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.

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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 behaviors, 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 mellitus (T2DM). Approximately 50% of women with a history of GDM will go on to develop T2DM within 5 to 19 years after delivery.^{2,4}

T2DM causes numerous complications, including retinopathy, kidney failure, cardiovascular disease, and lower limb amputation that increase 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 \$727 billion 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 behavioral 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 although 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 influence on postpartum weight loss,¹¹ whereas 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 barriers faced by women at this life stage. Barriers such as time constraints related to child-care 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 focused 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.york.ac.uk/PROSPERO>). Methods of the review were developed using the Cochrane Handbook for Systematic Reviews of Interventions¹⁶ and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were used for reporting the methods and outcomes.¹⁷

Eligibility Criteria

The review included dietary intervention (intervention trials, including counseling and/or food provided by any health professional) or dietary intake (observational) studies targeting women of any age, with a previous diagnosis of GDM. Because the focus of this review included the prevention of (pre-) diabetes in women with prior GDM, recruitment may

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 toward beneficial effects of a low-glycemic 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 heme 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.

have commenced during pregnancy; however, studies were only included in the case that 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 behaviors (eg, 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 in the case that 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. Randomized controlled trials (RCTs); controlled trials; pre–post studies; as well as 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. **Figure 1** highlights the 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: Cumulative Index to Nursing and Allied Health Literature, Embase, Medline, Cochrane Central, Proquest, and Scopus. The following medical subject heading 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

Category	Result
Population	Women (postpartum onward) with a history of gestational diabetes
Intervention/ exposure	Dietary intervention (intervention studies), or dietary intake (energy, nutrients, foods, or dietary patterns) (observational studies)
Comparison	Control group (eg, standard care as part of randomized controlled trial) or no control group (eg, 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 (ie, no restrictions on randomization and inclusion of a control group), observational studies (ie, cross-sectional, retrospective, and prospective studies)

Figure 1. 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.

“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 [Figure 2](#) (available at www.jandonline.org). Other publications were identified from the reference lists of included articles and from relevant previously published review articles.

Selection Process

All records identified were assessed by two independent reviewers for eligibility based on the information contained in the title and abstract. The full text of all publications that appeared to meet the eligibility screening ([Figure 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 text articles were assessed for methodologic quality by two independent reviewers. Intervention studies were assessed using the Cochrane risk of bias tool.¹⁶ 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 was used to assess the quality of nonrandomized studies, including case-control and cohort studies.¹⁹ A star system is used to classify 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 articles. 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 were extracted and for observational studies exposures examined and exposure assessment were extracted.

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 3](#). 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)^{19,20} and the Nurses’ Health Study II (NHSII) (n=4).^{21–24} Therefore, this review includes five articles^{19,20,25–27} reporting on findings from four intervention studies, and seven articles^{21–24,28–30} reporting on findings from four observational studies.

Study Characteristics

The main characteristics of the included intervention and observational studies are summarized in [Tables 1](#) and [2](#). 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 3](#) and [4](#) (available at www.jandonline.org).

Intervention Studies

Intervention studies included RCTs conducted in Malaysia (n=65 to 77)^{19,20} and Australia (n=193),²⁶ and randomized crossover studies from the United States (n=17)²⁵ and Sweden (n=7)²⁷ ([Table 1](#)). Women had a mean baseline age between 31 and 40 years, and mean baseline body mass index (BMI) between 25 and 28. The studies from Malaysia, the United States, and Sweden recruited high-risk women who were overweight or obese,^{19,20,25} had prediabetes or a family history of diabetes,^{19,20} or had a diagnosis of impaired glucose tolerance at 12-months postpartum.²⁷ Women were

Figure 3. 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.

recruited at a median of 4 months post-GDM pregnancy in the Malaysian RCT^{19,20} and 1 to 3 years post-GDM in the Swedish crossover trial,²⁷ whereas the time since GDM pregnancy was not reported in the studies from Australia or the United States.^{25,26}

The dietary intervention studies focused on carbohydrate quality (glycemic index)^{19,20,27} and carbohydrate quantity

(percentage of total energy intake),²⁵ or included general advice in line with dietary guidelines²⁶ (Table 3, available at www.jandonline.org). The Malaysian low-glycemic index RCT^{19,20} included education sessions on restricting energy and fat intake and increasing dietary fiber intake, with the goal to achieve a 5% to 7% reduction in body weight (for women with BMI >23) or to maintain current weight (BMI

Table 1. 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

Author(s), year	Country	Study design, no. of women	Eligibility criteria	Recruitment setting	Participant characteristics ^a	Intervention groups, duration, and follow-up	Outcome
Ghani and colleagues, ¹⁹ 2014	Malaysia	Randomized controlled trial N=77 (n=39 in low glycemic index intervention; n=38 in control group)	Included: Women with a history of gestational diabetes aged 20-40 y, without a current diagnosis of diabetes, at risk of type 2 diabetes (at least 1 of the 4 following risk factors: BMI >23, 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 presence of other health complications and use of drugs affecting body weight and glucose control	Women were recruited from the endocrine clinic of a tertiary hospital	Time since gestational diabetes pregnancy: median 4 mo Age at baseline (mean): 31 y Previous births (mean): 2 BMI ^b (mean): 26	(1) Low glycemic index intervention (2) Control group Intervention duration not reported. Women were followed for 12 mo post-intervention	Fasting plasma glucose
Shyam and colleagues, ²⁰ 2013	Malaysia	Randomized controlled trial N=65 women (n=34 in low glycemic index intervention; n=31 in the control group)	Included: Women with a history of gestational diabetes aged 20-40 y, without a current diagnosis of diabetes, at risk of type 2 diabetes (at least 1 of the 4 following risk factors: BMI >23, 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 presence of other health complications and use of drugs affecting body weight and glucose control	Women were recruited from the endocrine clinic of a tertiary hospital	Time since gestational diabetes pregnancy: median 4 mo Age at baseline (mean): 31 y Previous births (mean): 2 BMI (mean): 26	(1) Low glycemic index intervention (2) Control group Intervention duration not reported. Women were followed for 6 mo post-intervention	Fasting plasma glucose, 2-h glucose

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Table 1. 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 (*continued*)

Author(s), year	Country	Study design, no. of women	Eligibility criteria	Recruitment setting	Participant characteristics ^a	Intervention groups, duration, and follow-up	Outcome
Östman and colleagues, ²⁷ 2006	Sweden	Randomized crossover study N=7	Included: Women with a history of gestational diabetes 1-3 y before the study who had a diagnosis of impaired glucose tolerance at 12 mo postpartum	Not reported	Age at baseline (mean): 32 y BMI (mean): 28	(1) Dietary intervention 1 (2) Dietary intervention 2. Participants were crossed over after a 3-wk intervention and 3-wk washout period (total duration 9 wk). No control group. No post-intervention follow-up.	Insulin secretion, insulin sensitivity, fasting glucose, and insulin
Wein and colleagues, ²⁶ 1999	Australia	Randomized controlled trial N=193 (n=97 in intervention group; n=96 in control group)	Included: Women with a history of gestational diabetes who had a diagnosis of impaired glucose tolerance and who could communicate directly or through translation. No exclusion criteria reported	Women were recruited from the Mercy Hospital for Women in Melbourne between November 1989 and July 1991	Age at baseline (mean): 38-40 y Previous births (mean): 3 BMI (mean): 25-26	(1) Lifestyle intervention (2) Control group Intervention duration not reported. Women were followed for up to 6 y (median follow-up=51 mo [4 y 3 mo] post-intervention)	Type 2 diabetes
Peterson and colleagues, ²⁵ 1995	United States	Randomized crossover study N=17	Included: Women with a history of gestational diabetes who were overweight or obese, 1-4 y postpartum, not nursing, and aged 21-50 y Excluded: Women with any medical condition for which a calorie-restricted diet may be harmful, including pregnancy or planned pregnancy during the trial, hypertension, diuretics use, thyroid disease, or diabetes	Not reported	Age at baseline (mean): 34-38 y Previous births (mean): 3 BMI (mean): 25-26	(1) Dietary intervention 1 (2) Dietary intervention 2 Participants were crossed over after a 6-wk intervention (total duration=12 wk). No control group. No post-intervention follow-up	Serum fasting insulin

^aParticipant 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.^bBMI=body mass index.

Table 2. 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

Author(s), year	Country	Study design, follow-up, no. of women	Eligibility criteria	Recruitment setting	Participant characteristics ^a	Exposure(s)	Outcome(s)
Tobias and colleagues, ²⁴ 2018	United States	Prospective nested case-control study (Nurses' Health Study II, as part of the Diabetes and Women's Health Study) N=172 diabetes cases and 175 age-matched controls	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 Excluded: Women with cancer, missing dietary data, or missing metabolite data	In 1989, nurses aged 25-42 y in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, and Texas were recruited through invitations	Years since first gestational diabetes pregnancy (mean): 12 y (cases) and 3 y (controls) Age at baseline blood draw (mean): 43 y Ethnicity: 91% (cases) 94% (controls) white BMI ^b (mean): 31.6 (cases) and 25.5 (controls)	Total and subtypes of branched-chain amino acids: isoleucine, leucine and valine	Type 2 diabetes
Mercier and colleagues, ²⁹ 2018	Canada	Cross-sectional No follow-up N=281	Included: Women aged ≥ 18 y with a diagnosis of gestational diabetes between 2003 and 2013. Excluded: Women pregnant during the study or with diabetes before pregnancy	Women were recruited since 2009 through a provincial health plan registry and through medical records from 2 major hospitals within a neonatal care unit in Quebec City	Time since gestational diabetes pregnancy (mean): 6 y Age at baseline (mean): 37 y Previous births (mean): 2 BMI (mean): 26-29	Fruit and vegetable intake	Abnormal glucose tolerance, including impaired fasting glucose, impaired glucose tolerance, prediabetes, and type 2 diabetes
Andersson-Hall and colleagues, ³⁰ 2018	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 y Age at baseline (mean): 38-41 y Ethnicity: 33%-53% Scandinavian BMI (mean): 26-30	Intake of energy, carbohydrates, protein, and fat; frequency of meat, fish, and vegetarian meals; and type of cooking fat used (proportion of butter, margarine, and vegetable oil)	Impaired glucose tolerance and type 2 diabetes

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Table 2. 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 (*continued*)

Author(s), year	Country	Study design, follow-up, no. of women	Eligibility criteria	Recruitment setting	Participant characteristics ^a	Exposure(s)	Outcome(s)
Bao and colleagues, ²¹ 2016	United States	Prospective cohort (Nurses' Health Study II, as part of the Diabetes and Women's Health Study) Followed-up from 1991 to 2001, at 4-yearly intervals N=3,976	Included: Women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001. Excluded: Women with chronic disease (type 2 diabetes, cardiovascular disease, or cancer) before gestational diabetes pregnancy or before return of first postgestational diabetes food frequency questionnaire, multiple pregnancy, no postgestational diabetes food frequency questionnaire	In 1989, nurses aged 25-42 y in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, and Texas were recruited through invitations	Age at baseline (mean): 38 y Ethnicity: 91%-93% white BMI (mean): 26-27	Dietary total iron, heme iron, nonheme iron, and supplemental iron (from multivitamin and specific iron supplements)	Type 2 diabetes
Bao and colleagues, ²² 2016	United States	Prospective cohort (Nurses' Health Study II, as part of the Diabetes and Women's Health Study) Followed-up from 1991 to 2001, at 4-yearly intervals N=4,502	Included: Women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001. Excluded: Women with chronic disease (type 2 diabetes, cardiovascular disease, or cancer) before gestational diabetes pregnancy or before return of first postgestational diabetes	In 1989, nurses aged 25-42 y in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, and Texas were recruited through invitations	Age at baseline (mean): 38 y Ethnicity: 91%-93% white >1 previous birth: 80%-84% BMI (mean): 25-29	Overall (based on total carbohydrate, protein, and fat intake), animal (based on total carbohydrate, animal protein and animal fat intake) and vegetable low-carbohydrate dietary pattern (based on total	Type 2 diabetes

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Table 2. 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 (*continued*)

Author(s), year	Country	Study design, follow-up, no. of women	Eligibility criteria	Recruitment setting	Participant characteristics ^a	Exposure(s)	Outcome(s)
			food frequency questionnaire, multiple pregnancy, no postgestational diabetes			carbohydrate, vegetable protein, and vegetable fat)	
Tobias and colleagues, ²³ 2012	United States	Prospective cohort (Nurses' Health Study II, as part of the Diabetes and Women's Health Study) Followed-up from 1991 to 2001, at 4-yearly intervals N=4,413	Included: Women with prevalent gestational diabetes before 1991, or incident gestational diabetes between 1991 and 2001. Excluded: Women with chronic disease (type 2 diabetes, cardiovascular disease, or cancer) before gestational diabetes pregnancy or before return of first postgestational diabetes food frequency questionnaire, multiple pregnancy, no postgestational diabetes food frequency questionnaire >70 food frequency questionnaire items left blank or unrealistic energy intake (<500 kcal/d or >3,500 kcal/d)	In 1989, nurses aged 25-42 y in California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, and Texas were recruited through invitations	Time from gestational diabetes pregnancy to type 2 diabetes diagnosis (mean): 13.8 y Age at baseline (mean): 38 y Ethnicity: 91%-93% white BMI (mean): 21-22	Three a priori dietary pattern scores: the alternate Mediterranean diet, Dietary Approaches to Stop Hypertension, and alternate Healthy Eating Index	Type 2 diabetes
	Korea		Included: Women with a recent gestational	Between June 2006 and March 2009, pregnant	Time since gestational diabetes	Total energy, carbohydrates,	Type 2 diabetes and prediabetes

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Table 2. 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 (*continued*)

Study design, follow-up, no. of women		Eligibility criteria	Recruitment setting	Participant characteristics ^a	Exposure(s)	Outcome(s)
Author(s), year	Country					
Kim and colleagues, ²⁸ 2011	Cross-sectional No follow-up N=381	diabetes pregnancy and normal glucose levels in early pregnancy. Excluded: Women with β -cell—specific autoantibodies including glutamic acid decarboxylase antibodies	women visiting the Cheil General Hospital (Seoul, Korea) were recruited	pregnancy: 6-12 wk Age at baseline (mean): 34-35 y No previous birth: 40%-46% Prepregnancy BMI (mean): 23-25	total, animal and plant protein, total, animal, plant, saturated, mono- and polyunsaturated fat, n-3 and n-6 fatty acids, dietary fiber	(impaired glucose tolerance and/or impaired fasting glucose)

^aParticipant 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.

^bBMI=body mass index.

<23). In the Swedish crossover trial, participants were provided with low-glycemic and high-fiber bread products or high-glycemic and low-fiber bread products, with the aim to determine effects on metabolic parameters.²⁷ The dietary intervention that focussed on carbohydrate quantity was a crossover 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 (ie, 40% or 25% of energy from fat, respectively) for breakfast, lunch, and snacks, and a meal plan for dinner that comprised one-third of total calories. The goal was to achieve weight loss of 1 to 2 lb (0.45 to 0.9 kg) per week.²⁵ The RCT conducted by Wein and colleagues²⁶ included provision of a dietary advice sheet (Target on Healthy Eating) for intervention and control groups, whereas the intervention group in addition received telephone contact with a dietitian every 3 months (so possibly 24 times over a 6- year follow-up). Interventions were delivered through a combination of one-on-one sessions with nutritionists, group education sessions, e-mail, and short messaging reminders.^{19,20,25,26} Women in the control groups received general dietary recommendations and did not receive counseling or personal advice. All interventions were focused 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^{19,20} or received a reminder of the need for regular exercise.²⁶ Diabetes-related outcomes following the interventions included fasting plasma glucose,^{19,20,27} serum fasting insulin,^{25,27} insulin secretion and sensitivity,²⁷ and T2DM defined using the 1985 World Health Organization guidelines²⁶ (Table 3, available at www.jandonline.org).

Observational Studies

Observational studies included cross-sectional studies from Canada (N=281),²⁹ Korea (N=381),²⁸ and Sweden (N=137),³⁰ a longitudinal study from the United States (NHSII [N= 3,976 to 4,502],²¹⁻²³ and a nested case-control study within the NHSII (n=347)²⁵ (Table 2). Women had a mean baseline age between 34 and 43 years, and a mean baseline BMI between 21 and 32. Studies were conducted at different times after GDM pregnancies, ranging from 6 to 12 weeks²⁸ to 14 years post-GDM pregnancy.²³

Dietary intake was assessed using validated food frequency questionnaires^{21-24,29,30} or a 24-hour dietary recall²⁹ (Table 4, available www.jandonline.org). Studies examined overall dietary patterns (low-carbohydrate dietary pattern²²; alternate Mediterranean diet (aMED); Dietary Approaches to Stop Hypertension (DASH) and alternate Healthy Eating Index (aHEI)²³; fruit and vegetable intake²⁹; frequency of meat, fish, and vegetarian meals³⁰; cooking fat used³⁰; macronutrients^{28,30}; branched chain amino acids²⁴; and iron intake²¹). Diabetes-related outcomes, including abnormal glucose tolerance, prediabetes, and T2DM, were defined according to the 2017 American Diabetes Association Guidelines,^{21-24,28} the 2013 Canadian Diabetes Association Guidelines²⁹ or the 1999 World Health Organization Guidelines³⁰ (Table 4, available at www.jandonline.org).

Table 5. 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

Author(s), year	Outcome incidence	Results	Covariates included in analysis
Ghani and colleagues, ¹⁹ 2014	Not applicable (continuous outcome)	<p>Changes in fasting plasma glucose (mean±standard deviation):</p> <p>Women with fasting insulin <2 µIU/mL^a:</p> <ul style="list-style-type: none"> Intervention group: 0.48±1.2 mmol/L^b Control group: 0.18±0.32 mmol/L^b (<i>P</i>=0.16 for intervention vs control) <p>Women with fasting insulin ≥2 µIU/mL^a:</p> <ul style="list-style-type: none"> Intervention group: -0.12±0.27 mmol/L^b Control group: 0.17±0.32 mmol/L^b (<i>P</i>=0.03 for intervention vs control) 	None/not reported
Shyam and colleagues, ²⁰ 2013	Not applicable (continuous outcome)	<p>Overall:</p> <p>Changes in fasting plasma glucose (mean±standard deviation):</p> <ul style="list-style-type: none"> Intervention group: -0.2±0.6 mmol/L^b Control group: 0.1±0.6 mmol/L^b (<i>P</i>≥0.05 for intervention vs control) <p>Changes in 2-h plasma glucose:</p> <ul style="list-style-type: none"> Intervention group: -0.2±2.8 mmol/L^b Control group: 0.8±2.0 mmol/L^b (<i>P</i>=0.03 for intervention vs control) <p>Women with baseline normoglycemia:</p> <p>Changes in fasting plasma glucose (mean±standard deviation):</p> <ul style="list-style-type: none"> Intervention group: 0.31±0.53 mmol/L^b Control group: 0.15±0.41 mmol/L^b (<i>P</i>=0.29 for intervention vs control) <p>Changes in 2-h plasma glucose (mean±standard deviation):</p> <ul style="list-style-type: none"> Intervention group: 0.24±2.04 mmol/L^b Control group: 0.88±1.2 mmol/L^b (<i>P</i>=0.22 for intervention vs control) <p>Women with baseline dysglycemia:</p> <p>Changes in fasting plasma glucose (mean±standard deviation):</p> <ul style="list-style-type: none"> Intervention group: 0.49±1.7 mmol/L^b Control group: 0.04±0.45 mmol/L^b (<i>P</i>=0.51 for intervention vs control) <p>Changes in 2-h plasma glucose (mean±standard deviation):</p> <ul style="list-style-type: none"> Intervention group: -0.49±4.05 mmol/L Control group: 0.47±2.22 mmol/L (<i>P</i>=0.57 for intervention vs control) 	Glycemic load and carbohydrate intake

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Table 5. 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 (*continued*)

Author(s), year	Outcome incidence	Results	Covariates included in analysis
Östman and colleagues, ²⁷ 2006	Not applicable (continuous outcomes)	No changes in fasting glucose, fasting insulin, and insulin sensitivity after either intervention No changes in insulin secretion after high glycemic index and low-fiber bread products Changes in insulin secretion after low glycemic index and high fiber bread products: 1,185.4±264 μ U/mL ^a min (preintervention) to 751.4±141 μ U/mL ^a min (postintervention) at 0-60 min ($P<0.05$)	None/not reported
Wein and colleagues, ²⁶ 1999	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 body mass index and change in body mass index
Peterson and colleagues, ²⁵ 1995	Not applicable (continuous outcome)	Serum fasting insulin at baseline, end of first intervention, and end of second intervention, respectively (mean±standard deviation): <ul style="list-style-type: none"> 40% Carbohydrate group (first intervention): 17±6, 12±7, 15±12 mU/L^c 55% Carbohydrate group (first intervention): 24±13, 22±6, 26±10 mU/L^c Differences between treatment groups were not significant ($P>0.05$)	None/not reported

^aTo convert μ U/mL insulin to pmol/L, multiply μ U/mL by 6.945. To convert pmol/L insulin to μ U/mL, multiply pmol/L by 0.14. Insulin of 2 μ U/mL=13.89 pmol/L.

^bTo convert mmol/L glucose to mg/dL, multiply mmol/L by 18.02. To convert mg/dL glucose to mmol/L, multiply mg/dL by 0.0555. Glucose of 6.1 mmol/L=109.92 mg/dL.

^cTo convert mU/L insulin to pmol/L, multiply mU/L by 6.954. To convert pmol/L to mU/L, multiply pmol/L by 0.144. Insulin of 17 mU/L=118.065 pmol/L.

Effects of Dietary Interventions on Diabetes Outcomes

Results from dietary intervention studies showed mixed effects on diabetes outcomes (Table 5). Findings from the low-glycemic index, energy restricted RCT showed no significant changes in fasting glucose levels after 6²⁰ and 12¹⁹ months in the overall population, but 2-hour plasma glucose had declined significantly more for women in the intervention compared with the control group after 6 months.²⁰ 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 μ U/mL (13.89 pmol/L) but not with baseline fasting insulin < 2 μ U/mL (13.89 pmol/L).¹⁹ Findings from the crossover trial providing low-glycemic and high-fiber bread products showed no changes in fasting glucose, fasting insulin, and insulin sensitivity, but insulin secretion was lower after consuming the low-glycemic and high-fiber bread products for 3 weeks compared with before.²⁷ An intervention, with a median follow-up of 51 months (ie, 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 toward a beneficial effect (relative risk 0.63, 95% CI 0.35 to 1.14) relative to the control group who received no dietitian contact.²⁶ A crossover 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.²⁵

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 6). Prevalence of prediabetes was 34%²⁹ and 42%²⁹ in two cross-sectional studies, and incidence of T2DM ranged from 7% at 6 to 12 weeks post-GDM pregnancy²⁸ to 16% at 14 years post-GDM pregnancy.^{21,22}

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.²² 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

Table 6. 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

Author(s), year	Outcome incidence	Results	Covariates included in analysis
Tobias and colleagues, ²⁴ 2018	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 (<i>P</i> trend=0.004) Leucine: 4.66, 95% CI 1.60-13.53 (<i>P</i> trend=0.01) Valine: 5.71, 95% CI 1.85-17.60 (<i>P</i> trend=0.009) Total branched-chain amino acids: 4.63, 95% CI 1.61-13.36 (<i>P</i> 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 ^a , Alternative Healthy Eating Index-2010 adherence dietary quality score
Mercier and colleagues, ²⁹ 2018	n=126 (45%) abnormal glucose tolerance cases, including 34% prediabetes and 11% type 2 diabetes	Women with abnormal glucose tolerance had significantly lower fruit and vegetable servings (mean $\pm$ standard deviation: 6.5 $\pm$ 0.2) and vegetables servings (3.9 $\pm$ 0.2) and tended to have lower fruit servings (2.6 $\pm$ 0.2) than women with normal glucose tolerance (7.4 $\pm$ 0.2, 4.5 $\pm$ 0.2, and 3.0 $\pm$ 0.1, respectively) (<i>P</i> =0.001, <i>P</i> =0.04, and <i>P</i> =0.10, respectively). Odds ratios for abnormal glucose tolerance: Fruit and vegetables per 1 serving: 0.88, 95% CI 0.81-0.97 Vegetables per 1 serving: 0.88, 95% CI 0.78-1.00 Fruit per 1 serving: 0.88, 95% CI 0.76-1.02 Fruit and vegetables <7 vs ≥ 7 serving: 1.84, 95% CI 1.13-3.00	Age and BMI
Andersson-Hall and colleagues, ³⁰ 2018	n=32 (23.4%) impaired glucose tolerance cases and n=17 (12.4%) type 2 diabetes cases	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 (<i>P</i> >0.05). Compared with women with normal glucose tolerance, women with impaired glucose tolerance (<i>P</i> =0.01) and type 2 diabetes (<i>P</i> =0.01) had lower proportions of butter used for cooking, and women with type 2 diabetes also had higher proportion of margarine used for cooking (<i>P</i> =0.004).	Age, ethnicity, BMI
Bao and colleagues, ²¹ 2016	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 heme iron intake: 1.80, 95% CI 1.18-2.74 for top (1.5 mg/d) vs bottom (0.7 mg/d) category Dietary nonheme 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, <i>trans</i> fat, cholesterol, animal and vegetable protein, glycemic load, cereal fiber, calcium, magnesium, vitamin C, supplemental iron (for heme and nonheme iron analysis), and total dietary iron (for supplemental iron analysis)

(continued on next page)

Table 6. 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 (*continued*)

Author(s), year	Outcome incidence	Results	Covariates included in analysis
Bao and colleagues, ²² 2016	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 (<i>P</i> trend≤0.001) and 1.36, 95% CI 1.04-1.78 (<i>P</i> trend=0.003) Animal low-carbohydrate diet score: 2.18, 95% CI 1.68-2.83 (<i>P</i> trend≤0.001) and 1.40, 95% CI 1.06-1.84 (<i>P</i> trend=0.004) Vegetable-carbohydrate diet score: 1.29, 95% CI 1.00-1.67 (<i>P</i> trend=0.14) and 1.19, 95% CI 0.91-1.55 (<i>P</i> trend=0.50)	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, glycemic index
Tobias and colleagues, ²⁴ 2012	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 (<i>P</i> trend=0.002) and 0.76, 95% CI 0.55-1.05 (<i>P</i> trend=0.13) Dietary Approaches to Stop Hypertension: 0.54, 95% CI 0.39-0.73 (<i>P</i> trend≤0.001) and 0.68, 95% CI 0.49-0.94 (<i>P</i> trend=0.04) Alternate Healthy Eating Index: 0.43, 95% CI 0.31-0.59 (<i>P</i> trend≤0.001) and 0.65, 95% CI 0.46-0.92 (<i>P</i> 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)
Kim and colleagues, ²⁸ 2011	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; and total, animal, and monounsaturated fat. There were no differences in intake of carbohydrates, plant protein, plant, saturated-, polyunsaturated-, and n-3 and n-6 fatty acids, and fiber	Prepregnancy BMI

^aBMI=body mass index.

confounders such as age, ethnicity, BMI, parity, lifestyle, and other dietary factors.²³ Although adjustment for BMI attenuated the risk estimates, statistically significant associations remained when BMI was added to the model.^{22,23} 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 heme iron were at higher risk of developing T2DM, whereas high dietary nonheme iron intake was associated with a lower risk after adjustment for key confounders.²¹ 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.²⁹ Kim and colleagues²⁸ 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 prepregnancy 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.³⁰ 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.³⁰

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 4 and 5, available at www.jandonline.org). All five studies had unclear risk of detection and attrition bias, whereas 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 Newcastle-Ottawa Scale (Table 7, available at www.jandonline.org). Main concerns were representativeness of the study sample (no random sample of women in the community), 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 adequacy of follow-up rate (studies either did not report on the follow-up rate, or did not describe the lost population in the case that 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 heme 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, whereas findings from two cross-sectional studies on total energy, protein, and fat intake in relation to 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 Whereas previous reviews reported on only two diet-alone interventions,^{20,26} this review identified five articles that reported on four studies.^{19,20,25-27} These trials were based on small samples and not powered to detect significant differences.^{19,20,25-27} These trials also varied in terms of intervention content (advice focused on carbohydrate quality,^{19,20,27} carbohydrate quantity²⁵ or overall diet in line with national guidelines²⁶), and examined different outcome measures (glucose,^{19,20,27} insulin,^{25,27} or T2DM²⁶). Although findings from

intervention studies generally indicated trends toward 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.³¹ Findings from that intensive intervention that focused on diet and physical activity to achieve and maintain weight loss of at least 7% of initial body weight showed >50% reduction in the risk of developing T2DM in women at high risk of T2DM including women with previous GDM³¹; 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,²⁴ total and heme iron,²¹ and a diet relatively low in carbohydrates and high in animal fat and protein,²² and beneficial associations for diets rich in fruit, vegetables, nuts, fish, and legumes, and low in red and processed meats and sugar-sweetened beverages.^{23,29} These results support dietary recommendations for the general population^{32,33} and for diabetes prevention.³⁴ Findings from observational studies were rated to be of medium to high quality (score of 5 to 7 out of 9), and observed associations were based on analyses adjusted for BMI^{21-24,28,29} and physical activity.²¹⁻²⁴ These findings therefore suggest that, whereas BMI partly attenuated the associations,^{22,23} consuming a healthy diet may help reduce T2DM risk independent of BMI.

Implications for Practice and Research

There is strong evidence that the majority of T2DM cases in the general population can be prevented through a healthy lifestyle,^{34,35} yet lifestyle interventions targeting women with prior GDM have only recently emerged. With the growing rates of GDM, T2DM, and the 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 <25% of women returning for a postnatal glucose tolerance test, mainly due to lack of time and awareness of risks.³⁶ Previous studies have shown poor diet quality and

low adherence to dietary recommendations among women with a GDM history,^{37,38} and a significant knowledge gap on future health risks and the recommended lifestyle modifications.³⁸ Although 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 by 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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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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AUTHOR CONTRIBUTIONS

E. D'Arcy, J. Rayner, and D. A. J. M. Schoenaker conducted the research. E. D'Arcy and D. A. J. M. Schoenaker analyzed the data, wrote the manuscript, and had primary responsibility for the final content of the manuscript. All authors designed the research and read and approved the final manuscript.

Search no.	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.	

Figure 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. CINAHL=Cumulative Index to Nursing and Allied Health Literature.

Table 3. 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

Author(s), year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
Ghani and colleagues, ¹⁹ 2014	<p>(1) Low glycemic index intervention group: Women received conventional healthy dietary recommendations including nutrition education at baseline through a structured 1-on-1 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 fiber intake. The goal was to achieve a 5%-7% reduction in body weight when BMI^a >23 or to maintain current weight when BMI <23. Energy requirements were calculated, and women with BMI >23 had a 500-kcal energy restricted diet, capped at 1,800 kcal/d. Women were followed-up quarterly, and received fortnightly reminders using e-mail 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 min at least 5 times a week.</p> <p>In addition to conventional healthy dietary recommendations, women received low glycemic index education, including advice on how to choose low glycemic index options in place of high glycemic index staples like bread, rice, and breakfast cereal. Women were asked to restrict rice intake to once per day and include 1 low glycemic index food at each meal. (2) Control group: Women received conventional healthy dietary recommendations only</p>	Compliance was monitored through assessments of dietary intake (3-d dietary records at baseline, 3 and 6 mo), and nutrition knowledge assessment pertaining to the group-specific concepts. After 6 mo, mean percentage of calories from carbohydrates, and glycemic index and glycemic load were significantly lower in the intervention compared with the control group. Fiber intake was significantly higher in the intervention group	<p>Plasma glucose was measured on blood samples drawn in the fasting state (12 h). Diagnostic criteria: Not applicable (continuous outcome)</p>
Shyam and colleagues, ²⁰ 2013	Similar to Ghani and colleagues, ¹⁹ 2014	Similar to Ghani and colleagues, ¹⁹ 2014	<p>Plasma glucose was measured on blood samples drawn in the fasting state (12 h). 2-h postload blood glucose was measured after a 75 g oral glucose tolerance test. Diagnostic criteria: Not applicable (continuous outcome)</p> <p><i>(continued on next page)</i></p>

Table 3. 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 (*continued*)

Author(s), year	Intervention goals and content	Intervention compliance	Outcome assessment and criteria
Östman and colleagues, ²⁷ 2006	(1) Low glycemic index and high fiber bread products (2) High glycemic index and low-fiber bread products Participants were asked to eat 7 slices of low glycemic index/high-fiber or high-glycemic index/low-fiber bread across 3 meals/d. 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 euglycemic-hyperinsulinemic clamp. Diagnostic criteria: Not applicable (continuous outcomes)
Wein and colleagues, ²⁶ 1999	(1) Lifestyle intervention: Women were given dietary questionnaires and a standard dietary advice sheet ("Target on Healthy Eating") and in addition had 3-monthly telephone contacts 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 assessed 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 Organization guidelines 1985
Peterson and colleagues, ²⁵ 1995	(1) Dietary intervention 1: 40% carbohydrates (2) Dietary intervention 2: 55% carbohydrates 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 energy prescription consisted of 16.5 kcal/kg body weight at entry into the trial with a mean energy consumption of 1,500 kcal/24 h for both groups The anticipated weight loss was calculated at 1 to 2 lb/wk	Women were instructed to maintain a daily diary wherein they recorded all foods consumed by time of day. These were reviewed every 1 or 2 wk. All participants showed significant weight loss during the first 6 wk regardless of treatment assignment. Weight loss attenuated during the second 6 wk of the study also regardless of treatment assignment. The diet score at enrolment did not differ between the intervention and control groups (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; $P=0.32$)	Serum fasting insulin was assessed at baseline and after 6 wk and 12 wk Diagnostic criteria: Not applicable (continuous outcome)

^aBMI=body mass index.

Table 4. 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

Author(s), year	Exposure assessment	Outcome assessment and criteria
Mercier and colleagues, ²⁹ 2018	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 ^a and normal 2-h postoral glucose tolerance test glucose <7.8 mmol/L ^a Impaired glucose tolerance: normal fasting glucose <6.1 mmol/L ^a and 2-h postoral glucose tolerance test glucose 7.8 to 11.0 mmol/L ^a Prediabetes: Impaired fasting glucose and/or impaired glucose tolerance and/or glycated hemoglobin between 6.0% and 6.4% Type 2 diabetes: fasting glucose ≥7.0 mmol/L ^a and/or 2-h postoral glucose tolerance test glucose ≥11.1 mmol/L ^a and/or glycated hemoglobin ≥6.5%
Bao and colleagues, ^{21,22} 2016	Validated semi-quantitative food frequency questionnaire.	Type 2 diabetes diagnosis was self-reported. A validation study showed 94% of self-reported cases were confirmed by medical records
Tobias and colleagues, ^{23,24} 2012 and 2018	Administered as part of survey questionnaire	Diagnostic criteria: American Diabetes Association Guidelines 1997 Type 2 diabetes: 1) One or more classic symptoms (eg, excessive thirst, polyuria, unintentional weight loss, or hunger) plus elevated glucose concentrations (fasting plasma glucose ≥7.0 mmol/L ^a or random plasma glucose ≥11.1 mmol/L ^a); 2) No symptoms reported but ≥2 elevated plasma glucose concentrations on more than 1 occasion (fasting glucose ≥7.0 mmol/L ^a ; random glucose ≥11.1 mmol/L ^a ; or 2-h postoral glucose tolerance test glucose ≥11.1 mmol/L ^a); or 3) Treatment with insulin or an oral hypoglycemic agent. Before 1998, fasting plasma glucose ≥7.8 mmol/L ^a was used instead of ≥7.0 mmol/L ^a according to the criteria of the National Diabetes Data Group
Andersson-Hall and colleagues, ³⁰ 2018	Validated semiquantitative food frequency questionnaire. Completed during study visit	Blood samples were taken at the study visit 6 y after pregnancy. Diagnostic criteria: 1999 World Health Organization guidelines Type 2 diabetes: fasting glucose ≥7.0 mmol/L ^a or 2-h postoral glucose tolerance test glucose ≥11.1 mmol/L ^a Impaired glucose tolerance: fasting glucose 6.1 to 6.9 mmol/L ^a and/or 2-h postoral glucose tolerance test glucose 7.8 to 11.0 mmol/L ^a
Kim and colleagues, ²⁸ 2011	24-h Recall Administered by a skilled dietitian	Type 2 diabetes and prediabetes were assessed at a clinical visit at 6-12 wk postpartum Diagnostic criteria: American Diabetes Association Guidelines 1997 Type 2 diabetes: fasting glucose >7.0 mmol/L ^a or 2-h glucose >11.1 mmol/L ^a Impaired glucose tolerance: fasting glucose <6.1 mmol/L ^a and 2-h glucose 7.8 to 11.0 mmol/L ^a Impaired fasting glucose: fasting glucose 6.1 to 6.9 mmol/L ^a inclusive with 2-h glucose <7.8 mmol/L ^a

^aTo convert mmol/L glucose to mg/dL, multiply mmol/L by 18.02. To convert mg/dL glucose to mmol/L, multiply mg/dL by 0.0555. Glucose of 6.1 mmol/L=109.92 mg/dL.

Table 7. 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

Study	Selection				Comparability	Outcome			Total score
	Representativeness of exposed cohort ^b	Selection of nonexposed cohort ^c	Ascertainment of exposure ^d	Outcome not present at start of study ^e	Comparability of cases and controls on basis of design or analysis ^f	Outcome assessment ^g	Adequate duration of follow-up ^h	Adequacy of follow-up rate ⁱ	
Tobias and colleagues, ²⁴ 2018	C	A★	B★	A★	A★ B★	B★	A★	D	7
Mercier and colleagues, ²⁹ 2018	B★	A★	B★	B	A★	A★	A★	D	6
Andersson-Hall and colleagues, ³⁰ 2018	B★	A★	B★	B	A★	A★	A★	B★	7
Bao and colleagues, ²¹ 2016	C	A★	B★	A★	A★ B★	B★	A★	D	7
Bao and colleagues, ²³ 2016	C	A★	B★	A★	A★ B★	B★	A★	D	7
Tobias and colleagues, ²⁴ 2012	C	A★	B★	A★	A★ B★	B★	A★	D	7
Kim and colleagues, ²⁸ 2011	A★	A★	C	A★	-	A★	A★	C	5

^aRisk of bias was assessed using the Newcastle-Ottawa Scale. 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.¹⁸

^bRepresentativeness 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 (eg, only specific occupation); (D) no description of the derivation of the cohort.

^cSelection of the nonexposed 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 nonexposed cohort.

^dAscertainment of exposure was scored as (A [star]) secure record (eg, controlled diet); (B [star]) structured interview/validated dietary recall/diet history/food frequency questionnaire; (C) written self-report (eg, nonvalidated dietary assessment); (D) no description.

^eDemonstration that outcome of interest was not present at start of study was scored as (A [star]) yes (no type 1 or type 2 diabetes before pregnancy and before study entry); (B) no.

^fComparability 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 (eg, parity, family history of diabetes, smoking, physical activity, other dietary factors).

^gOutcome assessment was scored as (A [star]) independent blind assessment (eg, hospital record/oral glucose tolerance test); (B [star]) record linkage or validated self-reported diagnosis; (C) self-report (not validated); (D) no description.

^hAdequate duration of follow-up for outcomes to occur was scored as (A [star]) yes, in the case that—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.

ⁱAdequacy 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 included and excluded participants) or ≤10% lost during follow-up; (C) follow-up rate <90% or no description of those lost; (D) no statement.

Figure 4. 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.¹⁶

Figure 5. 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.¹⁶