

# Effects of low-glycemic-index diets in pregnancy on maternal and newborn outcomes in pregnant women: a meta-analysis of randomized controlled trials

Ru Zhang<sup>1</sup> · Shufen Han<sup>1</sup> · Guo-Chong Chen<sup>1</sup> · Zeng-Ning Li<sup>2</sup> · Irma Silva-Zolezzi<sup>3</sup> · Gerard Vinyes Parés<sup>4</sup> · Yi Wang<sup>4</sup> · Li-Qiang Qin<sup>1</sup>

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## Abstract

**Purpose** Maternal diet with a high glycemic index (GI) is associated with fetal overgrowth and higher infant body adiposity. Effects of low-GI diet on maternal and newborn outcomes have been assessed in both healthy pregnancy and gestational diabetes mellitus, but the results remain inconclusive. This meta-analysis aimed to examine the effects of low-GI diets on maternal and newborn outcomes. **Methods** PubMed, Clinical Trials, and Cochrane Library databases were searched for relevant randomized trials up to January 2016. Random- or fixed-effects models were used to calculate combined treatment effects. **Results** A total of 11 trials involving 1985 women were eligible for analysis. This meta-analysis assessed 7 maternal and 11 newborn outcomes. Of these, gestational weight gain (GWG), fasting blood glucose (FBG), newborn birth weight, ponderal index (PI), proportion of macrosomia, and large for gestational age (LGA) were investigated in

more than 8 trials. Compared with control diets, low-GI diets significantly reduced FBG (weight mean differences (WMD) =  $-0.18$  mmol/L, 95 % CI:  $-0.33$ ,  $-0.02$ ), 2-h postprandial glucose level (WMD =  $-0.33$  mmol/L, 95 % CI:  $-0.54$ ,  $-0.12$ ), and the proportion of LGA (RR = 0.52, 95 % CI: 0.31, 0.89). A lower GWG (WMD =  $-0.69$  kg, 95 % CI:  $-1.74$ , 0.36) and birth weight (WMD =  $-0.10$  kg, 95 % CI:  $-0.23$ , 0.03) were also observed without significant differences. Heterogeneity was observed in the GWG, FBG, and birth weight analyses. Low-GI diets did not affect other maternal and newborn outcomes. In subgroup and sensitivity analyses, the intervention effects of low GI on GWG and FBG varied. **Conclusions** Low-GI diets may have beneficial effects on maternal outcomes for those at risk of developing high glucose levels, without causing adverse effects on newborn outcomes. However, results should be interpreted with caution because of the evidence of heterogeneity and limited number of studies.

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✉ Yi Wang  
yi.wang@rd.nestle.com

✉ Li-Qiang Qin  
qinliqiang@suda.edu.cn

<sup>1</sup> Department of Nutrition and Food Hygiene, School of Public Health, Soochow University, 199 Renai Road, Dushu Lake Higher Education Town, Suzhou 215123, China

<sup>2</sup> Department of Nutrition, First Hospital of Hebei Medical University, Shijiazhuang 050031, China

<sup>3</sup> Nutrition and Health Research, Nestlé Research Center, Lausanne, Switzerland

<sup>4</sup> Nestlé Research Center, Beijing 100095, China

**Keywords** Low glycemic index · Pregnancy outcomes · Randomized controlled trials · Meta-analysis

## Introduction

The nutritional status of the mother during pregnancy plays a vital role in fetal growth and development, with glucose as the main energy substrate [1]. However, different carbohydrate foods produce varied glycemic responses, which influence maternal blood glucose concentrations [2]. In 1981, Jenkins [3] proposed the use of glycemic index (GI) to rank postprandial glycemic responses to the equivalent portions of carbohydrates in different foods. Carbohydrates are then classified according to their induced glycemic

responses as either high or low GI. Among these two types of carbohydrates, those with low GI produce low glyce-mic response, e.g., whole grain breads, cereals, and nuts, whereas high-GI foods produce a high glyce-mic response, e.g., refined grains, desserts, and soft drinks. Alterations in maternal metabolism provide nutrients in excess of those required for normal fetal growth and for maternal and fetal energy requirements. In this context, the presence of any degree of abnormal glucose tolerance represents an altered environment for the growth of the fetus [4]. A dietary intake of carbohydrates with low GI induces individuals to obtain normal gestational weight gain (GWG) and normal infant birth weight, whereas carbohydrates with high GI results in fetoplacental overgrowth and predisposition to fetal macrosomia [5].

Previous systematic reviews and meta-analyses demonstrated that low-GI diets may reduce insulin requirements and birth weight without adverse effects on pregnant women with gestational diabetes mellitus (GDM), suggesting that low-GI diets are an appropriate dietary intervention for GDM when glucose load is controlled [6, 7]. As the research in this field is active and fast-moving, a number of recent randomized controlled trials (RCTs) have been published to assess the effects of dietary GI on maternal and newborn outcomes in pregnant women with or without GDM. However, these trials yielded varied results because of the differences in the study design and participant characteristics [8–18]. Thus, the feasibility of using low-GI diets to replace current recommended pregnant diets remains inconclusive. The present study aims to analyze the overall effects of low-GI diets on maternal and newborn outcomes in pregnant women regardless of their health status by conducting a meta-analysis of RCTs.

## Materials and methods

### Literature search

This study was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [19]. A systematic literature search for English publications was conducted in the databases of PubMed, Clinical Trials, and the Cochrane Central Register of controlled Trials up to January 2016. Search terms included glycemic index, glycemic load, carbohydrates combining with pregnancy, and gravidas. The search was limited to human clinical trials. A manual search was also performed using the reference lists of original articles and recent reviews. Authors of the original studies were not contacted for additional information.

### Study selection

Studies were selected based on the following criteria: (1) The study design was a RCT; (2) the study was conducted in pregnant women ( $\geq 18$  years old, with a singleton pregnancy); (3) the study comprised a control or a comparison group, and the intervention was low-GI diet with dietary GI level; (4) the dietary intervention was more than 4 weeks; and (5) pregnancy outcomes included maternal or newborn outcomes providing data for statistical analysis. Maternal outcomes included the following: GWG, fasting blood glucose (FBG), 2-h postprandial glucose (2-h PG), glycated Hb A1c (HbA1c), gestational age at delivery, proportion of pregnant women who use insulin, and proportion of cesarean delivery. Newborn outcomes included the following: birth weight, ponderal index (PI), head circumference, body length, abdominal circumference, proportion of large for gestational age (LGA; birth weight  $>90$ th centile), small for gestational age (SGA; birth weight  $<10$ th centile), macrosomia (birth weight  $>4$  kg), prematurity, birth centile, and birthweight centile.

### Data extraction and quality assessment

The following characteristics of each study were recorded: the first author's name, publication year, country of origin, sample size, study design details, participant characteristics (mean age, body weight, body mass index (BMI), health status, and gestation age at recruitment), dietary GI level, and maternal or newborn outcomes mentioned above. If more than one time point for the follow-up was reported, data from the longest period were used. The Jadad scale was used to assess the methodological quality of each included trial by assigning scores ranging from 0 to 5 for reported randomization, blinding, and withdrawal [20]. Two authors (R-Z and LQ-Q) independently conducted the literature search, study selection, and data extraction. Any divergence was resolved by discussion.

### Statistical analysis

For binary data, combined relative risk (RR) with 95 % confidence interval (CI) was evaluated. For continuous data, weighted mean difference (WMD) with 95 % CIs was calculated. Standard deviations (SDs) for net changes were obtained from the baseline in each group. If not reported, they were derived from standard errors, median and interquartile ranges by using a standard formula [21]. If SDs for the baseline and final values were only provided, SDs were imputed according to the method of Follmann et al. [22] with an assumed correlation coefficient of 0.5.

The heterogeneity of the effect size among studies was tested using the Cochran's  $Q$  test at the  $P < 0.10$  level of

significance. We calculated  $I^2$  values, a quantitative measure of inconsistency across studies [23]. A random-effects model was used when  $P < 0.10$  at the  $Q$  test; otherwise, a fixed-effects model was applied [24]. To explore the possible influences of study designs and participant characteristics on the combined effect sizes, we further conducted pre-specified subgroup analyses using stratified outcomes from  $\geq 8$  trials. In addition, we investigated the influence of a single study on the overall risk estimate by omitting one study in each turn. Potential publication bias was assessed using Begg’s funnel plots and the Egger’s regression test [25]. All analyses were performed using STATA version 12.0 (StataCorp, College Station, TX, USA).  $P < 0.05$  was considered statistically significant, except otherwise specified.

## Results

### Literature search

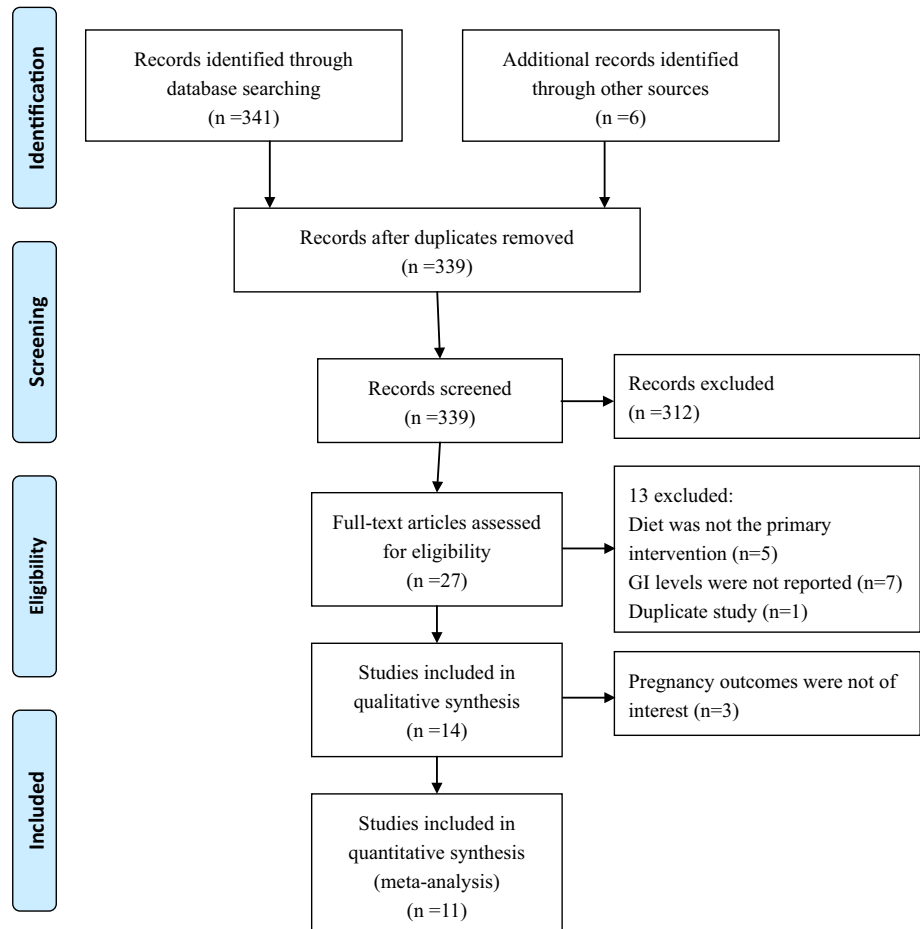
We initially identified 339 potentially eligible publications, most of which were excluded after browsing titles and

abstracts because they were animal studies and reviews, and did not follow a randomized design. After reviewing the full text of the remaining 27 articles, 16 were excluded. The main reasons for which were as follows: Diet was not the primary intervention, the dietary GI levels were not reported, and pregnancy outcomes were not of our interest. Walsh et al. [12] and Macgowan et al. [26] reported the results from the same trial (the ROLO study), and the study of Walsh et al. was included because of the larger population size. Clapp et al. [5, 27] provided additional information for the previous article [18]. To obtain sufficient data, we used supplementary data in one systematic review [7], which were not reported in the original study [17], instead of contacting authors for additional information. Eleven RCTs were selected for the final analysis [8–18]. The flowchart of literature search is presented in Fig. 1.

### Study characteristics

The characteristics of the selected trials are presented in Table 1. Of the 11 trials published from 1997 to 2016, 5 were conducted in Australia, 2 in the USA, and 1 each in Ireland, Mexico, Canada, and China. Only 1 trial followed

**Fig. 1** Flowchart for selection of eligible studies



**Table 1** Characteristics of the included randomized controlled trials in this meta-analysis

Author	Location	Design	Status	Sample size	Age (years)	Weight (kg)	BMI (kg/m <sup>2</sup> )	Baseline FBG (mmol/L)	Gestation weeks at recruitment	GI		Jadad score
										Intervention	Control	
Markovic [8]	Australia	O	At high risk of GDM	72/67	34.7	NR	25.2	NR	17.6 (14–20)	50.4 ± 4.7	57.7 ± 5.1	2
Ma [9]	China	O	GDM	41/42	30 (18–45)	NR	21.5	4.88	27.7 (24–26)	50.1 ± 2.2	53.8 ± 2.5	3
Moses [10]	Australia	P, O	Healthy	296/280	29.9	67.1	24.5	NR	16.5 (<20)	52.8 ± 5.2	55.8 ± 5.0	3
Perichart-Perera [11]	Mexico	P, SB	GDM	61/46	32.1	74	31.1	5.5	21.7 (≤29)	47.2 ± 6.9	48.6 ± 8.4	3
Walsh [12]	Ireland	O	Previously delivered a macrosomic infant	372/387	32	73.6	26.8	4.5	12.9 (<18)	56.0 ± 3.8	57.7 ± 3.9	2
Grant [13]	Canada	O	GDM and IGTP	23/24	34 (18–45)	NR	26.5	4.74	29 (>28)	49 ± 3.9	58 ± 2.4	2
Louie [14]	Australia	P, DB	GDM	47/45	33.2 (18–45)	NR	24	4.65	29.3 (20–32)	47 ± 6.9	53 ± 6.7	4
Rhodes [15]	USA	SB	Overweight or obese	25/21	33.5	85.8	31.7	4.25	19.7 (13–28)	51.8 ± 6.9	58.0 ± 4.3	3
Moses [16]	Australia	O	GDM	31/32	31 (18–40)	85	32.4	4.65	30.1 (28–32)	48 ± 5.0	56.0 ± 6.2	3
Moses [17]	Australia	O	Healthy	32/30	29.9 (21–40)	69.9	25.5	4.35	12–16	51 ± 5.7	58 ± 5.5	1
Clapp [18]	USA	O	Healthy	10/10	34.5	62.3	NR	NR	>8	71 ± 2.4	84 ± 2.4	2

DB double blind, GDM gestational diabetes mellitus, IGTP impaired glucose tolerance of pregnancy, NR not reported, O open label, P parallel, SB single blind

a double-blind design and 2 applied a single-blind design. Sample sizes varied from 20 to 576, with a total of 1985 pregnant women. The mean age of pregnant women ranged from 29.9 to 34.7 years, and mean BMI from 21.5 to 32.4 kg/m<sup>2</sup>. Five trials were conducted in pregnant women with GDM, pregestational type 2 diabetes mellitus (T2DM), or impaired glucose tolerance during pregnancy. The other trials studied healthy pregnant women ( $n = 3$ ), overweight/obese pregnant women ( $n = 1$ ), women who previously delivered a macrosomic infant ( $n = 1$ ), and women who were at high risk of GDM ( $n = 1$ ). Dietary intervention was initially conducted from 12.9 to 30.1 weeks of gestation, and five trials continued the intervention until delivery. The dietary GI ranged from 47 to 71 (median 50.4) in the intervention groups and from 48.6 to 84 (median 57.7) in the control groups. Nine trials measured the dietary intake by using 3-day diet records, and other two used 24-h dietary recalls. Most participants in the control group received healthy eating diet advice. The Jadad scale of these trials ranged from 1 to 4. The characteristics of maternal and newborn outcomes in the included trials are given in Table 2.

### Effects of low-GI diets on maternal outcomes

Low-GI diet significantly reduced FBG (WMD =  $-0.18$  mmol/L, 95 % CI:  $-0.33, -0.02$ ,  $n = 8$ ) (Fig. 2) and 2-h PG ( $n = -0.33$  mmol/L, 95 % CI:  $-0.54, -0.12$ ,  $n = 4$ ), but did not affect HbA1c levels (WMD =  $0.02$  %, 95 % CI:  $-0.03, 0.08$ ,  $n = 3$ ). Low-GI diets produced somewhat lower GWG (WMD =  $-0.69$  kg, 95 % CI:  $-1.74, 0.36$ ,  $n = 9$ ) than control diets without significant difference (Fig. 3). In contrast, no significant change was observed in gestational age at delivery (MWD =  $0.03$ , 95 % CI:  $-0.14, 0.20$ ,  $n = 5$ ), proportion of cesarean delivery (RR =  $1.07$ , 95 % CI:  $0.75, 1.53$ ,  $n = 5$ ), and insulin use (RR =  $1.01$ , 95 % CI:  $0.77, 1.33$ ,  $n = 3$ ) (Supplementary Fig. 1). GWG ( $P = 0.027$ ,  $I^2 = 53.8$  %) and FBG analyses ( $P < 0.001$ ,  $I^2 = 73.7$  %) showed heterogeneity across studies.

### Effects of low-GI diets on newborn outcomes

The meta-analysis results showed a borderline significant reduction in birth weight (WMD =  $-0.10$  kg, 95 % CI:  $-0.23, 0.03$ ,  $n = 11$ ) (Fig. 4) and a significant reduction in the proportion of LGA (RR =  $0.52$ , 95 % CI:  $0.31, 0.89$ ,  $n = 8$ ) (Fig. 5). No differences were observed in other newborn outcomes, including PI (MWD =  $-0.07$  kg/m<sup>3</sup>, 95 % CI:  $-0.71, 0.57$ ,  $n = 8$ ), body length (MWD =  $-0.05$  cm, 95 % CI:  $-0.66, 0.55$ ,  $n = 6$ ), head circumference (MWD =  $-0.13$  cm, 95 % CI:  $-0.68, 0.41$ ,  $n = 5$ ),

abdominal circumference (MWD =  $-0.65$  cm, 95 % CI:  $-2.23, 0.92$ ,  $n = 3$ ), SGA (RR =  $1.33$ , 95 % CI:  $0.71, 2.50$ ,  $n = 6$ ), macrosomia (RR =  $0.95$ , 95 % CI:  $0.83, 1.09$ ,  $n = 8$ ), prematurity (RR =  $0.70$ , 95 % CI:  $0.39, 1.28$ ,  $n = 5$ ), birth centile (MWD =  $-7.87$ , 95 % CI:  $-21.92, 6.19$ ,  $n = 3$ ), and birthweight centile (MWD =  $-1.22$ , 95 % CI:  $-4.46, 2.02$ ,  $n = 3$ ) (Supplementary Fig. 2). Significant heterogeneity was observed for the analysis of birth weight ( $P < 0.001$ ,  $I^2 = 80.7$  %), PI ( $P = 0.009$ ,  $I^2 = 62.6$  %), body length ( $P = 0.002$ ,  $I^2 = 73.5$  %), head circumference ( $P = 0.005$ ,  $I^2 = 73.3$  %), abdominal circumference ( $P < 0.001$ ,  $I^2 = 91.9$  %), and birth centile ( $P = 0.005$ ,  $I^2 = 81.1$  %).

### Subgroup and sensitivity analyses

GWG, FBG, birth weight, LGA, macrosomia, and PI were investigated in 9, 8, 11, 8, 8, and 8 trials, respectively. Subgroup analysis was performed on these six outcomes. The significant decrease in maternal FBG was diminished when trials were limited to blind design, BMI  $\geq 25$  kg/m<sup>2</sup>, and GI difference  $< 7$ . Low-GI diets did not affect FBG when trials were stratified by GDM condition. The significant decrease in GWG by low-GI diets was observed when the analysis was limited to trials with a GI difference  $\geq 7$ . On the other hand, the results of birth weight, LGA, macrosomia, and PI by any stratification were consistent with the overall estimates (Table 2).

Sensitivity analyses were performed to examine the effect of a single trial on the overall results by omitting one trial in each turn. When the study of Walsh et al. [12] was excluded, maternal FBG reduction became more pronounced (WMD =  $-0.28$  mmol/L, 95 % CI:  $-0.36, -0.20$ ) without heterogeneity across the studies ( $P = 0.190$ ,  $I^2 = 31.2$  %). In addition, omitting the trial by Ma et al. [9] resulted in less reduction in FBG by  $0.13$  mmol/L (95 % CI:  $-0.29, 0.02$ ) and in 2-h PG by  $0.21$  mmol/L (95 % CI:  $-0.49, 0.07$ ). When the study of Moses et al. [17] was excluded, reduced GWG became significant (WMD =  $-0.99$  kg, 95 % CI:  $-1.95, -0.03$ ) without heterogeneity across the studies ( $P = 0.122$ ,  $I^2 = 38.6$  %). When the trial by Perichart-Perera et al. [11] was excluded, low-GI diet significantly decreased prematurity (RR =  $0.45$ , 95 % CI:  $0.20, 0.99$ ).

### Publication bias

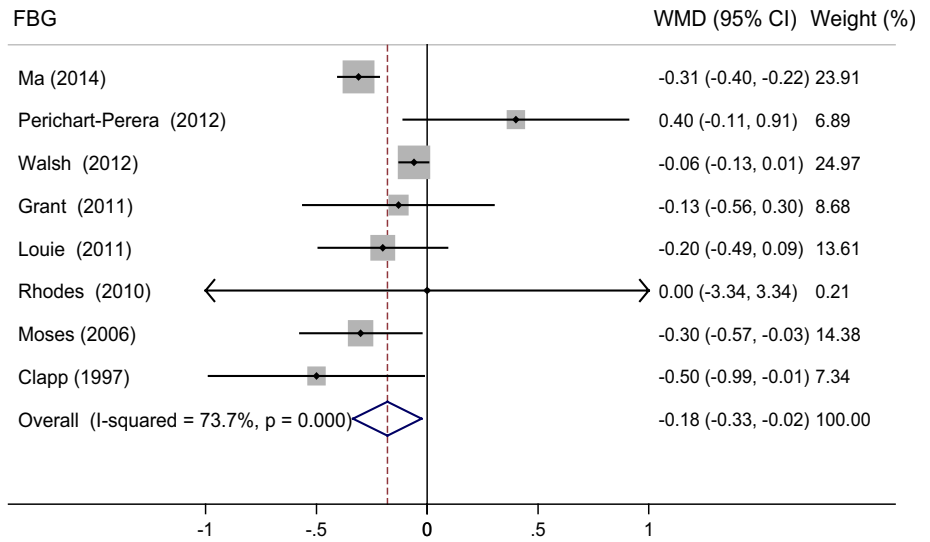
No publication bias was found as assessed by Begg's funnel plot and Egger's test, except a possible publication bias for analyses 2-h PG (Egger's test,  $P = 0.004$ ), LGA (Egger's test,  $P = 0.014$ ), SGA (Egger's test,  $P = 0.044$ ), and macrosomia (Egger's test,  $P = 0.033$ ).

**Table 2** Results of subgroup analyses according to trial or participant characteristics

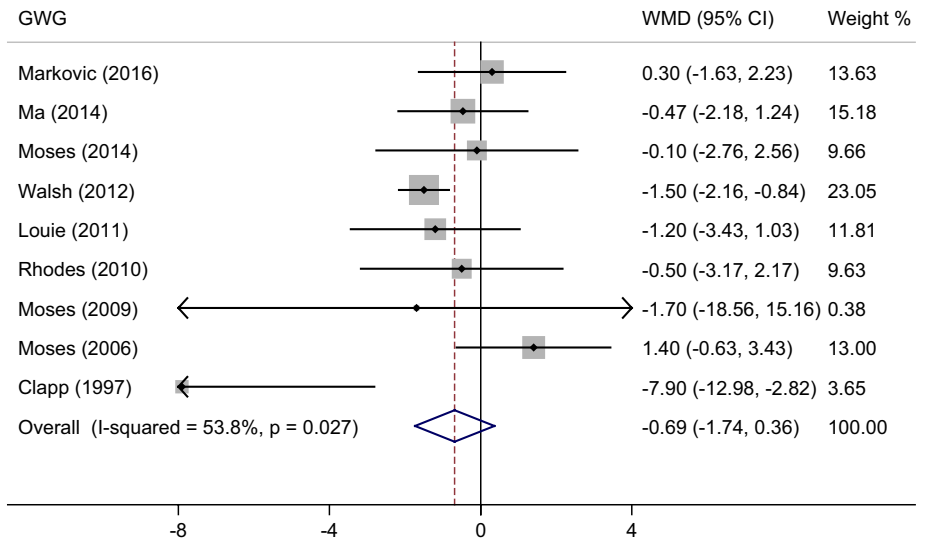
	GWG (kg)				FBG (mmol/L)				Birth weight (kg)				LGA				Macrosomia				Ponderal index(kg/m <sup>3</sup> )			
	N	WMD (95% CI)	P	I <sup>2</sup> (%)	N	WMD (95% CI)	P	I <sup>2</sup> (%)	N	WMD (95% CI)	P	I <sup>2</sup> (%)	N	RR (95% CI)	P	I <sup>2</sup> (%)	N	RR (95% CI)	P	I <sup>2</sup> (%)	N	RR (95% CI)	P	I <sup>2</sup> (%)
Total	9	-0.69 (-1.74, 0.36)	0.027	53.8	8	-0.18 (-0.33, -0.02)	0	73.7	11	-0.10 (-0.23, 0.03)	0	80.7	8	0.52 (0.31, 0.89)	0.083	44.4	8	0.95 (0.83, 1.09)	0.873	0	8	-0.07 (-0.71, 0.57)	0.009	62.6
Study design																								
Open	7	-0.66 (-2.02, 0.70)	0.008	65.2	5	-0.23 (-0.40, -0.05)	0	81.7	8	-0.14 (-0.29, 0.01)	0	83.7	5	0.39 (0.12, 1.31)	0.089	50.5	5	0.96 (0.84, 1.11)	0.853	0	6	-0.29 (-1.10, 0.53)	0.004	70.7
Blind	2	-0.91 (-2.62, 0.80)	0.907	0	3	0.05 (-0.45, 0.54)	0.132	50.7	3	0.03 (-0.31, 0.37)	0.013	77	3	1.31 (0.50, 3.41)	0.386	0	3	0.61 (0.20, 1.87)	0.562	0	2	0.42 (-0.44, 1.29)	0.344	0
BMI (kg/m <sup>2</sup> )																								
<25	3	-0.61 (-1.82, 0.60)	0.804	0	2	-0.30 (-0.39, -0.21)	0.480	0	3	-0.02 (-0.05, 0.09)	0.692	0	1	2.87 (0.61, 13.50)	0.775	0	2	0.40 (0.08, 1.98)	0.775	0	2	0.20 (-0.20, 0.60)	1.000	0
≥25	5	-0.28 (-1.69, 1.14)	0.050	57.8	5	-0.08 (-0.25, 0.09)	0.187	35.2	7	-0.03 (-0.16, 0.11)	0.028	57.5	6	0.53 (0.27, 1.02)	0.431	0	6	0.97 (0.84, 1.11)	0.871	0	5	0.18 (-0.74, 1.09)	0.069	53.9
GDM																								
No	6	-0.70 (-2.23, 0.83)	0.005	70.5	4	-0.19 (-0.39, 0.02)	0.15	43.6	6	-0.09 (-0.27, 0.08)	0	89.3	4	0.26 (0.07, 1.06)	0.135	46.1	3	0.98 (0.85, 1.13)	0.685	0	6	-0.33 (-1.18, 0.51)	0.006	69.4
Yes	3	-0.75 (-2.10, 0.61)	0.873	0	4	-0.14 (-0.38, 0.10)	0.045	62.8	5	-0.11 (-0.23, 0.02)	0.712	0	4	1.29 (0.58, 2.89)	0.668	0	5	0.47 (0.18, 1.23)	0.997	0	2	0.50 (-0.28, 1.27)	0.328	0
GI difference																								
<7	5	-1.13 (-4.47, 2.21)	0.667	0	5	-0.12 (-0.32, 0.07)	0	82.8	6	0.01 (-0.08, 0.09)	0.085	48.4	3	1.37 (0.56, 3.40)	0.386	0	5	0.97 (0.84, 1.11)	0.721	0	4	0.24 (-0.14, 0.63)	0.775	0
≥7	4	-1.26 (-1.83, -0.69)	0.011	73.2	3	-0.30 (-0.51, -0.09)	0.534	0	5	-0.31 (-0.72, 0.10)	0	87.9	5	0.30 (0.14, 0.62)	0.089	50.5	3	0.62 (0.25, 1.53)	0.978	0	4	-0.56 (-1.88, 0.76)	0.002	80.4

GWG gestational weight gain, FBG fasting blood glucose, LGA large for gestational age, BMI body mass index, GDM gestational diabetes mellitus, GI glycaemic index

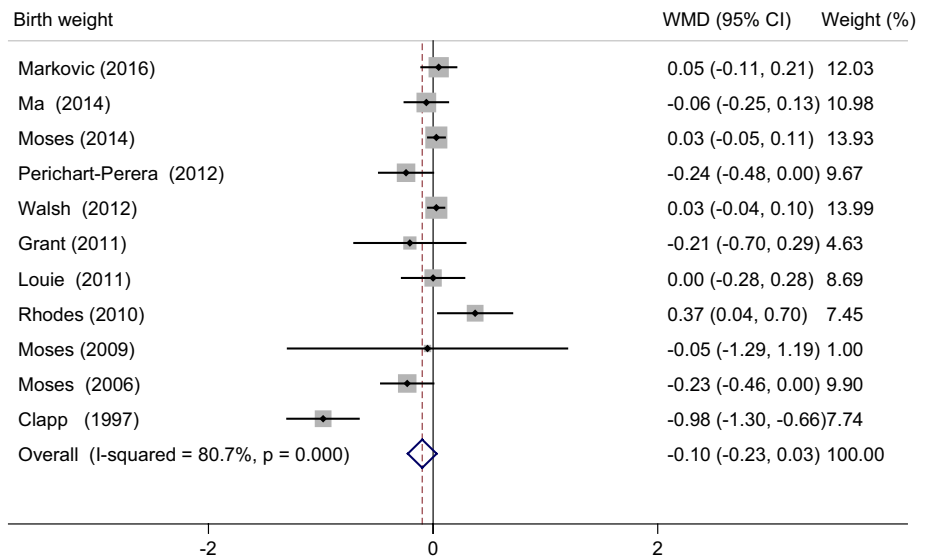
**Fig. 2** Meta-analysis of the effect of low-glycemic-index (GI) diets on gestational weight gain (GWG) as compared to the control. *WMD* weighted mean difference (kg)



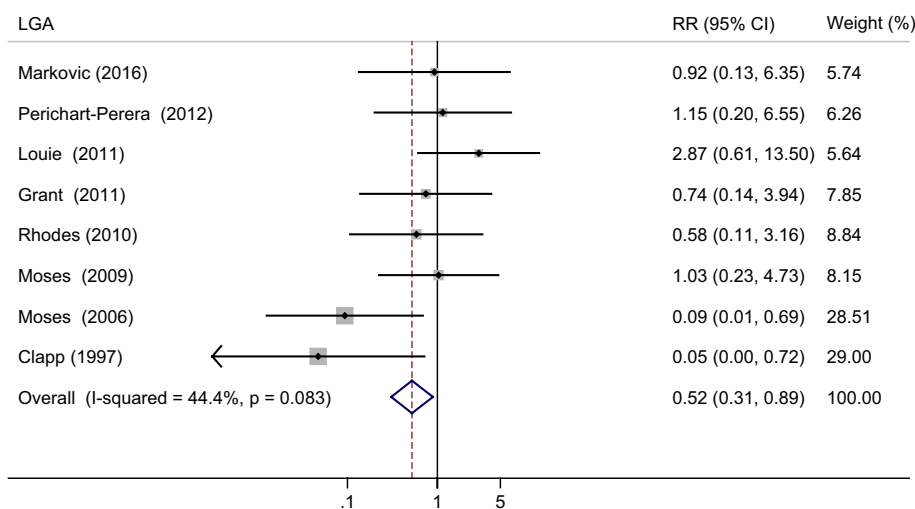
**Fig. 3** Meta-analysis of the effect of low-glycemic-index (GI) diets on maternal fasting blood glucose (FBG) as compared to the control. *WMD* weighted mean difference (mmol/L)



**Fig. 4** Meta-analysis of the effect of low-glycemic-index (GI) diets on newborn birth weight as compared to the control. *WMD* weighted mean difference (kg)



**Fig. 5** Meta-analysis of the effect of low-glycemic-index (GI) diets on proportion of large for gestational age (LGA) as compared to the control. *RR* relative risk



## Discussion

Maternal dietary macronutrient intake throughout pregnancy affects maternal metabolism and in utero environment. As glucose is a major energy substrate for fetal growth, varying degrees of glucose intolerance, even if less than that conventionally required for the diagnosis of gestational diabetes, will result in alterations in utero environment and thus will influence fetal growth and adiposity [28]. Oostdam et al. [29] evaluated six types of intervention during pregnancy in the prevention of GDM using meta-analysis; the results showed that dietary intervention, such as low-GI diet advice, may reduce GDM incidence compared with the standard care. A previous systemic review also reported that low-GI diets may reduce the need for insulin in pregnant women with GDM [6]; this finding was confirmed by a recent meta-analysis [7].

So far, both reviews excluded trials conducted among healthy women and the number of selected trials was less than five. In fact, women with even a mildly elevated blood glucose level have a higher risk of giving birth to a LGA infant [29]. Beneficial effects on birth weight were already observed in pregnant women without GDM after low-GI diets [18]. Thus, in the present updated meta-analysis, we have included participants of healthy pregnant women, women with gestational hyperglycemia, and women with pregestational T2DM. Moreover, the pregnancy outcomes in the present meta-analysis included 7 maternal and 11 newborn outcomes, which were more comprehensive than the previous relevant studies.

Maternal hyperglycemia and hyperglycemic excursions (during fasting, after a glucose load, and postprandial) could lead to adverse pregnancy and offspring outcomes [30–32]. By definition, a low-GI diet is expected to lower postprandial glucose when glucose load is controlled. A recent trial found that glucose levels after breakfast, lunch,

and dinner in pregnant women with GDM were significantly lower after administering low-GI staple diets than those after providing normal diabetic control diet. This trial was not included in the present study because it is a short-term intervention with no other outcomes evaluated [33]. The present meta-analysis showed a significant reduction in FBG by 0.18 mmol/L and 2 h PG by 0.33 mmol/L, which suggested the beneficial effects of low-GI diets beyond postprandial glucose. The current results updated the previous meta-analysis including only 3 trials, in which the lowering effect of low-GI diet on maternal FBG was not observed [29]. However, the subgroup analysis revealed that the effects of low-GI diets on FBG diminished when trials were stratified by GDM condition and gestation week at recruitment. This observation may be explained by a low statistical power resulting from the limited number of trials in each subgroup ( $n = 4$ ). It is important to note that the intervention in GDM group usually started after GDM diagnosis around 24–28 weeks, which leaves a very short time window for any intervention. Nevertheless, the minor improvement in circulating blood glucose is effective to reduce excessive newborn weight.

Excessive GWG is considered a risk factor not only for GDM but also for excessive fetal growth [34, 35]. High GWG was related to long-term adverse health outcomes for the mother–newborn pair [36]. Mourtakos et al. [37] found that excessive GWG was associated with a higher risk of greater infant size at birth and a higher BMI status at the ages of 2 and 8 years. Sridhar et al. [38] also demonstrated that GWG outside the recommendations increased the odds of childhood overweight and obesity, independent of several potential confounders, such as birth weight. Thus, gestational weight must be controlled in a rational range. A recent meta-analysis has shown that a low-GI diet promoted weight loss in overweight or obese people [39]. Therefore, a low-GI diet may also provide benefits



to weight management during pregnancy. Dietary interventions have shown the greatest reduction in gestational weight gain compared to other methods. Although reduced GWG did not reach significant in the present meta-analysis, the low-GI diets significantly decreased GWG by 0.99 kg compared with the control group when the study of Moses et al. [17] was excluded. Moses study was the source of heterogeneity in GWG analysis, and low-GI diet caused higher GWG compared with the control group. However, that result may be wrested by the significant lower BMI in the low-GI diet group than in the control group (24.4 vs. 26.6 kg/m<sup>2</sup>,  $P = 0.04$ ). A recent 6-month randomized trial conducted on women with previous GDM found that subjects in the low-GI group lost an average of 1.3 kg compared with the 0.1 kg in the conventional healthy dietary recommendation [40]. The present analysis revealed inconsistent results on GWG and FBG, suggesting that the effects of low-GI diets on GWG and FBG appeared to be related to study design and characteristics of participants. This result was consistent with previous meta-analysis on patients with GDM [7].

In theory, reduced FBG by low-GI diet in the present meta-analysis could decrease newborn birth weight. Horan et al. [28] found that low-GI dietary intervention in pregnancy had a beneficial effect on neonatal central adiposity as determined using the ratio of waist to length. The maternal dietary GI even affects childhood health. Okubo et al. [41] found that maternal dietary GI in early pregnancy was positively associated with fat mass at 4 and 6 years of age. In the present meta-analysis, a borderline significant reduction in birth weight of 0.12 kg was observed. In a previous meta-analysis on 4 trials, low-GI diets reduced the newborn birth weight (WMD  $-0.16$  kg, 95 % CI:  $-0.25$ ,  $-0.08$ ) compared with control diets in pregnant women with GDM [7]. However, in the present subgroup for women with GDM with recent trials added, the reduction in newborn weight was still retained in borderline significance. In fact, the disadvantage of birth weight reduction should be considered, particularly in pregnant women who are underweight, at nutritional risk, or from a low-income country. Participants in the included trials did not suffer from apparent malnutrition. Thus, the issue of low birth weight did not fall within the scope of this study. Besides, women exhibited reduced risk of having an LGA infant after administering with low-GI diets in the present meta-analysis, which is consistent with Oostdam et al. [29]. In addition to the borderline significant reduction in birth weight and LGA, low-GI diets minimally affected the other 9 newborn outcomes. The current results were generally consistent with these of previous studies, in which no effects were observed in the majority of outcomes. However, Viana et al. [7] found that pregnant women with GDM used insulin less frequently. The partial discrepancy among these meta-analysis results

could be related to a relative small number of trials and low quality of evidence.

Some observational epidemiological studies also supported the present findings. A prospective cohort study on 13,110 eligible women in the Nurses' Health Study II found that women whose dietary GI was higher than 57 units had a 30 % increased risk of developing GDM compared with participants whose dietary GI was lower than 51 units [42]. A cohort including 1082 gravidas in the Camden Study found that GI was positively and significantly related to maternal plasma glucose, HbA1c, and infant birth weight [43]. A recent prospective cohort study during the 10 years of follow-up has shown that higher intake of nuts, which are typical low-GI food sources [44], was associated with a significantly lower risk of GDM by 27 % as a result of improved insulin sensitivity [45]. These results highlighted the clinical importance of dietary sources in assessing the health effects of low-GI diets.

The current meta-analysis was primarily limited by considerable heterogeneity across studies, such as the main outcomes of GWG and FBG and birth weight, which complicated the interpretation of the findings. The heterogeneity can be attributed to study design and characteristics of participants. Most included RCTs used an open-label design. As such, blinding of the treatment to the participants or investigator is difficult, perhaps impossible, because of the nature of dietary intervention/advice design. More importantly, the methods of intervention and control may be the source of heterogeneity. Regarding intervention, these RCTs differed in values of dietary GI and sometimes in co-interventions. For example, all participants in the Clapp study participated in an exercise program before and after pregnancy, which may reinforce the effect of the dietary intervention [18]. On the other hand, three studies declared that low-GI diets for intervention were supported or supplied by relevant companies [13, 15, 16]. Regarding control, high-GI dietary advice [14, 16–18] or low-fat dietary advice [15] was used in some trials. In general, high-GI diets, rather than normal diets, are the dominant diet in individuals living in the Western industrialized societies [27]. Other limitations, which also resulted in heterogeneity, included different criteria for screening and diagnosis of GDM, start of counseling in first or second trimester, and frequency of counseling that varied from twice only to weekly during pregnancy. Finally, the SDs of the net changes were not available in some trials. SDs were derived from the standard errors, median and interquartile ranges, or standard deviations for the initial and final values. These methods employed may not be ideal and result in some inaccuracies.

Based on the current available evidence, we concluded that low-GI diets may have beneficial effects on maternal outcomes without causing adverse effects on newborn

outcomes in general pregnant women. The risk of adverse pregnancy outcomes can be reduced by low-GI dietary intervention because of the controlled maternal blood glucose level. However, the results should be interpreted with caution because of the evidence of heterogeneity across studies, possible publication bias, and limited number of studies. Hence, large, well-designed, intervention RCTs must be conducted on pregnant women to address the effects of low-GI diets on pregnancy outcomes.

#### Compliance with ethical standards

**Conflict of interest** Irma Silva-Zolezzi is employee of Nestlé Research Center, Lausanne. Gerard Vinyes Parés and Yi Wang are employees of Nestlé Research Center Beijing. The authors state that there is no conflict of interest.

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