REVIEW

Western Dietary Patterns, Foods, and Risk of Gestational Diabetes Mellitus: A Systematic Review and Meta-Analysis of Prospective Cohort Studies

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ABSTRACT

An increasing number of epidemiological studies suggest that adherence to Western dietary patterns (WDPs) is associated with risk of gestational diabetes mellitus (GDM), but results remain inconsistent. Therefore, we conducted a systematic review and meta-analysis of the effect of WDPs and typical Western dietary foods on GDM. A literature search was performed in PubMed, Embase, Web of Knowledge, and the Cochrane Library up to December 2019. Cohort studies investigating the combined associations of WDPs with incidence of GDM were included. Reviewers were paired, and they independently reviewed and assessed studies, extracted data, and evaluated study quality. Pooled HRs were calculated using random-effects models. Heterogeneity and publication bias tests were also conducted. Twenty-one prospective cohort studies with 191,589 participants, including 12,331 women with GDM, were included in our analysis. The pooled risk ratio (RR) of WDPs was 1.52 (95% CI: 1.21, 1.91), indicating a significant association with GDM risk in Western countries. Potatoes (pooled RR: 1.12; 95% CI: 0.93, 1.35) showed a nonsignificant ($P > 0.05$) relation to GDM risk. However, consumption of animal meat (pooled RR: 1.35; 95% CI: 1.16, 1.57) and fast food (pooled RR: 1.75; 95% CI: 1.41, 2.19) showed a positive association with the risk of developing GDM. Subgroup analysis demonstrated that the consumption of red meat and processed red meat increased the risk of GDM more than either poultry or fish intake. Our study provides further evidence for understanding the relation between dietary factors and increased GDM risk and contributes to reducing the incidence of GDM through healthy diets. *Adv Nutr* 2021;12:1353–1364.

Keywords: Western dietary pattern, gestational diabetes mellitus, typical Western dietary foods, fast food, red meat, potatoes

Introduction

Gestational diabetes mellitus (GDM), defined as any degree of glucose intolerance with onset or first recognition during pregnancy (1), is one of the most common metabolic disorders and medical complications during pregnancy. It has been estimated that GDM affects almost 1–15% of women worldwide, with the number of women affected increasing during the past decade (2, 3). According to the International Diabetes Federation, in 2013, >1 million pregnant women in China had GDM and >18.4 million pregnant women had GDM worldwide (4, 5). GDM can potentially impact the health outcome of both the mother and the fetus during pregnancy, delivery, and beyond. For pregnant women with GDM, the risks for pregnancy-induced hypertension, intrahepatic cholestasis during pregnancy, premature rupture of membranes, cesarean section, and postpartum hemorrhage are all increased (6, 7). Some cohort studies have also shown that GDM patients have a high risk of developing type 2 diabetes mellitus later in life (5, 8). For infants, the risks for preterm birth, newborn asphyxia, obesity, type 2 diabetes, and chronic kidney diseases later in life are also greatly increased (6, 9). Considering the high prevalence of GDM, its annual increasing trend, and its impact on both the short-term and the long-term health of mothers and their

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Supplemental Tables 1 and 2 and Supplemental Figures 1–4 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/advances.

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Abbreviations used: AGE, advanced glycation end product; GDM, gestational diabetes mellitus; IR, insulin resistance; NOS, Newcastle–Ottawa Scale; RR, risk ratio; WDP, Western dietary pattern.

offspring, GDM has become an important public health issue (6, 9, 10).

Although the pathogenesis of gestational diabetes is unclear, current studies suggest that it is a complex disease with a combination of genetic and environmental factors (11). Interest is growing in predicting which women will develop GDM, given that early detection and intervention can greatly improve outcomes for both mother and child. Known risk factors increasing the risk of GDM include increased maternal age, obese or overweight mothers, prior history of GDM, family history of type 2 diabetes, and history of previous fetal death (2, 3). In addition, with increased overall socioeconomic status, physical activity has decreased, and food intake has changed from low-energy, high-fiber foods to high-energy, high-fat, and high-sugar foods with increased processing (12). These changes in lifestyle and eating habits are undoubtedly and significantly related to the increased risk of GDM (13, 14). As a result, the correlation between micronutrients, or certain types of foods such as vitamin D, eggs, meat, and fruit, and GDM has received widespread attention from researchers (14, 15).

Dietary patterns reflect the dietary habits of people. Currently, Western dietary patterns (WDPs) are popular in both Eastern and Western countries (12, 16). However, substantial evidence from epidemiological and clinical studies has shown that WDPs, defined as high intake of red meat, processed meat, refined grain products, sweets, fast food, and French fries (14, 17), have been associated with increased risk for several diseases, such as type 2 diabetes, obesity, metabolic syndrome, and coronary heart disease (17, 18). However, current research findings on WDPs and the risk of GDM are inconsistent. To our knowledge, there has been no systematic review and meta-analysis of WDPs and the risk of GDM.

Therefore, the aim of this systematic review and meta-analysis was to investigate the association between WDPs, typical Western foods (animal meat, potatoes, and fast food), and the risk of GDM in an effort to better understand and prevent GDM.

Methods

This systematic review and meta-analysis was registered at PROSPERO as CRD42020162109 and conducted according to the guidelines of the Meta-analysis Of Observational Studies in Epidemiology group (19).

Search strategy

Relevant literature was searched for in PubMed, Embase, MEDLINE, Web of Knowledge, and the Cochrane Library within a range of published years from January 1980 to December 2019, limited to studies published in the English language. The following MeSH terms were used: "pregnancy-induced diabetes," "gestational diabetes," "gestational diabetes mellitus," "Western diets," "Western dietary pattern," "dietary pattern," "Occidental diets," "meat-sweet diet," "fast food," "convenience food," "ready to eat foods," "ready prepared foods," "meat," "meat protein," "poultry," "fish," "red meat," "pork," "beef," "processed red meat," "meat products," "potato," "French fried," "fried chips," and "boiled potato." In addition, we set an e-mail alert in databases and journals to receive notifications for any newly published papers. Unpublished data, conference papers, editorials, theses, and patents were not included. Furthermore, to search for more studies, we also hand-checked the reference lists of original publications and previous meta-analyses or reviews.

Study selection

Two investigators (CX and YJ) independently reviewed and assessed the publications on the basis of titles and abstracts and then assessed the full text according to the following inclusion criteria: *1*) original studies with prospective cohort design (because the data from randomized trials were limited and the results from prospective cohort studies have been inconsistent); *2*) the study was published in the English language; *3*) the exposure of interest was Western diet and Western dietary foods; *4*) the outcome of interest was GDM; and *5*) multivariate-adjusted relative risk or HRs with corresponding 95% CIs were reported. Studies that did not meet the inclusion criteria were excluded during the initial review. When uncertainty existed during the abstract review, we retrieved and assessed the full-text article. Two reviewers (ZW and GL) resolved any uncertainty through discussion. If duplicate reports from the same study cohort were identified, only the most recent publication with the most detailed information or the study with the largest population was included.

Data extraction

Two investigators (CX and YJ) extracted the data, including first author's name; year of publication; country; duration of follow-up; age range; name of cohort studies; number of participants and incident cases; diagnostic method and criteria of GDM; dietary assessment method and period; food items; multivariate-adjusted risk (HR or RR with the corresponding 95% CI) estimate that compared the highest with the lowest quantiles, which represent the highest and poorest adherence to the WDPs or foods, respectively; and confounding factors of interest. If a study provided data from different time points, only data from the most recent time point were used.

Quality assessment

The Newcastle–Ottawa Scale (NOS) (20) adapted for cohort studies was used by 2 investigators (ZW and WQ) to assess the quality of the included articles. The NOS consists of rating 3 major characteristics: the selection process of the cohort (4 points), if adjustments for known confounding factors were performed (2 points), and the diagnostic method and criteria of exposure or outcome (3 points). Studies with a NOS score of $\geq$5 points were considered as of high quality.

Statistical analysis

Multivariate-adjusted RRs or HRs were used to estimate the association between consumption of WDPs or Western foods and the risk of GDM (all eligible studies adopted

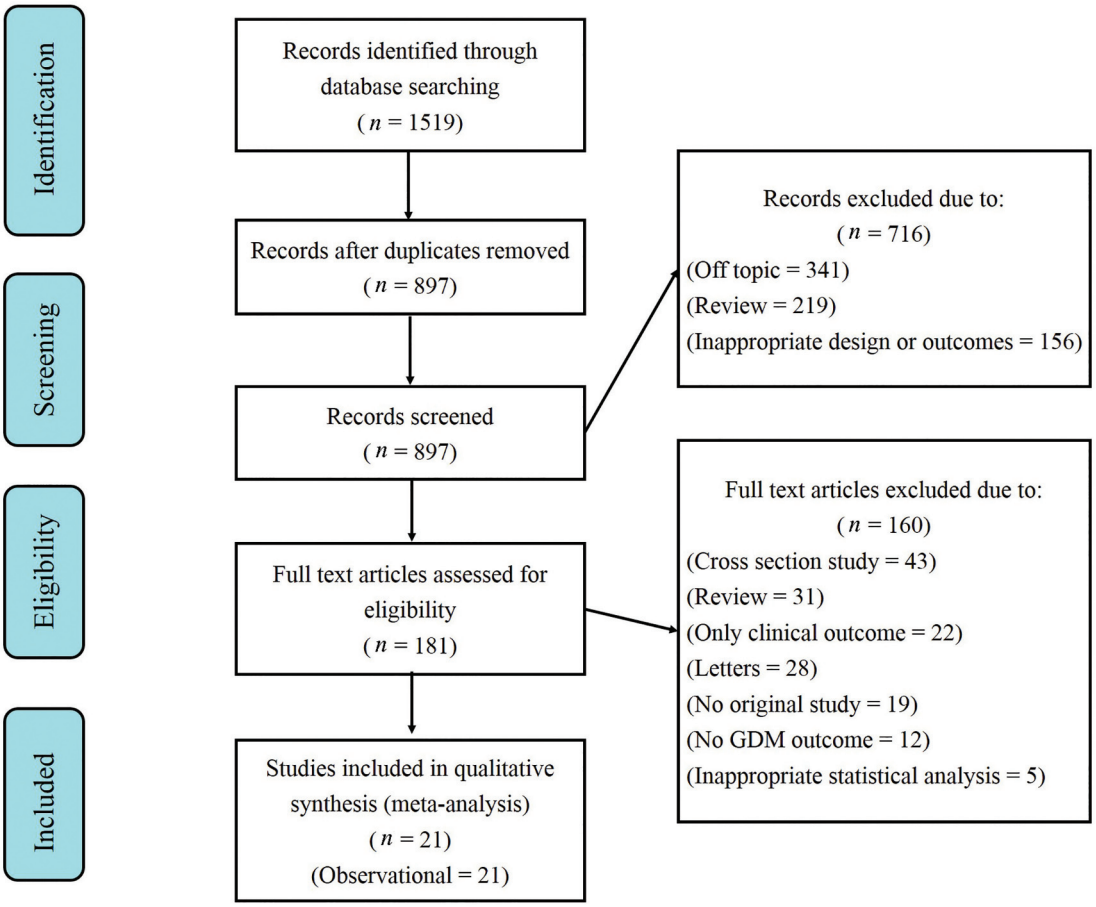

FIGURE 1 Flow diagram of prospective observational studies of Western dietary patterns and incident GDM. GDM, gestational diabetes mellitus.

Cox proportional hazards models, so HRs were identical to RRs expressing their association). Moreover, these values were transformed by taking their natural logarithms and calculating their SEs and corresponding 95% CIs. Because of unexplained heterogeneity between studies, the pooled RRs were computed using the random-effects model to summarize the effect within and between included studies.

For each outcome, a heterogeneity test was carried out using Cochrane Q test and I^2 statistics. For the Q statistic, $P < 0.1$ was considered to be statistically significant. For the I^2 statistic, I^2 scores $\geq$50% were considered as indicating the presence of between-study heterogeneity. If there was substantial heterogeneity, we performed prespecified subgroup analyses on the basis of the quality score of the study (quality score <5 compared with $\geq$5), dietary assessment period (prepregnancy and early pregnancy compared with midpregnancy), study area (United States, China or Asia, and Europe and America), type of meat (red meat and processed red meat compared with poultry and fish), and the number of study cases ($\leq$3000, 3001–10,000, and $\geq$10,001 cases) because these were thought to be possible sources of heterogeneity.

Furthermore, potential publication bias was investigated using funnel plots. Sensitivity analysis was performed to estimate the robustness of the results by omitting 1 study at each stage to determine if an individual study or a group of studies had considerable influence on our results. All statistical analyses were performed using Stata software, version 14.0 (Stata Corp) and Review Manager software, version 5.3 (The Cochrane Collaboration), with the level of significance at $P < 0.05$ unless explicitly stated otherwise.

Results

The flowchart for study selection is shown in **Figure 1**. Overall, 1519 potentially relevant records were identified, of which 1489 records were identified through database searching, whereas 30 records were included by checking the reference lists of identified reports. However, 622 records were removed because of duplication. Therefore, 897 articles remained for further screening of titles and abstracts. After investigating the articles by their titles and abstracts, 716 more articles were excluded, and 181 articles were eligible for detailed full-text assessment. Of these, we excluded 160 articles due to the following reasons: letter article,

cross-sectional study, review article, clinical trial, not an original study, inappropriate statistical analysis, and the study outcome was not GDM. Finally, a total of 21 published articles were included in this systematic review and meta-analysis.

Study characteristics

The characteristics of the studies included in the systematic review and meta-analysis are presented in **Table 1**. Twenty-one articles with 191,589 participants and 12,331 cases of GDM were included in this systematic review and meta-analysis (**Supplemental Table 1**). All studies were published between 2006 and 2018. Eight articles were conducted in the United States (14, 21–27), 5 in China (28–32), 4 in European countries (33–36), 1 in Australia (37), 1 in Singapore (38), and 2 in Iran (39, 40). The age of the participants ranged from 17 to 45 y. Study follow-up periods ranged from 0.3 to 20 y. Dietary intake information was collected using validated semiquantitative FFQs in most studies. Liang et al. (30) and He et al. (29) adopted FFQs combined with 24-h dietary recall, and 1 study used a 4-d weighed food record (36). Information regarding the validation of FFQs is provided in **Supplemental Table 2**. The outcome of GDM was identified by the oral-glucose-tolerance test or self-reported questionnaire. The American Diabetes Association criteria were used by most studies for the diagnosis of GDM (21–26, 39, 40). However, 8 studies adopted the diagnosis criteria from the International Association of Diabetes and Pregnancy Study Groups (28, 29, 31, 32) or formal national diabetes data groups (14, 33–35), respectively. Eight studies conducted dietary assessment at early pregnancy, and 2 studies did so at midpregnancy; the remaining 11 studies were all conducted prepregnancy during the year prior to conception. Adjustments for potential confounding factors such as age, BMI, dietary intake of energy, physical activity, and family history of type 2 diabetes were made. Moreover, the quality assessment and the quality scores carried out on all the studies ranged from 3 to 8 (Supplemental Table 2). Sixteen studies were classified as of high quality (quality score $\geq$5), and the remaining 5 studies were of low quality (quality score <5).

Western diet consumption and risk of GDM

The effect of adherence to WDPs and the intake of typical Western foods on GDM risk is shown in **Figure 2**. Five independent cohort studies based on WDPs were included, and the pooled RR of 1.31 (95% CI: 0.99–1.74) indicated no significant ($P > 0.05$) association between WDPs and GDM risk, with a significant between-study heterogeneity ($I^2 = 63\%$, $P = 0.03$). Another 5 studies reported that consumption of potatoes showed no significant ($P > 0.05$) association with GDM risk, but there was between-study heterogeneity (pooled RR: 1.12; 95% CI: 0.93, 1.35; $I^2 = 74\%$). In contrast, the pooled RR from the random effects model for 11 studies showed that animal meat consumption significantly ($P < 0.05$) increased the risk of GDM (pooled RR: 1.35; 95% CI: 1.16, 1.57; $I^2 = 65\%$). In addition, fast food consumption was considered in 4 studies; the pooled RR of 1.75 (95% CI: 1.41, 2.19) indicated that fast food also had a significant effect ($P < 0.05$) on GDM risk, although without significant heterogeneity ($I^2 = 0\%$).

Publication bias and sensitivity analysis

We found no evidence of publication bias by visual inspection of the funnel plot (**Supplemental Figure 1**). Sensitivity analysis was conducted by sequentially excluding each study, one at a time, and the deletion of any study showed no significant change in the pooled RR, indicating robust results.

Subgroup analyses

Significant heterogeneity was found among WDPs, potatoes, and animal meat intake and GDM risk; therefore, further subgroup analyses were performed. For WDPs intake (**Table 2**, **Supplemental Figure 2**), subgroup analysis was stratified by number of study cases, dietary assessment period, and study area. Results indicated that WDPs intake was significantly ($P < 0.05$) associated with risk of GDM in studies with more cases, from European countries and the United States, and when dietary assessment was performed during the prepregnancy period (pooled RR: 1.52; 95 CI%: 1.21, 1.90; $I^2 = 0\%$). For potato intake (**Table 3**, **Supplemental Figure 3**), subgroup analyses were stratified by number of study cases and quality score of the study. The results shown in Table 3 indicate that potato intake had significant association ($P < 0.05$) with risk of GDM in high-quality studies (pooled RR: 1.45; 95% CI: 1.02–2.05), despite significant heterogeneity ($I^2 = 61\%$). Subgroup analysis for animal meat consumption (**Table 4**, **Supplemental Figure 4**) was also stratified by number of study cases, dietary assessment period, quality score of study, and study area. Similarly, as shown in Table 4, the pooled RR reflected that animal meat intake was positively associated with GDM risk in studies conducted in the United States (pooled RR: 1.49; 95% CI: 1.33–1.68; $I^2 = 0\%$), number of study cases >10,000 (pooled RR: 1.47; 95% CI: 1.29–1.66; $I^2 = 0\%$), studies with high-quality score (pooled RR: 1.45; 95% CI: 1.22–1.72; $I^2 = 63\%$), and dietary assessments conducted during the prepregnancy period (pooled RR: 1.48; 95% CI: 1.31–1.66; $I^2 = 0\%$). In addition, the type of animal meat was also considered; the pooled RRs indicated that red meat (pooled RR: 1.72; 95% CI: 1.48–2.00; $I^2 = 0\%$) and processed red meat (pooled RR: 1.68; 95% CI: 1.38–2.05; $I^2 = 0\%$) were both significantly associated ($P < 0.05$) with increased GDM risk.

Overall, in subgroup analysis, several factors—including number of study cases, study quality score, dietary assessment period, study area, and type of animal meat—are potential sources of heterogeneity. GDM was positively associated with WDP foods in studies of high quality, with a large number of cases, and dietary assessments conducted during prepregnancy in the United States or European countries, wherein participants consumed primarily red or processed red meat.

TABLE 1 Characteristics of included cohort studies[1]

Study, year (Ref)	Reference country	Study name	Age, y	Follow-up, y	Food	Size/cases, *n*	Assessment of GDM	Dietary assessment method	Method used to identify dietary pattern	Dietary assessment period	Covariate adjustments[2]	Quality score
Goshtasebi et al., 2018 (39)	Iran	Tehranian women	18–45	NA	Potato	1026/71 (ADA)[3]	OGTT	FFQ	NA	Early pregnancy	3, 5, 9, 12, 18, 36, 37	3
Bao et al., 2016a (24)	United States	Nurses' Health Study II	22–44	20	Animal meat	68,897/4502 (ADA)	Questionnaire self-report and medical records	FFQ	Factor analysis	Prepregnancy over the previous year	1, 4, 5, 6, 7, 8, 9, 10, 12, 13, 23, 38	8
Bao et al., 2013 (21)	United States	Nurses' Health Study II	25–44	10	Animal meat	15,294/870 (ADA)	Questionnaire self-report	FFQ	NA	Prepregnancy over the previous year	1, 4, 6, 7, 9, 10, 12, 14, 18, 19, 20, 23, 29, 30, 31, 36	8
Bao et al., 2014a (22)	United States	Nurses' Health Study II	25–44	10	Fried food	15,027/847 (ADA)	Questionnaire self-report	FFQ	NA	Prepregnancy over the previous year	1, 4, 6, 8, 9, 12, 14, 17	7
Bao et al., 2016b (25)	United States	Nurses' Health Study II	25–44	10	Potato	21,693/854 (ADA)	Questionnaire self-report	FFQ	Factor analysis	Prepregnancy over the previous year	1, 4, 6, 8, 9, 12, 14, 17	7
Liang et al., 2018 (30)	China	NPGSC study	Mean = 26.5	3	Animal meat	6299/1203 (CMH)	OGTT	FFQ and 24-h dietary recall	NA	Prepregnancy and early over the previous year	1, 4, 6, 8, 9, 11, 12, 29, 30, 31, 33	6
He et al., 2015 (29)	China	BIGCS	Mean = 28.9	NA	Animal protein	3063/644 (IADPSG)	OGTT	FFQ and 24-h dietary recall	Principal component analysis	Midpregnancy	1, 3, 6, 11, 12, 17	5
Lamyian et al., 2017 (40)	Iran	Tehranian women study	18–45	1.4	Fast food	1026/71 (ADA)	OGTT	FFQ	NA	Early pregnancy	1, 3, 6, 9, 12, 16, 18, 36, 37	5
Mak et al., 2018 (31)	China	NA	18–40	0.3	Animal meat	1337/199 (IADPSG)	OGTT	FFQ	Exploratory factor analysis	Midpregnancy	1, 3, 4, 6, 7, 12	4
Marí-Sanchis et al., 2018 (35)	Spain	SUN project[4]	28	3	Animal meat	3298/172 (FNDG)	OGTT and medical record	FFQ	NA	Prepregnancy over the previous year	1, 2, 6, 7, 8, 9, 12, 15, 17, 18, 27, 32	7
Zhou et al., 2018 (32)	China	TMCHC study	17–45	NA	Animal meat	2775/248 (IADPSG)	OGTT	FFQ	Principal component analysis	Early pregnancy	1, 3, 4, 6, 8, 9, 10, 11, 12, 16, 17, 35	6
Osorio–Yáñez et al., 2017 (26)	United States	Omega study	33	NA	Fried food	3414/169 (ADA)	OGTT	FFQ	NA	Early pregnancy	1, 3, 4, 7, 9, 10, 12, 18, 19, 24, 25, 27	6
Tryggvadottir et al., 2016 (36)	Iceland	NA	18–40	1.5	French fries	168/17 (WHO)	OGTT	4-d weighed food record	Principal component analysis	Early pregnancy	1, 4, 6, 16	3
Zhang et al., 2006 (14)	United States	Nurses' Health Study II	25–44	8	Western dietary	13,110/758 (FNDG)	Questionnaire self-report	FFQ	Factor analysis	Prepregnancy over the previous year	1, 4, 6, 8, 9, 10, 12, 14	8
Bao et al., 2014b (23)	United States	Nurses' Health Study II	25–44	10	Animal meat	13,110/758 (ADA)	Questionnaire self-report	FFQ	Factor analysis	Prepregnancy over the previous year	1, 4, 6, 8, 9, 10, 12, 14	7

(*Continued*)

TABLE 1 (*Continued*)

Study, year (Ref)	Reference country	Study name	Age, y	Follow-up, y	Food	Size/cases, *n*	Assessment of GDM	Dietary assessment method	Method used to identify dietary pattern	Dietary assessment period	Covariate adjustments[2]	Quality score
Dominguez et al., 2014 (33)	Spain	SUN project	28	12	Fast food	3048/159 (FNDG)	Questionnaire self-report	FFQ	NA	Prepregnancy over the previous year	1, 4, 6, 7, 8, 9, 10, 12, 15, 17, 18, 27	6
Donazar-Ezcurra et al., 2017 (34)	Spain	SUN project	25–33	10.3	Western dietary	3455/173 (FNDG)	Questionnaire self-report	FFQ	Factor analysis	Prepregnancy over the previous year	1, 2, 6, 7, 8, 12	5
Schoenaker et al., 2015 (37)	Australia	Australian Longitudinal Study	18–23	9	Western dietary	3853/292 (NA)	Questionnaire self-report	FFQ	Factor analysis	Prepregnancy over the previous year	1, 2, 4, 6, 7, 8, 9, 15, 33	6
Du et al., 2017 (28)	China	NA	28	NA	Western dietary	757/64 (IADPSG)	OGTT	3 d 24-h dietary recalls	Factor analysis	Early pregnancy	1, 3, 4, 6, 7, 8, 9, 12	4
De Seymour et al., 2016 (38)	Singapore	GUSTO study	31	NA	Western dietary	909/160 (NA)	OGTT	3 d 24-h dietary recalls	Factor analysis	Early pregnancy	1, 2, 3, 4, 6, 8, 8, 10, 11, 17, 37	5
Radesky et al., 2008 (27)	United States	Project viva[5]	18–40	NA	Animal meat	1733/91 (NA)	OGTT	FFQ	Factor analysis	Early pregnancy	1, 2, 4, 6, 8, 37	4

[1] BIGCS, Born in Guangzhou Cohort Study; GDM, gestational diabetes mellitus; GUSTO, Growing Up in Singapore Towards Healthy Outcomes; NA, not available; NPGSC, Nutrition in Pregnancy and Growth in Southwest China; OGTT, oral-glucose-tolerance test; TMCHC, Tongji Maternal and Child Health Cohort.

[2] Covariate adjustments: 1, age; 2, number of pregnancies; 3, education; 4, race; 5, menopausal status; 6, BMI; 7, physical activity; 8, smoking; 9, dietary intake of energy; 10, alcohol; 11, income; 12, family history of diabetes; 13, oral contraceptive use; 14, physical activity; 15, hypertension; 16, weight gain; 17, diet quality score; 18, total fiber; 19, meat; 20, vegetables; 21, legumes; 22, fruits and nuts; 23, glycemic index; 24, dietary vitamin D intake; 25, fish; 26, eggs; 27, sugar and confectioneries (sweets); 28, nonalcoholic beverages; 29, saturated lipids; 30, monounsaturated lipids; 31, polyunsaturated lipids; 32, heme iron intake; 33, polycystic ovary syndrome; 34, job; 35, family history of obesity; 36, total cholesterol intake; 37, history of GDM; 38, age at first birth.

[3] Diagnostic criteria: ADA, American Diabetes Association (21–26, 39, 40); CMH, Chinese Ministry of Health (30); FNDG, The formal National Diabetes Data Group (14, 33–35); IADPSG, International Association of Diabetes and Pregnancy Study Groups (28, 29, 31, 32); WHO (36).

[4] The SUN project is a prospective dynamic cohort study entirely composed of university graduates.

[5] Project viva is a prospective cohort study of pregnant women and their children.

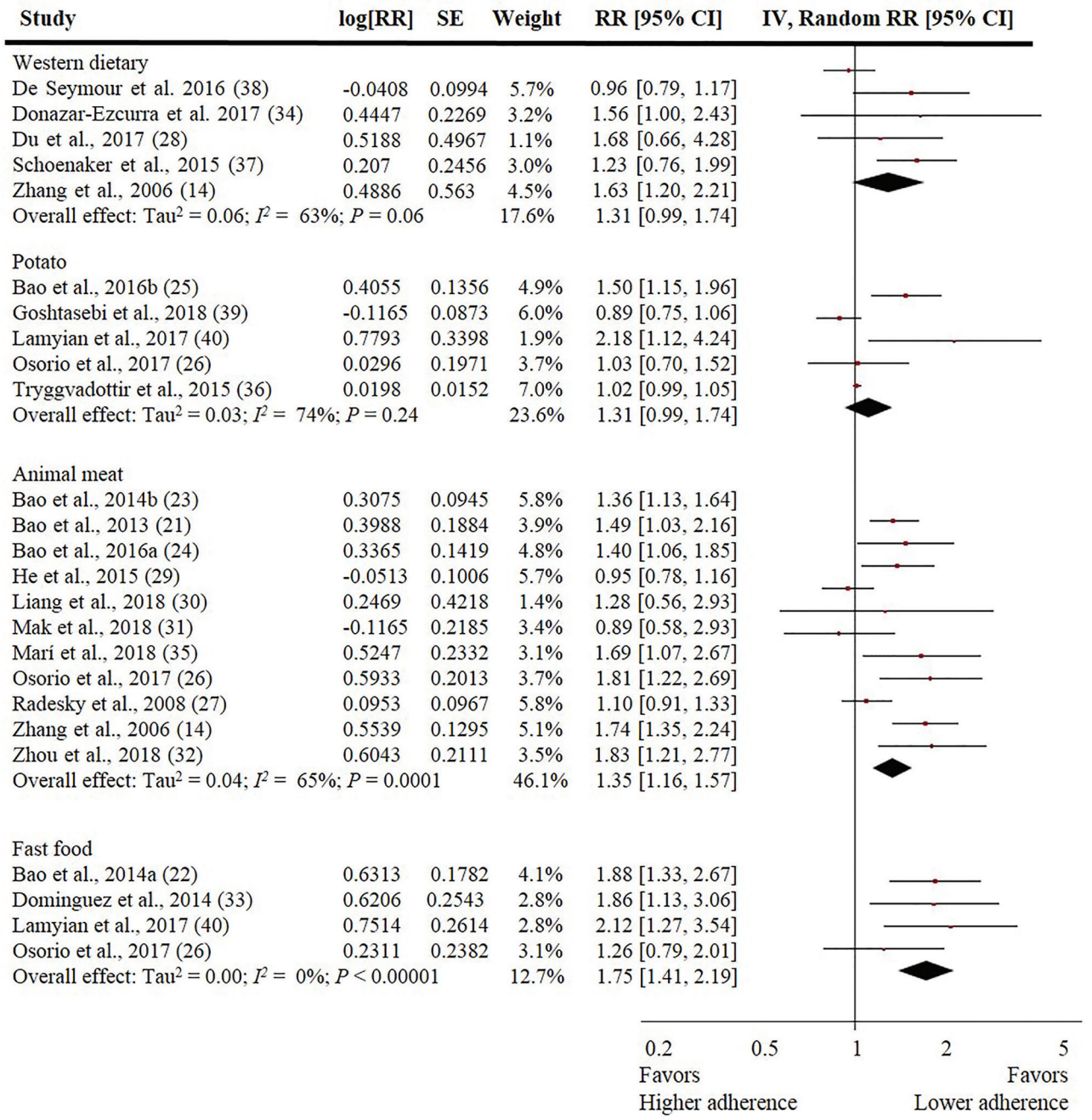

FIGURE 2 Forest plot of studies examining the association between Western dietary patterns and risk of gestational diabetes mellitus in pregnant women. IV, Inverse Variance methods.

Discussion

This study is the first systematic review and meta-analysis assessing the relation between the consumption of WDPs or typical Western foods and the risk of GDM. Among the included studies, 14 showed that red meat or fast food consumption is significantly ($P < 0.05$) related to increased risk of GDM, whereas no significant ($P > 0.05$) association was found between the consumption of potatoes or adherence to a WDP and GDM risk.

WDPs are generally known as unhealthy, characterized by a high consumption of red meat, processed meat, fast food, refined grains, and other energy-dense foods (14, 34). Many studies have shown that WDPs may increase the risk of many chronic diseases, such as cardiovascular disease, diabetes, and obesity (17, 18). To date, many prospective cohort studies have suggested that adherence to WDPs is associated with higher risk of type 2 diabetes (18), which shares some pathophysiological similarities with GDM.

TABLE 2 Subgroup analyses of Western dietary intake and RR of gestational diabetes mellitus[1]

Variables	Cases, *n*	RR (95% CI)	Test of heterogeneity[2]		*P*[3]
			P	I^2, %	
Study case, *n*					
≥3001	2	1.05 (0.70, 1.55)	0.25	24	0.82
≤3000	3	1.52 (1.21, 1.90)	0.62	0	<0.01
Dietary assessment period					
Prepregnancy	3	1.52 (1.21, 1.91)	0.62	0	<0.01
Early pregnancy	2	1.05 (0.70, 1.55)	0.25	24	0.82
Study area					
Europe and America	3	1.52 (1.21, 1.91)	0.62	0	<0.01
Asia	2	1.05 (0.70, 1.55)	0.25	24	0.82

[1] I^2, inconsistency; RR, risk ratio.
[2] *P* for heterogeneity was assessed by using Cochran's test, and $P < 0.1$ was considered to indicate significant heterogeneity across studies. The I^2 statistic was calculated by using Cochran's test, and $I^2 > 50\%$ was considered to indicate significant heterogeneity across studies.
[3] *P* for meta-analysis: $P < 0.05$ was considered to indicate a significant effect of Western dietary intake on the risk ratio of gestational diabetes mellitus by using a random-effects model.

Although significant correlations between Western foods and GDM risk were observed in subgroup analysis, our meta-analysis showed no significant association between WDP consumption and GDM risk overall. Differences in the diet habits of individual participants might lead to collective differences in the composition of total food assessed among different studies. Therefore, we performed subgroup analysis to further consider the association of several typical Western foods with GDM risk.

The finding of no significant association between potato consumption and GDM risk is inconsistent with the results of other prospective cohort studies and meta-analyses. This may be due to limited evidence available or the low quality of included studies. Another important possibility is the difference among processing methods of potatoes in the included studies. As such, studies have shown that frequent consumption of French fries or potato chips is associated with increased type 2 diabetes risk, whereas boiled potatoes are inversely associated with risk of type 2 diabetes (41, 42). Further high-quality investigations are required to ascertain the relation between the consumption of potatoes, especially French fries, and GDM risk.

Fast foods are common in WDPs, and the results of our study demonstrated a significant ($P < 0.05$) association between fast food consumption and the risk of GDM. Even if the precise molecular mechanisms are unclear, our findings are still plausible because many prospective cohort studies have reported that frequent fast food consumption is also significantly associated ($P < 0.05$) with an increased incidence of type 2 diabetes (43). Several biological mechanisms have been proposed to explain the detrimental effects of fried food consumption on GDM risk. Of note, *trans*-fatty acids, which are generated during the frying process through polymerization, oxidation, and hydrogenation (41), were demonstrated to lead to insulin resistance and increased risk of type 2 diabetes (44). Moreover, evidence also indicates that higher intake of *trans*-fats may also be associated with greater risk of GDM (26, 33). In addition, the high energy density of fast foods can interfere with the regulation of appetite and cause a significant reduction in sensory-specific satiety,

TABLE 3 Subgroup analyses of potato intake and RR of gestational diabetes mellitus[1]

Variables	Cases, *n*	RR (95% CI)	Test of heterogeneity[2]		*P*[3]
			P	I^2, %	
Study case, *n*					
≥3001	2	1.28 (0.89, 1.84)	<0.1	59	0.19
≤3000	3	1.08 (0.85, 1.36)	<0.1	81	0.04
Study quality					
High quality (≥5)	3	1.45 (1.02, 2.05)	<0.1	61	0.04
Low quality (<5)	2	0.98 (0.87, 1.11)	0.12	58	0.73

[1] I^2, inconsistency; RR, risk ratio.
[2] *P* for heterogeneity was assessed by using Cochran's test, and $P < 0.1$ was considered to indicate significant heterogeneity across studies. The I^2 statistic was calculated by using Cochran's test, and $I^2 > 50\%$ was considered to indicate significant heterogeneity across studies.
[3] *P* for meta-analysis: $P < 0.05$ was considered to indicate a significant effect of potato intake on the RR of gestational diabetes mellitus by using a random-effects model.

TABLE 4 Subgroup analyses of meat intake and RR of gestational diabetes mellitus[1]

Variables	Cases, *n*	RR (95% CI)	Test of heterogeneity[2]		*P*[3]
			P	I^2, %	
Study case, *n*					
≤3000	3	1.20 (0.85, 1.37)	<0.1	69	0.30
3001–10,000	4	1.36 (0.91, 2.03)	<0.1	74	0.13
≥10,001	4	1.47 (1.29, 1.66)	0.48	0	<0.01
Dietary assessment period					
Prepregnancy	6	1.48 (1.31, 1.66)	0.71	0	<0.01
Early pregnancy	4	1.36 (1.02, 1.81)	<0.1	67	0.03
Midpregnancy	3	1.12 (0.77, 1.64)	<0.1	77	0.56
Study quality					
High quality (≥5)	9	1.45 (1.22, 1.72)	<0.1	63	<0.01
Low quality (<5)	2	1.06 (0.89, 1.26)	0.38	0	0.49
Type of meat					
Red meat	3	1.72 (1.48, 2.00)	0.68	0	<0.01
Processed red meat	3	1.68 (1.38, 2.05)	0.61	74	<0.01
Poultry and fish	2	0.95 (0.74, 1.23)	0.82	0	0.70
Study area					
United States	5	1.49 (1.33, 1.68)	0.48	0	<0.01
China	4	1.15 (0.81, 1.63)	<0.1	66	0.43

[1] I^2, inconsistency; RR, risk ratio.
[2] *P* for heterogeneity was assessed by using Cochran's test, and $P < 0.1$ was considered to indicate significant heterogeneity across studies. The I^2 statistic was calculated by using Cochran's test, and $I^2 > 50\%$ was considered to indicate significant heterogeneity across studies.
[3] *P* for meta-analysis: $P < 0.05$ was considered to indicate a significant effect of animal meat on the RR of gestational diabetes mellitus by using a random-effects model.

ultimately leading to increased BMI and insulin resistance (IR) and potentially GDM (40, 45).

The correlation between meat consumption and increased GDM risk is also interesting. Currently, prospective cohort studies indicate that increased red meat consumption leads to IR, β-cell dysfunction, and increased risk of type 2 diabetes (46, 47). Although the detailed underlying mechanisms remain to be elucidated, several potential factors may play important roles. First, although protein may have beneficial effects on energy homeostasis, it has been proposed that high meat protein intake is positively linked to an elevated incidence of type 2 diabetes (21, 48, 49). In addition, a large amount of epidemiological evidence shows that branched-chain amino acids in red meat might lead to the development of IR and increase the risk for type 2 diabetes (50, 51). Second, frequent intake of animal fat such as cholesterol and saturated fat can lead to IR and an increased risk for GDM (30, 50). In addition, heme iron from red meat and high plasma iron concentrations can promote oxidative stress by Fenton reaction and increase the formation of hydroxyl radicals, which can cause IR or even damage pancreatic β-cells and reduce pancreatic insulin secretion over time (35, 48, 52). Moreover, processed red meats are usually treated with nitrites and nitrates that can react with amino compounds and convert into nitrosamines (35, 50). Previous evidence demonstrated that nitrosamines can cause IR by affecting the expression of insulin receptors, inflammation, and oxidative stress levels (48, 53). Furthermore, animal experiments have demonstrated that nitrosamines are poisonous to pancreatic β-cells and increase the risk of type 2 diabetes (54). In contrast, the observed inverse association between poultry or fish consumption and GDM risk was consistent with previous research results. It is thought that this inverse association may be due to the long-chain n–3 fatty acids from fish, which can improve IR and the plasma lipoprotein profile by inhibiting the inflammatory pathway and activating peroxisome proliferator–activated receptors (55). Although the mechanism behind the inverse association between poultry intake and GDM is unclear, we speculate that it may be related to the lower concentrations of heme iron, cholesterol, and saturated fatty acids in poultry meat.

Considering that Western foods are mainly processed using high-temperature techniques such as frying and baking, we speculate that WDPs intake and GDM risk may also be related to the harmful products generated during the Maillard reaction, including advanced glycation end products (AGEs), heterocyclic amines, and acrylamide. Recently, there has been accumulating evidence showing that the consumption of dietary AGEs affected insulin signal and is related to the development of IR and type 2 diabetes (56, 57) because the AGEs promote oxidative stress and inflammation. IR is promoted via increased expression of the receptor for advanced-glycation end products and reduced expression of AGE receptor-1 and sirtuin 1 while affecting insulin signaling via stimulation of protein kinase C and upregulation of TNF (58). In addition, clinical studies have reported that the accumulation of heterocyclic amines and acrylamide is related to increased risk for IR and type 2 diabetes in adults, but the pathogenesis is still unclear

(59, 60). In the future, clinical research and animal models should be performed to explain the relation between the Maillard reaction's harmful products and increased GDM risk.

Strengths and limitations

The strengths of our systematic review and meta-analysis are the number of included prospective cohort studies with large sample sizes, the fact that the RRs were adjusted for various confounders, and the fact that GDM cases were diagnosed by international diagnostic criteria. However, some limitations that could have affected the results must be mentioned. Typically, a limitation of this meta-analysis in cohort studies is that a causal link between GDM and WDPs cannot be inferred from correlations. Second, measurement errors and misclassifications are inevitable when estimating food consumption by FFQ or 24-h dietary recall. Third is the lack of specific information on WDPs because the amount of food consumed in Western diets tends to vary between and within populations. Fourth, the quality scores for some included studies were low. Furthermore, although the RRs of included studies were adjusted, residual confounding could not be completely excluded from our results. Finally, the number of comparisons performed increases the risk of making a type I error.

Conclusions

Our systematic review and meta-analysis has shown that adherence to a WDP before pregnancy is significantly associated with increased GDM risk. Consumption of several typical Western foods, such as red meat, processed red meat, and fast food, during the pre- or early pregnancy periods was also significantly associated with GDM, whereas both poultry and fish intake were inversely associated with GDM risk. Our analysis combined studies conducted in both Western and Eastern countries; therefore, our findings may contribute to understanding the relation between WDPs and GDM risk. Moreover, our findings may further reduce the incidence of GDM by encouraging healthy dietary patterns. Animal models or clinical studies are required to confirm the effect of the Maillard reaction's harmful products on the development of GDM in pregnant women.

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