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The Role of Diet in the Prevention of Diabetes among Women with Prior Gestational Diabetes: A Systematic Review of Intervention and Observational Studies

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Abstract

Background Women with prior gestational diabetes (GDM) have an increased lifetime risk of developing type 2 diabetes mellitus (T2DM). There are no up-to-date systematic reviews analyzing the relationship of diet with risk of developing T2DM following GDM. Objective To systematically review the evidence from intervention and observational studies on effects of dietary interventions and associations of dietary intake with T2DM outcomes in women with a GDM history. Methods Six electronic databases were searched (Cumulative Index to Nursing and Allied Health Literature, Embase, Medline, Cochrane Central, Proquest, and Scopus) for articles published until May 2019. This review includes intervention and observational studies among women of any age with a history of GDM that reported on the effects of dietary interventions or association of dietary intake (energy, nutrients, foods, dietary patterns) with T2DM, impaired glucose tolerance, impaired fasting glucose, or prediabetes. Results The systematic review identified five articles reporting results from four intervention studies, and seven articles reporting results from four observational studies. Findings from intervention studies indicated trends toward beneficial effects of a low-glycemic index diet, a low-carbohydrate diet, and a diet in line with general population dietary guidelines, but studies had unclear or high risk of bias. Findings from two cross-sectional and one prospective study indicated poorer diabetes outcomes for women with higher intakes of branched-chain amino acids, total and heme iron, and a diet relatively low in carbohydrates and high in animal fat and protein, and better outcomes among those consuming diets rich in fruit, vegetables, nuts, fish, and legumes, and low in red and processed meats and sugar-sweetened beverages, after adjustment for confounders, including body mass index. Conclusions Findings from observational studies support current dietary guidelines for the prevention of T2DM. Further dietary intervention studies are needed to confirm whether or not dietary modification following a GDM pregnancy reduces women's risk of developing T2DM.

Keywords

role, gestational, diet, diabetes:, systematic, review, intervention, observational, studies, prevention, diabetes, prior, women, among

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The role of diet in the prevention of diabetes among women with prior gestational diabetes: a systematic review of intervention and observational studies

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RESEARCH SNAPSHOT:

Research Question: Does diet play a role in the prevention of diabetes among women with a history of gestational diabetes?

Key Findings:

- This systematic review identified 12 articles published until May 2019, including five articles reporting on findings from four intervention studies, and seven articles reporting on findings from four observational studies.
- Intervention studies generally indicated a trend towards beneficial effects of a low-glycaemic index diet, a low carbohydrate diet, and a diet in line with general population guidelines, but had a high risk of bias.
- Observational studies indicated poorer diabetes outcomes for women with higher intakes of branched chain amino-acids, total and haem iron and a diet relatively low in carbohydrates and high in animal fat and protein, and better outcomes for women consuming diets rich in fruit, vegetables, nuts, fish and legumes, and low in red and processed meats and sugar-sweetened beverages.

ABSTRACT

Background: Women with prior gestational diabetes (GDM) have an increased lifetime risk of developing type 2 diabetes mellitus (T2DM). There are no up-to-date systematic reviews analysing the relationship of diet with risk of developing T2DM following GDM.

Objective: To systematically review the evidence from intervention and observational studies on effects of dietary interventions and associations of dietary intake with diabetes outcomes in women with a GDM history.

Methods: Six electronic databases were searched (CINAHL, EMBASE, Medline, Cochrane Central, Proquest and Scopus) for articles published until May 2019. This review includes intervention and observational studies among women of any age with a history of GDM that reported on the effects of dietary interventions or association of dietary intake (energy, nutrients, foods, dietary patterns) with T2DM, impaired glucose tolerance, impaired fasting glucose or pre-diabetes.

Results: The systematic review identified five articles reporting results from four intervention studies, and seven articles reporting results from four observational studies. Findings from intervention studies indicated trends towards beneficial effects of a low-glycaemic index diet, a low-carbohydrate diet, and a diet in line with general population dietary guidelines, but studies had unclear or high risk of bias. Findings from two cross-sectional and one prospective study indicated poorer diabetes outcomes for women with higher intakes of branched chain amino-acids, total and haem iron and a diet relatively low in carbohydrates and high in animal fat and protein, and better outcomes among those consuming diets rich in fruit, vegetables, nuts, fish and legumes, and low in red and processed meats and sugar-sweetened beverages, after adjustment for confounders including BMI.

Conclusions: Findings from observational studies support current dietary guidelines for the prevention of diabetes. Further dietary intervention studies are needed to confirm if dietary modification following a GDM pregnancy reduces women's risk of developing T2DM.

INTRODUCTION

Gestational diabetes mellitus (GDM) is defined as "glucose intolerance that begins or is first diagnosed during pregnancy".[1] Worldwide, the prevalence of GDM varies from an average of 6% in Europe to 13% in the Middle East and North Africa depending on factors such as health and lifestyle behaviours, ethnicity and diagnostic criteria,[2] and the incidence is increasing globally.[3] GDM usually resolves during the postpartum period; however women with a history of GDM remain a high-risk group for future development of type 2 diabetes (T2DM). Approximately 50% of women with a history of GDM will go on to develop T2DM within five to ten years after delivery.[2, 4]

T2DM causes numerous complications including retinopathy, kidney failure, cardiovascular disease and lower limb amputation, increasing an individual's overall risk of dying prematurely.[5] The burden of diabetes is enormous worldwide, for example, in 2017 diabetes was responsible for 4 million deaths and accounted for at least US 727 billion dollars in health expenditure globally.[6] Interventions that successfully prevent or delay the onset of T2DM in women with a previous history of GDM have the potential to improve an individual's long-term health and reduce the burden of morbidity associated with diabetes.[7]

Several systematic reviews and meta-analyses examining the effect of behavioural interventions, including increasing physical activity and/or improving diet quality, on diabetes risk in women with prior GDM have previously been published.[7-10] Two reviews that included meta-analyses highlighted that while 'intervention' is generally superior to 'no intervention', effect estimates varied widely between intervention studies.[8, 10] One potential explanation for this heterogeneity in findings may be that results were pooled from diverse study types that examined the effects of interventions with goals related to diet modification alone, physical activity alone, and both diet modification and physical activity.[8, 10] In addition

to intervention studies, one review included observational studies and found a limited number of studies that suggested healthful dietary patterns may be associated with lower risk of developing T2DM.[7] These previous reviews included studies published until early 2016 (for intervention studies)[10] or until 2014 (for observational studies).[7] Further systematic reviews are therefore needed to provide an up-to-date synthesis of the current evidence, incorporating findings from intervention and observational studies.

Interventions that focus on dietary modification alone may have the largest potential to improve diabetes outcomes in women with a history of GDM. For example, meta-analyses examining interventions aimed at reducing postpartum weight retention, which may positively influence diabetes risk, have found that physical activity-only interventions had no significant effect on postpartum weight loss,[11] while diet-only interventions achieved significant weight loss.[12] In practice, engagement and compliance with multi-component interventions, particularly with advice to increase physical activity during the postpartum period and beyond, may be compromised due to the barriers faced by women at this life-stage. Barriers such as time constraints related to childcare and returning to work may reduce the effectiveness of interventions.[13-15]

There are currently no up-to-date systematic reviews or meta-analyses that have focussed specifically on the effects of diet-only interventions or dietary intake on risk of developing diabetes among women with a previous history of GDM, and that incorporate evidence from both intervention and observational studies. Therefore, the aim of this research was to systematically review published intervention and observational studies to identify any effect of dietary interventions and associations of dietary intake with future diabetes risk for women with a previous diagnosis of GDM.

MATERIALS AND METHODS

The review was registered with PROSPERO International prospective register of systematic reviews (CRD42018090887) (http://www.crd.yorkac.uk/PROPSERO). Methods of the review were developed using the Cochrane Handbook for Systematic Reviews of Interventions[16] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used for reporting the methods and outcomes.[17]

Eligibility Criteria

The review included dietary intervention (intervention trials including counselling and/or food provided by any health professional) or dietary intake (observational) studies targeting women of any age, with a previous diagnosis of GDM. As the focus of this review included the prevention of (pre-) diabetes in women with prior GDM, recruitment may have commenced during pregnancy, however studies were only included if they reported outcomes and interventions during the postpartum period and beyond. Included interventions were those promoting a change in dietary intake, rather than nutritional supplement use, or other lifestyle behaviours e.g. physical activity. Supplement only studies including the provision of a capsule, pill or tablet containing amino acids, vitamins or minerals were excluded. Trials where multiple lifestyle interventions were combined, were included if diet was reported as a separate intervention arm or effect. Dietary intake could be assessed as energy, nutrients, foods, dietary patterns, or fortified food products. Randomised controlled trials (RCTs), controlled trials, pre-post studies, cross-sectional, retrospective and prospective studies were included in the systematic review. When multiple publications were available for the same study, the publication reporting the greatest number of participants for each outcome was selected. **Table 1** highlights the PICOS (population, intervention/exposure, comparator, outcomes, study design) categories for the formulation of the research question.

Search Strategy

The search strategy was developed in consultation with a subject specialist librarian. A systematic search for publications occurred in November 2017, and an updated search for any new publications in May 2019. The search was conducted without date limits, using six electronic databases: CINAHL; EMBASE; Medline; Cochrane Central; Proquest; and Scopus. The following MeSH terms, words and combinations of words were searched: ("gestational diabetes" or GDM or "pregnancy diabetes mellitus" or "pregnancy induced diabetes"); and (history or "medical history" or previous*); and (diet* or food* or carbohydrate* or nutrition* or "glycemic index" or GI); and ("type 2 diabetes" or diabetes or DM or T2DM or "impaired glucose tolerance" or "prediabetes" or "impaired fasting glucose"). Keywords were searched as free text in the title, abstract, or topic and combined using the Boolean operator "AND". Limits included English language and human subjects. Details on the search strategy used for Embase are given in **Table 2**. Additional publications were identified from the reference lists of included articles and from relevant previously published review articles.

Selection Process

All records identified were first assessed for eligibility based on the information contained in the title and abstract, by two independent reviewers. The full text of all publications that appeared to meet the eligibility screening (Table 1) was retrieved and subjected to a second independent assessment for relevance. Any discrepancy in assessment between reviewers was resolved through discussion.

Quality assessment

Selected full texts were assessed for methodological quality by two independent reviewers. Intervention studies were assessed using the Cochrane risk of bias tool.[18] All intervention

studies were coded as low, high or unclear risk in relation to sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, and selective reporting. The Newcastle-Ottawa Scale (NOS) was used to assess the quality of nonrandomised studies, including case-control and cohort studies.[19] A 'star system' is used which classifies the studies as good, fair or poor quality in relation to the selection of study groups, the comparability of groups and the ascertainment of either the exposure or outcome of interest for case-control and cohort studies respectively. Any discrepancies were discussed between reviewers and resolved.

Data Extraction

Two independent reviewers extracted relevant data from all included publications. The extracts were compared, and any difference was verified and resolved through discussion. The following information was extracted for all studies: study design, country, recruitment setting, eligibility criteria, population characteristics, duration of follow-up (if applicable), outcomes examined, outcome assessment and diagnostic criteria, outcome incidence (for binary outcomes), results, and covariates included in analysis; for intervention studies: intervention groups, duration, goals, content and compliance; and for observational studies: exposures examined and exposure assessment.

Data synthesis and Analysis

Due to heterogeneity across studies in dietary factors, study design, and outcomes of interest, it was not possible to combine study findings in a meta-analysis. Instead, results indicating significance and direction of the observed associations were qualitatively summarized in tables for each study. Information on study characteristics was extracted to describe studies and populations.

RESULTS

The numbers of identified and included studies are shown in **Figure 1**. The database search (n = 1,201) and screening of bibliographies (n = 3) yielded 1,204 unique articles. After screening of titles and abstracts, 45 full-text articles were reviewed. Of these, 12 met the inclusion criteria. Multiple articles were published based on data from a Malaysian dietary intervention (n = 2)[20, 21] and the Nurses' Health Study II (NHSII) (n = 4).[22-25] Therefore, this review includes five articles[20, 21, 26-28] reporting on findings from four intervention studies, and seven articles[22-25, 29-31] reporting on findings from four observational studies.

Study Characteristics

The main characteristics of the included intervention and observational studies are summarised in **Tables 3 and 4**. Detail on diabetes outcome assessment in each study, and on intervention goals, content and compliance (intervention studies) and dietary assessment (observational studies) are described in **Tables 5 and 6**.

Intervention studies

Intervention studies included RCTs conducted in Malaysia (N = 65 to 77)[20, 21] and Australia (N = 193),[27] and randomised cross-over studies from the USA (N = 17)[26] and Sweden (N = 7)[28] (Table 3). Women had a mean baseline age between 31 and 40 years, and mean baseline BMI between 25kg/m^2 and 28kg/m^2. The studies from Malaysia, the USA and Sweden recruited high risk women who were overweight or obese,[20, 21, 26] had prediabetes or a family history of diabetes,[20, 21] or had a diagnosis of impaired glucose tolerance at 12-months postpartum.[28] Women were recruited at a median of four months post-GDM pregnancy in the Malaysian RCT[20, 21] and 1-3 years post-GDM in the Swedish cross-over trial,[28] whereas the time since GDM pregnancy was not reported in the studies from Australia or the USA.[26, 27]

The dietary intervention studies focused on carbohydrate quality (glycaemic index)[20, 21, 28] and carbohydrate quantity (percentage of total energy intake),[26] or included general advice in line with dietary guidelines[27] (Table 5). The Malaysian low-glycaemic index RCT[20, 21] included education sessions on restricting energy and fat intake and increasing dietary fibre intake, with the goal to achieve a 5% to 7% reduction in body weight (for women with BMI >23 kg/m^2) or to maintain current weight (BMI <23 kg/m^2). In the Swedish cross-over trial, participants were provided with low-glycaemic and high-fibre bread products or high-glycaemic and low-fibre bread products, with the aim to determine effects on metabolic parameters.[28] The dietary intervention that focussed on carbohydrate quantity was a cross-over trial and included an energy-restricted diet where women received nutritional supplement bars that were identically wrapped and contained 20% protein and either 40% or 55% carbohydrates (i.e. 40% or 25% of energy from fat, respectively) for breakfast, lunch and snacks, and a meal plan for dinner which comprised a third of total calories. The goal was to achieve weight loss of 1lb to 2lbs (0.45kg to 0.9kg) per week.[26] The RCT conducted by Wein and colleagues included provision of a dietary advice sheet ('Target on Healthy Eating') for intervention and control groups while the intervention group in addition received phone contact with a dietitian every three months (so possibly 24 times over a six year follow-up).[27] Interventions were delivered through a combination of one-on-one sessions with nutritionists, group education sessions, email and short messaging reminders.[20, 21, 26, 27] Women in the control groups received general dietary recommendations and did not receive counselling or personal advice. All interventions were focussed on dietary modifications and did not include specific advice or goals related to physical activity. In line with general physical activity recommendations, women in the intervention and control groups were encouraged to engage in moderate physical activity for 30 minutes at least five times a week[20, 21] or received a reminder of the need for regular exercise.[27] Diabetes related outcomes

following the interventions included fasting plasma glucose,[20, 21, 28] serum fasting insulin,[26, 28] insulin secretion and sensitivity,[28] and T2DM defined using the 1985 WHO guidelines[27] (Table 5).

Observational studies

Observational studies included cross-sectional studies from Canada (N = 281),[30] Korea (N = 381)[29] and Sweden (N = 137),[31] a longitudinal study from the US (the NHSII, N = 3,976 to 4,502),[22-24] and a nested-case control study within the NHSII (N = 347)[25] (Table 4). Women had a mean baseline age between 34 and 43 years, and a mean baseline BMI between 21 kg/m^2 and 32kg/m^2. Studies were conducted at different times after GDM pregnancies, ranging from 6 to 12 weeks[29] to 14 years post-GDM pregnancy.[24]

Dietary intake was assessed using validated food frequency questionnaires (FFQs)[22-25, 30, 31] or a 24-hour dietary recall[29] (Table 6). Studies examined overall dietary patterns (low-carbohydrate dietary pattern, [23] alternate Mediterranean diet (aMED), Dietary Approaches to Stop Hypertension (DASH) and alternate Healthy Eating Index (aHEI),[24] fruit and vegetable intake,[30] frequency of meat, fish and vegetarian meals,[31] cooking fat used,[31] macronutrients,[29, 31] branched chain amino acids[25] and iron intake[22]). Diabetes related outcomes, including abnormal glucose tolerance, prediabetes and T2DM, were defined according to the 2017 American Diabetes Association Guidelines,[22-25, 29] the 2013 Canadian Diabetes Association Guidelines[30] or the 1999 WHO Guidelines[31] (Table 6).

Effects of Dietary Interventions on Diabetes Outcomes

Results from dietary intervention studies showed mixed effects on diabetes outcomes (**Table 7**). Findings from the low-glycaemic index, energy restricted RCT showed no significant changes in fasting glucose levels after six[21] and 12[20] months in the overall population, but 2-

hour plasma glucose had declined significantly more for women in the intervention compared to the control group after six months.[21] At the 12-month follow-up, fasting plasma glucose had significantly decreased in the intervention compared with the control group for women with baseline fasting insulin ≥2 μlU/ml^{-1} but not with baseline fasting insulin <2 μlU/ml^{-1}.[20] Findings from the cross-over trial providing low-glycaemic and high-fibre bread products showed no changes in fasting glucose, fasting insulin and insulin sensitivity, but insulin secretion was lower after consuming the low-glycaemic and high-fibre bread products for three weeks compared with before.[28] An intervention, with a median follow-up of 51 months (4 years and 3 months) providing general dietary advice and dietitian contact did not significantly reduce T2DM risk, although the risk estimate indicated a trend towards a beneficial effect (relative risk 0.63 (95% CI 0.35, 1.14) relative to the control group who received no dietitian contact.[27] A cross-over trial comparing different proportions of dietary energy from carbohydrates for a period of 12 weeks did not show a difference in fasting insulin levels between dietary interventions.[26]

Associations between Dietary Intake and Diabetes Outcomes

Findings from observational studies showed inverse associations between intake of a range of dietary factors and diabetes outcomes (**Table 8**). Prevalence of prediabetes was 34%[30] and 42%[29] in two cross-sectional studies, and incidence of T2DM ranged from 7% at 6-12 weeks post-GDM pregnancy[29] to 16% at 14 years post-GDM pregnancy.[22, 23]

In terms of overall dietary patterns, results based on the NSHII showed that a diet relatively low in carbohydrates was associated with higher T2DM risk, especially when fat and protein intake came largely from animal foods.[23] Findings from the same study also demonstrated lower T2DM risk with higher *a priori* dietary pattern scores including for the aMED, DASH and aHEI, after adjustments for key confounders including age, ethnicity,

BMI, parity, lifestyle and other dietary factors.[24] While adjustment for BMI attenuated the risk estimates, statistically significant associations remained when BMI was added to the model.[23, 24] A nested case-control study within the NHSII found higher intakes of branched chain amino acids were associated with higher risk of T2DM.[25] The NHSII also showed that women with the highest compared with the lowest intakes of total iron (dietary and supplemental), supplemental iron, and dietary haem iron were at higher risk of developing T2DM, whereas high dietary non-haem iron intake was associated with a lower risk after adjustment for key confounders.[22] Higher intake of fruit and vegetables was associated with lower odds of abnormal glucose tolerance in Canadian women based on a cross-sectional analysis adjusted for age and BMI.[30] Kim and colleagues found in their cross-sectional study that Korean women who had developed prediabetes or T2DM had higher intakes of total energy, total and animal protein, and total, animal and monounsaturated fat, after adjustment for pre-pregnancy BMI.[29] The Swedish cross-sectional study, however, did not find differences between women with normal glucose tolerance, impaired glucose tolerance and T2DM in terms of energy and macronutrient intake, after adjustment for key confounders.[31] This study showed that, compared with women with normal glucose tolerance, women with impaired glucose tolerance or T2DM had lower proportions of butter used for cooking, and women with T2DM had higher proportion of margarine used for cooking.[31]

Quality Assessment

Intervention studies

Based on the Cochrane risk of bias tool, intervention studies were at high risk of selection bias (random sequence generation (40% of studies), poor allocation concealment (40% of studies)) and performance bias (60% of studies) (**Figures 2 and 3**). All five studies had

unclear risk of detection and attrition bias, while most studies were scored as low risk of reporting bias.

Observational studies

Quality assessment scores for observational studies ranged from five to seven (out of nine indicating the lowest degree of bias) based on the NOS-scale (**Table 9**). Main concerns were 1) representativeness of the study sample (no random sample of women in the community), 2) comparability of exposed and unexposed participants based on design or analysis (the two cross-sectional studies did not adjust for potential key confounding factors, including parity, family history of diabetes, smoking, physical activity, and other dietary factors) and 3) adequacy of follow-up rate (studies either did not report on the follow-up rate, or did not describe the lost population if the follow-up rate was <90%).

DISCUSSION

Summary of main findings

This systematic review identified a limited number of intervention and observational studies that examined the role of diet in the prevention of diabetes among women with previous GDM. Five articles that reported on four small intervention studies found no strong evidence for a beneficial effect on glucose and insulin levels and on T2DM risk. Four articles that reported on associations with T2DM risk in a large prospective cohort study showed adverse associations for higher intakes of branched chain amino-acids, total and haem iron and a low carbohydrate diet, and protective associations for higher adherence to aMED, AHEI and DASH diet scores. Cross-sectional findings from one study showed lower intakes of fruit and vegetables among women with abnormal compared with normal glucose tolerance, while

findings from two cross-sectional studies on total energy, protein and fat intake in relation with prediabetes and impaired glucose tolerance were inconsistent. These observational findings were adjusted for confounding factors including BMI.

Interpretation

The inconclusive findings on the effectiveness of dietary interventions for diabetes prevention in women with a GDM history are consistent with previous systematic reviews of RCTs.[7-10] While previous reviews reported on only two diet-alone interventions,[21, 27] this review identified five articles that reported on four studies.[20, 21, 26-28] These trials were based on small samples and not powered to detect significant differences.[20, 21, 26-28] These trials also varied in terms of intervention content (advice focussed on carbohydrate quality,[20, 21, 28] carbohydrate quantity[26] or overall diet in line with national guidelines[27]), and examined different outcome measures (glucose[20, 21, 28], insulin[26, 28] or T2DM[27]). While findings from intervention studies generally indicated trends towards beneficial effects, the overall quality of these trials was rated as either unclear or high risk of bias. Based on the current evidence, a specific dietary intervention for diabetes prevention in women with prior GDM can therefore not be recommended. Previous systematic reviews have also consistently concluded that evidence for an effect of combined diet and physical activity interventions is inconclusive,[7-10] with the exception of strong evidence from the Diabetes Prevention Program (DPP).[32] Findings from this intensive intervention which focussed on diet and physical activity to achieve and maintain weight loss of at least 7% of initial body weight showed a greater than 50% reduction in the risk of developing T2DM in women at high risk of T2DM including women with previous GDM,[32] however, this personalised lifestyle intervention is unlikely to be feasible for implementation in routine care. As a limited number of studies have examined diet-alone and physical activity-alone interventions, it remains unclear which diabetes prevention approach would be most effective for women with a GDM history.[7-10] It has been

suggested based on combined diet and physical activity interventions that changes in diet were more often successfully implemented compared with changes in physical activity.[10] This may be explained by barriers related to being active and engaging in physical activity such as lack of time and energy, emotional distress, physical discomfort, and lack of child care support.[13-15] Further studies should explore the feasibility and acceptability of dietary interventions for women following childbirth, and future RCTs should accommodate barriers to improve intervention compliance among new mothers.

Findings from observational studies identified in this review showed adverse associations with diabetes outcomes for higher intakes of branched chain amino-acids,[25] total and haem iron[22] and a diet relatively low in carbohydrates and high in animal fat and protein,[23] and beneficial associations for diets rich in fruit, vegetables, nuts, fish and legumes, and low in red and processed meats and sugar-sweetened beverages.[24, 30] These results support dietary recommendations for the general population[33, 34] and for diabetes prevention.[35] Findings from observational studies were rated to be of medium to high quality (score of 5-7 out of 9), and observed associations were based on analyses adjusted for BMI[22-25, 29, 30] and physical activity.[22-25] These findings therefore suggest that, while BMI partly attenuated the associations,[23, 24] consuming a healthy diet may help reduce T2DM risk independent of BMI.

Implications for practice and research

While there is strong evidence that the majority of T2DM cases in the general population can be prevented through a healthy lifestyle,[35, 36] lifestyle interventions targeting women with prior GDM have only recently emerged. With the growing rates of GDM, T2DM and its associated health and economic burden worldwide,[5, 6] interventions that successfully prevent T2DM in this high-risk group are critical. Postnatal screening following a GDM pregnancy

represents an important opportunity for clinicians and health professionals to educate, counsel and engage women in prevention programs that may reduce their risk of progressing to diabetes. However, the uptake of postnatal follow-up by women with GDM is poor with less than 25% of women returning for a postnatal glucose tolerance test, mainly due to lack of time and awareness of risks.[37] Previous studies have shown poor diet quality and low adherence to dietary recommendations among women with a GDM history,[38, 39] and a significant knowledge gap on future health risks and the recommended lifestyle modifications.[39] While a causal effect of diet on T2DM following GDM has not been established, and further research is needed to develop effective postnatal preventive interventions, it seems prudent to inform women about their future risk of developing T2DM and the potential benefit of a healthy diet.

Strengths and limitations

Strengths of this systematic review include the focus on dietary intake, which has not been distinguished from effects of physical activity in previous systematic reviews. Moreover, this review includes all study designs (both intervention and observational), providing a more comprehensive overview of the current evidence. This review is restricted, however, by the lack of high-quality dietary intervention studies. Further evidence from postpartum dietary RCTs that follow women for a longer period of time are needed to confirm findings from observational studies. Current observational findings suggest that future RCTs should not only focus on carbohydrate quality and quantity, but also on other aspects of the overall diet including increasing intake of fruit, vegetables and other plant-based foods, and reducing animal products such as red and processed meats.

CONCLUSIONS

This systematic review indicates a lack of high quality dietary RCT evidence for the prevention of diabetes among women with prior GDM. Findings from observational studies have shown beneficial associations of several nutrients, foods and dietary patterns in line with current dietary recommendations and suggest diet may play a role in the prevention of diabetes among women with prior GDM. Further large prospective dietary RCTs that are acceptable to new mothers are needed to confirm if dietary modifications in line with healthy eating guidelines reduce the risk of T2DM among women following a GDM pregnancy.

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FIGURE LEGEND

Figure 1. Flow diagram of the literature search and screening process for a systematic review on effects of dietary interventions and associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes

Figure 2. Risk of bias for each individual intervention study included in a systematic review on effects of dietary interventions on diabetes outcomes in women with a history of gestational diabetes. Risk of bias was assessed using the Cochrane risk of bias tool (Higgins JPT, Green S (editors). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org).

Figure 3. Risk of bias summary for five intervention studies included in a systematic review on effects of dietary interventions on diabetes outcomes in women with a history of gestational diabetes. Risk of bias was assessed using the Cochrane risk of bias tool (Higgins JPT, Green S (editors). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org).

TABLES

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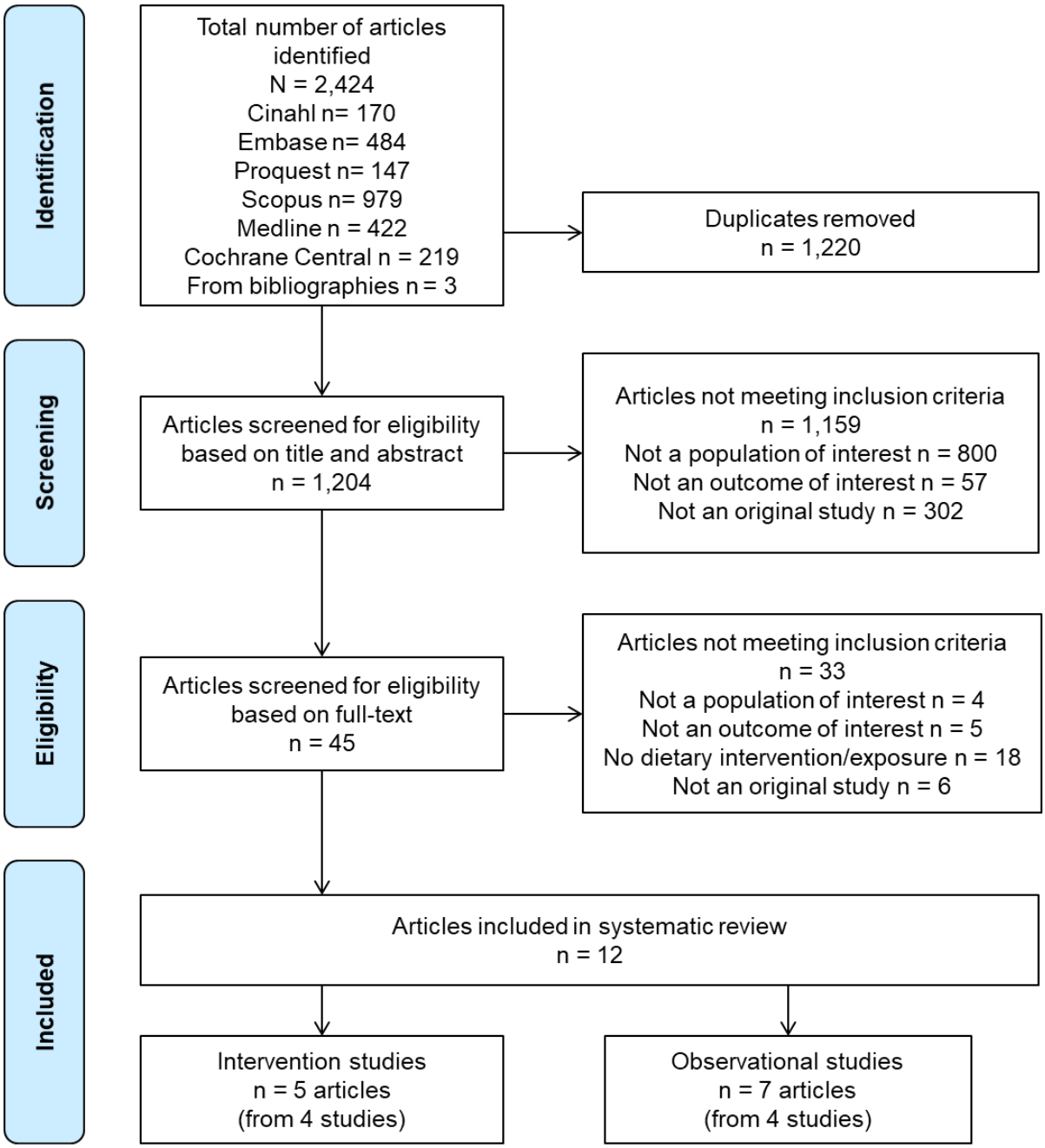

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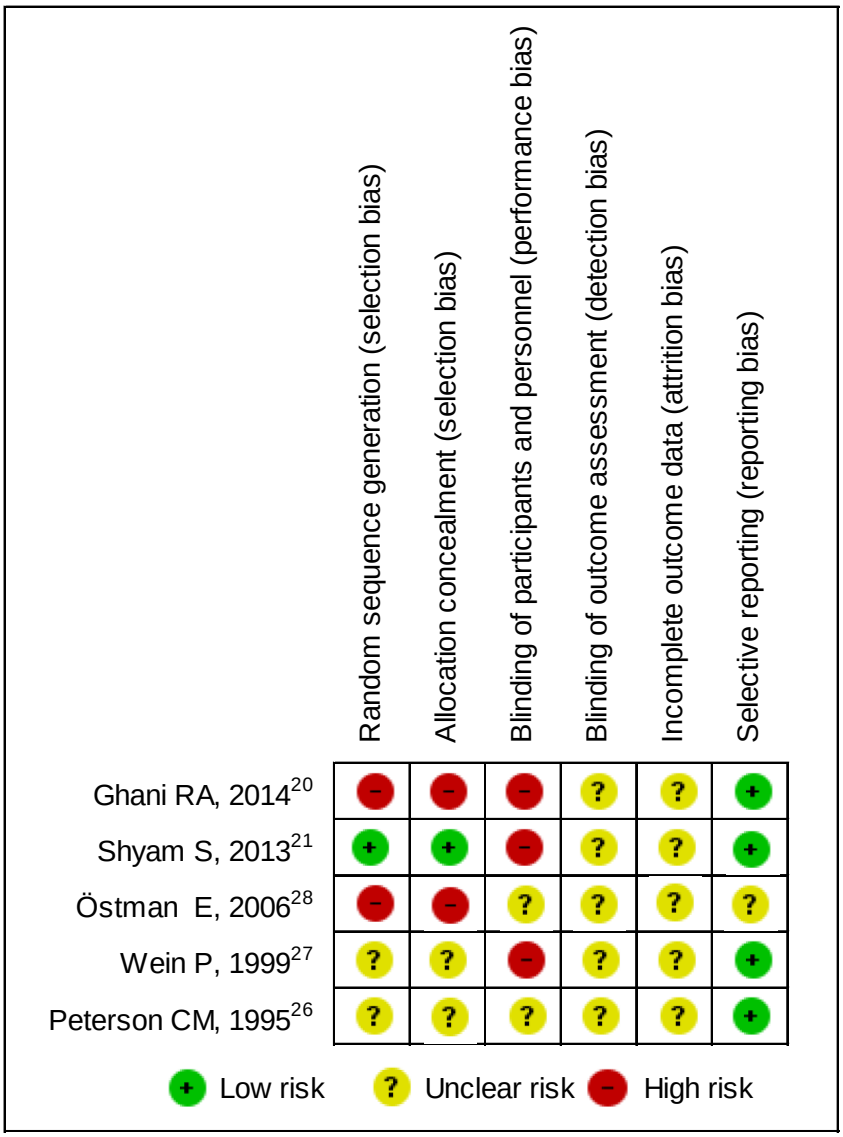

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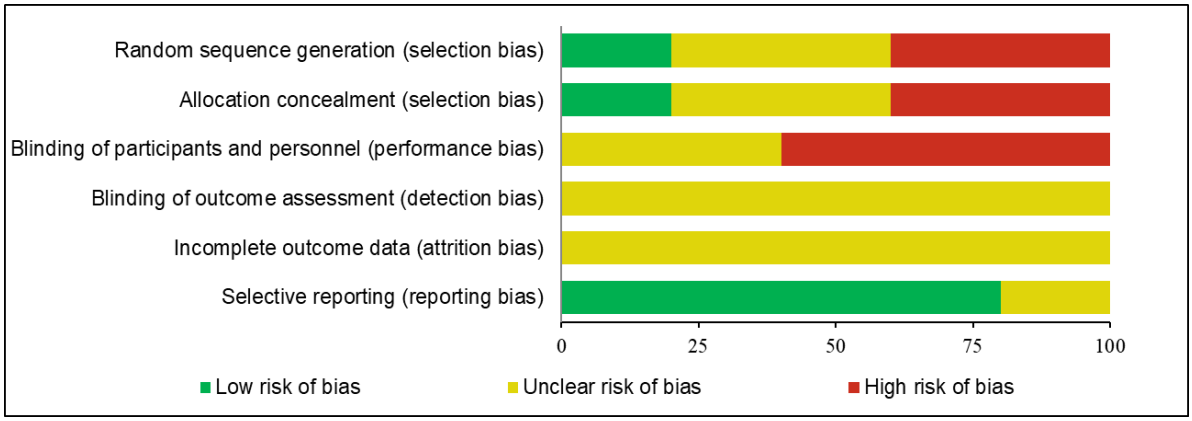

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Table 1. PICOS categories for formulation of the research question for a systematic review on effects of dietary interventions and associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes

Population	Women (postpartum onwards) with a history of gestational diabetes
Intervention/ exposure	Dietary intervention (intervention studies), or dietary intake (energy, nutrients, foods, dietary patterns) (observational studies)
Comparison	Control group (e.g. standard care as part of randomised controlled trial) or no control group (e.g. pre-post intervention study), not applicable for observational studies
Outcome	Type 2 diabetes, impaired glucose tolerance, impaired fasting glucose, or prediabetes
Study designs	Intervention studies (no restrictions on randomisation and inclusion of a control group), observational studies (cross-sectional, retrospective and prospective studies)

[online] Table 2. Search strategy for Embase in a systematic review on effects of dietary interventions and associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes

Search #	Search term[a]
1	gestational diabetes:ti,ab
2	GDM:ti,ab
3	pregnancy diabetes mellitus:ti,ab
4	pregnancy induced diabetes:ti,ab
5	1 or 2 or 3 or 4
6	history:ti,ab
7	medical history:ti,ab
8	previous*:ti,ab
9	6 or 7 or 8
10	diet*:ti,ab
11	food*:ti,ab
12	carbohydrate*:ti,ab
13	nutrition*:ti,ab
14	glycemic index:ti,ab
15	GI:ti,ab
16	10 or 11 or 12 or 13 or 14 or 15
17	type 2 diabetes:ti,ab
18	diabetes:ti,ab
19	DM:ti,ab
20	T2DM:ti,ab
21	impaired glucose tolerance:ti,ab
22	prediabetes:ti,ab
23	impaired fasting glucose:ti,ab
24	17 or 18 or 19 or 20 or 21 or 22 or 23
25	5 and 9 and 16 and 24

[a] Restricted to English language and human populations. Similar searches were conducted in all other databases.

Table 3. Characteristics of intervention studies included in a systematic review on effects of dietary interventions on diabetes outcomes in women with a history of gestational diabetes

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
Ghani RA, 2014[20]	Malaysia	Randomised controlled trial N = 77 (n = 39 in low glycaemic index intervention; n = 38 in control group)	Included: women with a history of gestational diabetes aged 20-40 years, without a current diagnosis of diabetes, at risk of type 2 diabetes (at least one of the four following risk factors: BMI>23 kg/m^2, or waist circumference>80 cm, or impaired glucose tolerance or impaired	Women were recruited from the endocrine clinic of a tertiary hospital.	Time since gestational diabetes pregnancy: median 4 months Age at baseline (mean): 31 years Previous births (mean): 2	(1) Low glycaemic index intervention, (2) Control group. Intervention duration not reported. Women were followed for 12 months post-intervention.	Fasting plasma glucose

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
			fasting glucose, or a family history of type 2 diabetes). Excluded: women with a diagnosis of type 2 diabetes, or presence of other health complications and usage of drugs affecting body weight and glucose control.		BMI (mean): 26 kg/m^2		
Shyam S, 2013[21]	Malaysia	Randomised controlled trial	Included: women with a history of gestational diabetes aged 20-40 years,	Women were recruited from the	Time since gestational diabetes	(1) Low glycaemic index	Fasting plasma glucose,

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
		N = 65 women (n = 34 in low glycaemic index intervention; n = 31 in the control group)	without a current diagnosis of diabetes, at risk of type 2 diabetes (at least one of the four following risk factors: BMI>23 kg/m^2, or waist circumference>80 cm, or impaired glucose tolerance or impaired fasting glucose, or a family history of type 2 diabetes). Excluded: women with a diagnosis of type 2 diabetes, or	endocrine clinic of a tertiary hospital.	pregnancy: median 4 months Age at baseline (mean): 31 years Previous births (mean): 2 BMI (mean): 26 kg/m^2	intervention, (2) Control group. Intervention duration not reported. Women were followed for 6 months post-intervention.	2-hours glucose

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
			presence of other health complications and usage of drugs affecting body weight and glucose control.				
Östman E, 2006[28]	Sweden	Randomized cross-over study N = 7	Included: Women with a history of gestational diabetes 1-3 years prior the study, who had a diagnosis of impaired glucose tolerance at 12-months postpartum.	Not reported	Age at baseline (mean): 32 years BMI (mean): 28 kg/m^2	(1) Dietary intervention 1 (2) Dietary intervention 2. Participants were crossed over after a 3-week	Insulin secretion, insulin sensitivity, fasting glucose and insulin

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
						intervention and 3-week washout period (total duration is 9 weeks). No control group. No post-intervention follow-up.	
Wein P, 1999[27]	Australia	Randomised controlled trial	Included: Women with a history of gestational diabetes who had a	Women were recruited from the Mercy Hospital for	Age at baseline (mean): 38-40 years	(1) Lifestyle intervention, (2) Control group.	Type 2 diabetes

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
		N = 193 (n = 97 in intervention group; n = 96 in control group)	diagnosis of impaired glucose tolerance and who could communicate directly or through translation. No exclusion criteria reported.	Women in Melbourne between November 1989 and July 1991	Previous births (mean): 3 BMI (mean): 25-26 kg/m^2	Intervention duration not reported. Women were followed for up to 6 years (median follow-up of 51 months (4 years and 3 months)) post-intervention.	

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
Peterson CM, 1995[26]	USA	Randomised cross-over study N = 17	Included: Women with a history of gestational diabetes who were overweight or obese, 1-4 years postpartum, not nursing, and aged 21-50 years. Excluded: women with any medical condition for which a calorie-restricted diet may be harmful including pregnancy or planned pregnancy during the trial,	Not reported	Age at baseline (mean): 34-38 years Previous births (mean): 3 BMI (mean): 25-26 kg/m^2	(1) Dietary intervention 1 (2) Dietary intervention 2. Participants were crossed over after a 6-week intervention (total duration is 12 weeks). No control group.	Serum fasting insulin

First author, year	Country	Study design, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Intervention groups, duration and follow-up	Outcome
			hypertension, diuretics use, thyroid disease, or diabetes.			No post-intervention follow-up.	

[a] Participant characteristics extracted were time since gestational diabetes pregnancy, age, ethnicity, parity and BMI, if reported. Characteristics are reported as a range across categories when no descriptive statistics were presented for the overall study population.

Table 4. Characteristics of observational studies included in a systematic review on associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
Tobias DK, 2018[25]	USA	Prospective nested case – control study (Nurses' Health Study II, as part of the Diabetes and Women's Health Study) N = 172 diabetes cases	Included: women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001, and with a plasma sample available from the biospecimen collection.	In 1989, nurses aged 25-42 years in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, and Texas	Years since first gestational diabetes pregnancy (mean): 12 years (cases) and 3 years (controls) Age at baseline blood draw (mean): 43 years Ethnicity: 91% (cases) 94% (controls) Caucasian	Total and subtypes of branched-chain amino acids: isoleucine, leucine and valine	Type 2 diabetes

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
		and 175 age-matched controls	Excluded: women with cancer, missing dietary data, or missing metabolite data.	were recruited through invitations.	BMI (mean): 31.6 (cases) and 25.5 (controls) kg/m^2		
Mercier R, 2018[30]	Canada	Cross-sectional No follow-up N = 281	Included: women aged ≥18 with a diagnosis of gestational diabetes between 2003 and 2013. Excluded: women pregnant during the study or	Women were recruited since 2009 through a provincial health plan registry and through medical records from two major hospitals	Time since gestational diabetes pregnancy (mean): 6 years Age at baseline (mean): 37 years Previous births (mean): 2	Fruit and vegetable intake	Abnormal glucose tolerance, including impaired fasting glucose, impaired glucose

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
			with diabetes before pregnancy.	within a neonatal care unit in Quebec City.	BMI (mean): 26-29 kg/m^2		tolerance, prediabetes and type 2 diabetes
Andersson-Hall U, 2018[31]	Sweden	Cross-sectional No follow-up N = 137	Included: women diagnosed with gestational diabetes between 2005 and 2009.	Women were recruited in the Gothenburg area through a telephone interview.	Time since gestational diabetes pregnancy (mean): 6 years Age at baseline (mean): 38-41 years Ethnicity: 33-53% Scandinavian BMI (mean): 26-30 kg/m^2	Intake of energy, carbohydrates, protein and fat, frequency of meat, fish and vegetarian meals, and type of cooking fat used	Impaired glucose tolerance and type 2 diabetes

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
						(proportion of butter, margarine and vegetable oil)	
Bao W, 2016(a)[22]	USA	Prospective cohort (Nurses' Health Study II, as part of the Diabetes and Women's Health Study)	Included: women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001. Excluded: women with chronic disease	In 1989, nurses aged 25-42 years in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio,	Age at baseline (mean): 38 years Ethnicity: 91-93% Caucasian BMI (mean): 26-27 kg/m^2	Dietary total iron, heme iron, non-heme iron, and supplemental iron (from multivitamin and specific	Type 2 diabetes

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
		Followed-up from 1991 to 2001, at 4-yearly intervals N = 3,976	(type 2 diabetes, cardiovascular disease, or cancer) before gestational diabetes pregnancy or before return of first post-gestational diabetes food frequency questionnaire, multiple pregnancy, no post-gestational diabetes food	Pennsylvania, South Carolina, and Texas were recruited through invitations.		iron supplements)	

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
			frequency questionnaire.				
Bao W, 2016(b)[23]	USA	Prospective cohort (Nurses' Health Study II, as part of the Diabetes and Women's Health Study)	Included: women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001. Excluded: women with chronic disease	In 1989, nurses aged 25-42 years in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio,	Age at baseline (mean): 38 years Ethnicity: 91-93% Caucasian >1 previous birth: 80-84% BMI (mean): 25-29 kg/m^2	Overall (based on total carbohydrate, protein and fat intake), animal (based on total carbohydrate, animal protein and animal fat	Type 2 diabetes

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
		Followed-up from 1991 to 2001, at 4-yearly intervals N = 4,502	(type 2 diabetes, cardiovascular disease, or cancer) before gestational diabetes pregnancy or before return of first post-gestational diabetes food frequency questionnaire, multiple pregnancy, no post-gestational diabetes food	Pennsylvania, South Carolina, and Texas were recruited through invitations.		intake) and vegetable low-carbohydrate dietary pattern (based on total carbohydrate, vegetable protein and vegetable fat)	

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
			frequency questionnaire.				
Tobias DK, 2012[24]	USA	Prospective cohort (Nurses' Health Study II, as part of the Diabetes and Women's Health Study)	Included: women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001. Excluded: women with chronic disease	In 1989, nurses aged 25-42 years in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio,	Time from gestational diabetes pregnancy to type 2 diabetes diagnosis (mean): 13.8 years Age at baseline (mean): 38 years Ethnicity: 91-93% Caucasian	Three a priori dietary pattern scores: the alternate Mediterranean diet (aMED), Dietary Approaches to Stop	Type 2 diabetes

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
		Followed-up from 1991 to 2001, at 4-yearly intervals N = 4,413	(type 2 diabetes, cardiovascular disease, or cancer) before gestational diabetes pregnancy or before return of first post-gestational diabetes food frequency questionnaire, multiple pregnancy, no post-gestational diabetes food	Pennsylvania, South Carolina, and Texas were recruited through invitations.	BMI (mean): 21-22 kg/m^2	Hypertension (DASH) and alternate Healthy Eating Index (aHEI)	

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
			frequency questionnaire, more than 70 food frequency questionnaire items left blank or unrealistic energy intake (<500 kcal/day or >3500 kcal/day).				
Kim S-H, 2011[29]	Korea	Cross-sectional No follow-up N = 381	Included: women with a recent gestational diabetes pregnancy and	Between June 2006 and March 2009, pregnant women visiting the Cheil	Time since gestational diabetes pregnancy: 6-12 weeks	Total energy, carbohydrates, total, animal and plant	Type 2 diabetes and prediabetes (impaired glucose

First author, year	Country	Study design, follow-up, n women	Eligibility criteria	Recruitment setting	Participant characteristics[a]	Exposure(s)	Outcome(s)
			normal glucose levels in early pregnancy. Excluded: women with b-cell–specific autoantibodies including glutamic acid decarboxylase antibodies (GADA).	General Hospital (Seoul, Korea) were recruited.	Age at baseline (mean): 34-35 years No previous birth: 40-46% Pre-pregnancy BMI (mean): 23-25 kg/m^2	protein, total, animal, plant, saturated, mono- and polyunsaturated fat, omega 3 and 6 fatty acids, dietary fibre	tolerance and/or impaired fasting glucose)

[a] Participant characteristics extracted were time since gestational diabetes pregnancy, age, ethnicity, parity and BMI, if reported. Characteristics are reported as a range across categories when no descriptive statistics were presented for the overall study population.

[online] Table 5. Intervention goals, content and compliance, and diabetes outcome assessment in intervention studies included in a systematic review on effects of dietary interventions on diabetes outcomes in women with a history of gestational diabetes

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
Ghani RA, 2014[20]	(1) Low glycaemic index intervention group: women received conventional healthy dietary recommendations including nutrition education at baseline through a structured one-on-one session with a research nutritionist, sample menus, and take-home reference booklets. Education sessions emphasised restriction of energy and fat intake and encouraged increases in dietary fibre intake. The goal was to achieve a 5-7% reduction in body weight if BMI>23 kg/m^2 or to maintain current weight if BMI <23 kg/m^2. Energy requirements were calculated, and women with BMI>23 kg/m^2 had a 500kcal energy	Compliance was monitored through assessments of dietary intake (3-day dietary records at baseline, 3 and 6 months), and nutrition knowledge assessment pertaining to the group-specific concepts. After six months, mean percentage of calories from carbohydrates, and glycaemic index and	Plasma glucose was measured on blood samples drawn in the fasting state (12 hours). Diagnostic criteria: not applicable (continuous outcome).

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
	restricted diet, capped at 1800kcal/day. Women were followed-up quarterly, and received fortnightly reminders using email or short messaging services reinforcing concepts of healthy living and motivating women to comply with the intervention. Women were also encouraged to engage in moderate physical activity for 30 minutes at least five times a week. In addition to conventional healthy dietary recommendations, women received low glycaemic index education including advice on how to choose low glycaemic index options in place of high glycaemic index staples like bread, rice and breakfast cereal. Women were	glycemic load were significantly lower in the intervention compared to the control group. Fibre intake was significantly higher in the intervention group.	

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
	asked to restrict rice intake to once/day and include 1 low glycaemic index food at each meal. (2) Control group: women received conventional healthy dietary recommendations only.		
Shyam S, 2013[21]	See above	See above	Plasma glucose was measured on blood samples drawn in the fasting state (12 hours). 2-hour post load blood glucose was measured after a 75 g oral glucose tolerance test. Diagnostic criteria: not applicable (continuous outcome).

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
Östman E, 2006[28]	(1) Low glycaemic index and high fibre bread products. (2) High glycaemic index and low fibre bread products. Participants were asked to eat seven slices of low glycaemic index /high fibre or high glycaemic index /low fibre bread across three meals per day. Participants were also supplied with butter, cheese and ham to be used on the bread in amounts according to written instructions. Apart from the bread meals, participants were asked to maintain their habitual diet throughout the study, but were not allowed to eat any other type of bread.	Not reported	Fasting glucose and insulin were measured on blood samples drawn in the fasting state. Insulin secretion and insulin sensitivity were assessed based on an intravenous glucose tolerance test followed by a euglycaemic-hyperinsulinaemic clamp. Diagnostic criteria: not applicable (continuous outcomes).

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
Wein P, 1999[27]	(1) Lifestyle intervention: women were given dietary questionnaires and a standard dietary advice sheet ('Target on Healthy Eating') and in addition had 3-monthly phone contact with a dietitian. (2) Control group: women were given dietary questionnaires and a standard dietary advice sheet ('Target on Healthy Eating') only. Both groups received a reminder of the need for regular exercise.	A diet score (based on the fat, residue and sugar content of the diet assesses through diet history) was assessed and not significantly different at trial entry between control and intervention groups, and were also not different at final assessment (diet improved in both groups).	Type 2 diabetes was assessed using an oral glucose tolerance test after an overnight fast. Diagnostic criteria: World Health Organisation guidelines 1985.
Peterson CM, 1995[26]	(1) Dietary intervention 1: 40% carbohydrates (2) Dietary intervention 2: 55% carbohydrates	Women were instructed to maintain a daily diary wherein they recorded all	Serum fasting insulin was assessed at baseline and after 6 and 12 weeks.

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
	Women received nutritional supplement bars for breakfast, lunch, and snacks. These were identically wrapped, each contained 180 kcal with 20% protein, and either 40% or 55% carbohydrates. A meal plan for dinner was provided. The daily caloric prescription consisted of 16.5 kcal/kg bodyweight at entry into the trial with a mean caloric consumption of 1500 kcal/24 hour for both groups. The anticipated weight loss was calculated at 1 to 2 lbs/week.	foods consumed by time of day. These were reviewed every one or two weeks. All participants showed significant weight loss in the first 6 weeks regardless of treatment assignment. Weight loss attenuated during the second 6 weeks of the study also regardless of treatment assignment. The diet score at enrolment did not differ between the intervention and	Diagnostic criteria: not applicable (continuous outcome).

First author, year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
		control groups respectively (3.1 and 3.2, respectively). There was improvement in diet scores, but this was comparable in the intervention and control groups (0.64 and 0.56, p=0.32).	

[online] Table 6. Diet and diabetes outcome assessment in observational studies included in a systematic review on associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes

First author, year	Exposure assessment	Outcome assessment and criteria
Mercier R, 2018[30]	Validated 91-item food frequency questionnaire reflecting past month consumption Administered by a registered dietitian during a clinical visit	Glycemic measurements were obtained during each woman's visit at the clinical investigation unit. Diagnostic criteria: Canadian Diabetes Association Guidelines 2013 Impaired fasting glucose: fasting glucose 6.1 to 6.9 mmol/L and normal 2-hour post-oral glucose tolerance test glucose < 7.8 mmol/L Impaired glucose tolerance: normal fasting glucose < 6.1 mmol/L and 2-hour post- oral glucose tolerance test glucose 7.8 to 11.0 mmol/L Prediabetes: impaired fasting glucose and/or impaired glucose tolerance and/or A1C between 6.0 and 6.4% Type 2 diabetes: fasting glucose ≥ 7.0 mmol/L and/or 2-hour post- oral glucose tolerance test glucose ≥ 11.1 mmol/L and/or A1C value ≥ 6.5%

First author, year	Exposure assessment	Outcome assessment and criteria
Bao W, 2016(a)[22]	Validated semi-quantitative food frequency questionnaire. Administered as part of survey questionnaire	Type 2 diabetes diagnosis was self-reported. A validation study showed 94% of self-reported cases were confirmed by medical records.
Bao W, 2016(b)[23]		Diagnostic criteria: American Diabetes Association Guidelines 1997
Tobias DK, 2012[24] and 2018[25]		Type 2 diabetes: 1) one or more classic symptoms (excessive thirst, polyuria, unintentional weight loss, or hunger) plus elevated glucose concentrations (fasting plasma glucose ≥7.0 mmol/L or random plasma glucose ≥11.1 mmol/L); 2) no symptoms reported but ≥2 elevated plasma glucose concentrations on more than one occasion (fasting glucose ≥7.0 mmol/L; random glucose ≥11.1 mmol/L, or 2-hour post- oral glucose tolerance test glucose ≥11.1 mmol/L); or 3) treatment with insulin or an oral hypoglycemic agent. Before 1998, fasting plasma glucose ≥7.8 mmol/L was used instead of ≥7.0 mmol/L according to the criteria of the National Diabetes Data Group.
Andersson-Hall U, 2018[31]	Validated semi-quantitative food frequency questionnaire.	Blood samples were taken at the study visit 6 years after pregnancy.
		Diagnostic criteria: 1999 World Health Organisation guidelines
		Type 2 diabetes: fasting glucose ≥7.0 mmol/L or 2-hour post- oral glucose tolerance test glucose ≥11.1 mmol/L

First author, year	Exposure assessment	Outcome assessment and criteria
	Completed during study visit.	Impaired glucose tolerance: fasting glucose 6.1 to 6.9 mmol/L and/or 2-hour post- oral glucose tolerance test glucose 7.8 to 11.0 mmol/L
Kim S-H, 2011[29]	24-hour recall Administered by a skilled dietitian	Type 2 diabetes and prediabetes were assessed at a clinical visit at 6-12 weeks postpartum Diagnostic criteria: American Diabetes Association Guidelines 1997 Type 2 diabetes: fasting glucose >7.0 mmol/L or 2-hour glucose >11.1 mmol/L Impaired glucose tolerance: fasting glucose <6.1 mmol/L and 2-hour glucose 7.8 to 11.0 mmol/L Impaired fasting glucose: fasting glucose 6.1 to 6.9 mmol/L inclusive with 2-hour glucose <7.8 mmol/L

Table 7. Results from intervention studies included in a systematic review on effects of dietary interventions on diabetes outcomes in women with a history of gestational diabetes

First author, year	Outcome incidence	Results	Covariates included in analysis
Ghani RA, 2014[20]	Not applicable (continuous outcome)	Changes in fasting plasma glucose (mean ± standard deviation): Women with fasting insulin <2 μlU/ml^{-1}: - Intervention group: 0.48 ± 1.2 mmol/L - Control group: 0.18 ± 0.32 mmol/L (p = 0.16 for intervention vs control) Women with fasting insulin ≥2 μlU/ml^{-1}: - Intervention group: -0.12 ± 0.27 mmol/L - Control group: 0.17 ± 0.32 mmol/L (p = 0.03 for intervention vs control)	None/not reported
Shyam S, 2013[21]	Not applicable (continuous outcome)	Overall: Changes in fasting plasma glucose (mean ± standard deviation): - Intervention group: -0.2 ± 0.6 mmol/L	Glycaemic load and carbohydrate intake

First author, year	Outcome incidence	Results	Covariates included in analysis
		- Control group: 0.1 ± 0.6 mmol/L (p = >0.05 for intervention vs control) Changes in 2-hour plasma glucose: - Intervention group: -0.2 ± 2.8 mmol/L - Control group: 0.8 ± 2.0 mmol/L (p = 0.03 for intervention vs control) Women with baseline normoglycemia: Changes in fasting plasma glucose (mean ± standard deviation): - Intervention group: 0.31 ± 0.53 mmol/L - Control group: 0.15 ± 0.41 mmol/L (p = 0.29 for intervention vs control) Changes in 2-hour plasma glucose (mean ± standard deviation): - Intervention group: 0.24 ± 2.04 mmol/L	

First author, year	Outcome incidence	Results	Covariates included in analysis
		- Control group: 0.88 ± 1.2 mmol/L (p = 0.22 for intervention vs control) Women with baseline dysglycaemia: Changes in fasting plasma glucose (mean ± standard deviation): - Intervention group: 0.49 ± 1.7 mmol/L - Control group: 0.04 ± 0.45 mmol/L (p = 0.51 for intervention vs control) Changes in 2h plasma glucose (mean ± standard deviation): - Intervention group: -0.49 ± 4.05 mmol/L - Control group: 0.47 ± 2.22 mmol/L (p = 0.57 for intervention vs control)	

First author, year	Outcome incidence	Results	Covariates included in analysis
Östman E, 2006[28]	Not applicable (continuous outcomes)	No changes in fasting glucose, fasting insulin and insulin sensitivity after either intervention. No changes in insulin secretion after high glycaemic index and low fibre bread products. Changes in insulin secretion after low glycaemic index and high fibre bread products: 1,185.4 ± 264 mlU/l min (pre-intervention) to 751.4 ± 141 mlU/l min (post-intervention) at 0-60 min ($p < 0.05$).	None/not reported
Wein P, 1999[27]	Type 2 diabetes incidence: 26.8% in intervention group and 28.1% in control group	Type 2 diabetes: relative risk for intervention vs control group: 0.63 (95% CI 0.35, 1.14).	Intervention group, entry age, entry BMI and change in BMI

First author, year	Outcome incidence	Results	Covariates included in analysis
Peterson CM, 1995[26]	Not applicable (continuous outcome)	Serum fasting insulin at baseline, end of first intervention, and end of second intervention, respectively (mean ± standard deviation): - 40% carbohydrate group (first intervention): 17 ± 6, 12 ± 7, 15 ± 12 mU/L - 55% carbohydrate group (first intervention): 24 ± 13, 22 ± 6, 26 ± 10 mU/L Differences between treatment groups were not significant ($p > 0.05$).	None/not reported

Table 8. Results from observational studies included in a systematic review on associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes

First author, year	Outcome incidence	Results	Covariates included in analysis
Tobias DK, 2018[25]	n = 172 diabetes cases and 175 age-matched controls (nested-case control study)	Odds ratios for type 2 diabetes for top vs bottom quartile of intake: Isoleucine: 5.78, 95% CI 1.86, 17.95 (P trend = 0.004) Leucine: 4.66, 95% CI 1.60, 13.53 (P trend = 0.01) Valine: 5.71, 95% CI 1.85, 17.60 (P trend = 0.009) Total branched-chain amino acids: 4.63, 95% CI 1.61, 13.36 (P trend = 0.01)	Age, total energy intake, fasting status ≤8 h, alcohol intake, family history of diabetes, menopausal status and current menopausal hormone therapy use, physical activity, smoking status, ethnicity, BMI, Alternative Healthy Eating Index-2010 adherence dietary quality score
Mercier R, 2018[30]	n = 126 (45%) abnormal	Women with abnormal glucose tolerance had significantly lower fruit and vegetable serves (mean ± standard deviation: 6.5 ± 0.2) and	Age and BMI

First author, year	Outcome incidence	Results	Covariates included in analysis
	glucose tolerance cases, including 34% prediabetes and 11% type 2 diabetes	vegetables serves (3.9 ± 0.2) and tended to have lower fruit serves (2.6 ± 0.2) than women with normal glucose tolerance (7.4 ± 0.2, 4.5 ± 0.2 and 3.0 ± 0.1, respectively) (p = 0.001, p = 0.04 and p = 0.10, respectively). Odds ratios for abnormal glucose tolerance: Fruit and vegetables per 1 serve: 0.88, 95% CI 0.81-0.97 Vegetables per 1 serve: 0.88, 95% CI 0.78-1.00 Fruit per 1 serve: 0.88, 95% CI 0.76-1.02 Fruit and vegetables <7 vs ≥7 serves: 1.84, 95% CI 1.13-3.00	
Andersson-Hall U, 2018[31]	n = 32 (23.4%) impaired glucose tolerance cases and n = 17	There were no differences between groups in terms of energy, carbohydrate, protein and fat intake, meal frequency, and proportion of vegetable oil used for cooking (p >0.05). Compared with women with normal glucose tolerance, women with impaired glucose tolerance (p = 0.01) and type 2 diabetes (p = 0.01) had lower proportions of butter used	Age, ethnicity, BMI

First author, year	Outcome incidence	Results	Covariates included in analysis
	(12.4%) type 2 diabetes cases	for cooking, and women with type 2 diabetes also had higher proportion of margarine used for cooking (p = 0.004).	
Bao W, 2016(a)[22]	n = 614 (16%) type 2 diabetes cases	Hazard ratios for type 2 diabetes: Total iron intake: 1.64, 95% CI 1.20-2.25 for top (37.2 mg/d) vs bottom (11.6 mg/d) category Supplemental iron intake: 1.83, 95% CI 1.25-2.70 for top (≥30 mg/d) vs bottom (0 mg/d) category Dietary haem iron intake: 1.80, 95% CI 1.18-2.74 for top (1.5 mg/d) vs bottom (0.7 mg/d) category Dietary non-haem iron intake: 0.71, 95% CI 0.51-1.00 for top (16.6 mg/d) vs bottom (9.0 mg/d) category	Age, parity, BMI, age at first birth, ethnicity, oral contraceptive use, menopausal status, cigarette smoking, alcohol intake, physical activity, ratio of polyunsaturated fat to saturated fat, total energy intake, saturated fat, trans fat, cholesterol, animal and vegetable protein, glycaemic

First author, year	Outcome incidence	Results	Covariates included in analysis
			load, cereal fibre, calcium, magnesium, vitamin C, supplemental iron (for haem and non-haem iron analysis) and total dietary iron (for supplemental iron analysis)
Bao W, 2016(b)[23]	n = 722 (16%) type 2 diabetes cases	Hazard ratios for type 2 diabetes for top vs bottom quintiles of diet scores (confounder and confounder + BMI-adjusted models, respectively): Overall low-carbohydrate diet score: 2.13, 95% CI 1.65-2.76 (P trend = <0.001) and 1.36, 95% CI 1.04-1.78 (P trend = 0.003) Animal low-carbohydrate diet score: 2.18, 95% CI 1.68-2.83 (P trend = <0.001) and 1.40, 95% CI 1.06-1.84 (P trend = 0.004)	Age, parity, BMI, age at first birth, ethnicity, oral contraceptive use, menopausal status, cigarette smoking, alcohol intake, physical activity, family history of diabetes, total energy intake, glycaemic index

First author, year	Outcome incidence	Results	Covariates included in analysis
		Vegetable -carbohydrate diet score: 1.29, 95% CI 1.00-1.67 (P trend = 0.14) and 1.19, 95% CI 0.91-1.55 (P trend = 0.50)	
Tobias DK, 2012[24]	n = 491 (11%) type 2 diabetes cases	Hazard ratios for type 2 diabetes for top vs bottom quartile of dietary pattern scores (confounder and confounder + BMI-adjusted models, respectively): Alternate Mediterranean diet: 0.60, 95% CI 0.44-0.82 (P trend = 0.002) and 0.76, 95% CI 0.55, 1.05 (P trend = 0.13) Dietary Approaches to Stop Hypertension: 0.54, 95% CI 0.39-0.73 (P trend = <0.001) and 0.68, 95% CI 0.49-0.94 (P trend = 0.04) Alternate Healthy Eating Index: 0.43, 95% CI 0.31-0.59 (P trend = <0.001) and 0.65, 95% CI 0.46-0.92 (P trend = 0.01)	Age, total energy intake, parity, age at first birth, race/ethnicity, parental history of type diabetes, oral contraceptive use, menopausal status, smoking status, physical activity, alcohol intake, BMI (breastfeeding was not included in the models, but it was mentioned that this did not alter the findings)

First author, year	Outcome incidence	Results	Covariates included in analysis
Kim S-H, 2011[29]	n = 161 (42.3%) prediabetes cases n = 27 (7.1%) type 2 diabetes cases	Compared with women with normal glucose tolerance, women who developed prediabetes and type 2 diabetes had higher intakes of total energy, total and animal protein, total, animal and monounsaturated fat. There were no differences in intake of carbohydrates, plant protein, plant, saturated, polyunsaturated and omega 3 and 6 fatty acids, and fibre.	Pre-pregnancy BMI

[online] Table 9. Quality assessment for each individual observational study included in a systematic review on associations of dietary intake with diabetes outcomes in women with a history of gestational diabetes[a]

	Selection				Compara-bility	Outcome			
Study	Representativeness of exposed cohort[b]	Selection of non-exposed cohort[c]	Ascertainment of exposure[d]	Outcome not present at start of study[e]	Comparability of cases and controls on bases of design or analysis[f]	Outcome assessment[g]	Adequate duration of follow-up[h]	Adequacy of follow-up rate[i]	Total score
Tobias DK, 2018[25]	C	A★	B★	A★	A★ B★	B★	A★	D	7
Mercier R, 2018[30]	B★	A★	B★	B	A★	A★	A★	D	6
Andersson-Hall U, 2018[31]	B★	A★	B★	B	A★	A★	A★	B★	7
Bao W, 2016(a)[22]	C	A★	B★	A★	A★ B★	B★	A★	D	7
Bao W, 2016(b)[23]	C	A★	B★	A★	A★ B★	B★	A★	D	7
Tobias DK, 2012[24]	C	A★	B★	A★	A★ B★	B★	A★	D	7
Kim S-H, 2011[29]	A★	A★	C	A★	-	A★	A★	C	5

[a] Risk of bias was assessed using the Newcastle-Ottawa Scale (NOS). A study can be awarded a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability. (Wells GA, Shea B, O'connell D, Peterson J, Welch V, Losos M, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality if nonrandomized studies in meta-analyses. 2009).

[b] Representativeness of the exposed cohort was scored as (A [star]) truly representative of the average postpartum or mid-age woman with a history of gestational diabetes in the community (random sample); (B [star]) somewhat representative of the average postpartum or mid-age woman with a history of gestational diabetes in the community; (C) selected group of users e.g. only specific occupation; (D) no description of the derivation of the cohort.
[c] Selection of the non-exposed cohort was scored as (A [star]) drawn from the same community as the exposed cohort; (B) drawn from a different source; (C) no description of the derivation of the non-exposed cohort.
[d] Ascertainment of exposure was scored as (A [star]) secure record (e.g. controlled diet); (B [star]) structured interview/validated dietary recall/diet history/ food frequency questionnaire; (C) written self-report (e.g. non-validated dietary assessment); (D) no description.
[e] Demonstration that outcome of interest was not present at start of study was scored as (A [star]) yes (no type 1 or type 2 diabetes prior to pregnancy and prior to study entry); (B) no.
[f] Comparability of cohorts on the basis of the design or analysis was scored as (A [star]) study controls for age, ethnicity and body mass index; (B [star]) study controls for any additional factor (e.g. parity, family history of diabetes, smoking, physical activity, other dietary factors).
[g]Outcome assessment was scored as (A [star]) independent blind assessment (e.g. hospital record/oral glucose tolerance test); (B [star]) record linkage or validated self-reported diagnosis; (C) self-report (not validated); (D) no description.
[h] Adequate duration of follow-up for outcomes to occur was scored as (A [star]) yes, if – after baseline – all women were screened for type 2 diabetes or answered a question on whether they were diagnosed or treated for type 2 diabetes; (B) no.
[i] Adequacy of follow-up rate was scored as (A [star]) complete follow up or all subjects accounted for using multiple imputation; (B [star]) subjects lost to follow up unlikely to introduce bias (samples are comparable based on comparison of in- and excluded participants) or ≤10% lost during follow-up; (C) follow up rate <90% or no description of those lost; (D) no statement.