and endothelial-protective effects. However, glucose concentrations, inflammatory biomarkers, and placental function were not measured in this study, and these pathways remain speculative.

Importantly, temporal sequence and post-diagnosis behavioral changes must be considered when interpreting the subgroup findings. Women diagnosed with GDM before the dietary survey may have received dietary counseling and subsequently increased whole-grain consumption. Accordingly, the GDM-specific estimate should be interpreted as hypothesis-generating and may partly reflect post-diagnosis dietary modification.

4.3 Clinical and Public Health Implications

The findings support further investigation of carbohydrate quality as a component of prenatal dietary assessment. However, the present observational results are insufficient to establish a specific whole-grain recommendation for preventing SGA, particularly because intake quantity, total energy intake, and overall dietary quality were not measured comprehensively. While optimizing carbohydrate quality is a crucial aspect of prenatal care, further large-scale prospective studies and intervention trials with quantitative dietary assessments are required to establish specific clinical guidelines for different maternal populations.

4.4 Strengths and Limitations

This study has several notable strengths. First, the prospective cohort design ensured that maternal dietary exposure was assessed before delivery outcomes occurred,

thereby minimizing recall bias. Second, information on maternal conditions and neonatal outcomes was obtained directly from verified electronic medical records. Third, the study employed multiple analytical approaches, and Firth's penalized likelihood logistic regression was applied to improve the stability and validity of the effect estimates when sparse data were encountered.

However, several limitations must be acknowledged:

1. **Residual confounding:** Information on pre-pregnancy body mass index, gestational weight gain, total energy intake, socioeconomic status, smoking, physical activity, and overall dietary quality was unavailable or incomplete in the merged dataset.
2. **Selection bias:** Only 524 of 1,806 unique delivery records were successfully linked to dietary records. Similarity in measured characteristics does not exclude selection bias due to unmeasured differences.
3. **Exposure measurement error:** Whole-grain intake was self-reported and assessed by frequency rather than grams or servings. Misclassification is possible, and different whole-grain foods may not be nutritionally equivalent.
4. **Temporal sequence:** Some pregnancy complications, especially GDM, may have been diagnosed before the dietary survey and may have subsequently changed participants' diets.
5. **Limited event count:** Only 35 SGA events were observed, including four events in the GDM subgroup, limiting statistical power and model stability.
6. **Multiple comparisons:** Several subgroup and sensitivity analyses were conducted without adjustment for multiple comparisons, increasing the possibility of chance findings.
7. **Generalizability:** The sample was derived from specific Chinese hospital-based cohorts, which may limit generalizability to other regions and populations.

5 Conclusions

In this secondary analysis of two prospective birth cohorts, higher reported whole-grain intake frequency during late pregnancy was associated with lower odds of SGA. The association appeared stronger among women with recorded pregnancy complications, but statistical evidence for interaction was limited and complication-specific estimates were based on few SGA events. These findings should therefore be considered exploratory. Larger prospective studies using quantitative dietary assessment, clear temporal ascertainment of maternal conditions, and more comprehensive control of confounding are needed to confirm the association.

Abbreviations

ART Assisted reproductive technology
BMI Body mass index
CI Confidence interval
DAG Directed acyclic graph
FFQ Food frequency questionnaire
FGR Fetal growth restriction
GDM Gestational diabetes mellitus
OR Odds ratio
SD Standard deviation
SGA Small-for-gestational-age

Declarations

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Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Xuanwu Hospital, Capital Medical University (Approval No. [2023] No.126). Written informed consent was obtained from all participants prior to their enrollment in the source cohorts.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analyzed during the current study are not publicly available because they contain potentially identifiable maternal and neonatal information. De-identified data may be available from the corresponding author upon reasonable request and subject to institutional and ethical approval.

Code availability

The R code used for statistical analyses during the current study is available from the corresponding author on reasonable request.

Author contributions

YY: Conceptualization, Data curation, Formal analysis, Writing–original draft, Writing–review & editing.
YP: Writing–original draft, Writing–review & editing.
XQ: Data curation, Formal analysis.
YZ: Data curation, Formal analysis.
XC: Writing–review & editing.
HY: Supervision.
QZ: Supervision.
XW: Conceptualization, Writing–review & editing, Supervision.
All authors read and approved the final manuscript.

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Supplementary Materials

Table S1 Exploratory Stratified Analyses of the Association Between Whole-Grain Intake Frequency and Odds of SGA According to Specific Maternal Clinical Subgroups

Subgroup / Clinical Phenotype	**Sample (n)**	**SGA events**	**Adjusted OR (95% CI)**[1]	P **value**
Exploratory phenotypes				
Gestational diabetes mellitus (GDM)	67	4	0.05 (0.004–0.58)[2]	0.017
Gestational anemia	88	5	1.00 (0.23–4.27)	0.998

[1] Adjusted for maternal age at delivery, gravidity, parity, and cohort source.

[2] Estimated using Firth's penalized likelihood logistic regression due to sparse cellular data[cite: 1]. Note: Subgroups with zero SGA events (such as hypertensive disorders of pregnancy) are omitted due to non-estimability[cite: 1].