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Dietary interventions in pregnancy for the prevention of gestational diabetes: a literature review

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The aim of this review is to provide an overview of dietary interventions delivered during pregnancy for the prevention of gestational diabetes mellitus (GDM). GDM increases the risk of adverse pregnancy and neonatal outcomes, and also increases future cardiometabolic risks for both the mother and the offspring. Carrying or gaining excessive weight during pregnancy increases the risk of developing GDM, and several clinical trials in women with overweight or obesity have tested whether interventions aimed at limiting gestational weight gain (GWG) could help prevent GDM. Most dietary interventions have provided general healthy eating guidelines, while some had a specific focus, such as low glycaemic index, increased fibre intake, reducing saturated fat or a Mediterranean-style diet. Although trials have generally been successful in attenuating GWG, the majority have been unable to reduce GDM risk, which suggests that limiting GWG may not be sufficient in itself to prevent GDM. The trials which have shown effectiveness in GDM prevention have included intensive face-to-face dietetic support, and/or provision of key foods to participants, but it is unclear whether these strategies could be delivered in routine practice. The mechanism behind the effectiveness of some interventions over others remains unclear. Dietary modifications from early stages of pregnancy seem to be key, but the optimum dietary composition is unknown. Future research should focus on designing acceptable and scalable dietary interventions to be tested early in pregnancy in women at risk of GDM.

Keywords: Pregnancy: Gestational diabetes: Diet

Obesity in pregnancy

Over the past four decades, the prevalence of obesity (as defined by the BMI) in adults has risen dramatically[1], and obesity has become one of the most commonly presenting risk factors in obstetric practice. The prevalence of obesity in pregnancy rose from 9–10 % in the early 1990s, to 16–19 % in the subsequent decade[2,3], and in 2017, data from the UK Maternity Services Dataset from booking appointments showed that 18·3 % of women presented with obesity, and 3·3 % with severe obesity[4].

Obesity significantly increases the risk of pre-pregnancy, pregnancy and postpartum complications. Women with obesity are at high risk of developing pre-pregnancy type 2 diabetes mellitus and chronic hypertension[5,6], which in turn increase the risk of adverse outcomes for both the mother and the offspring,

Abbreviations: GDM, gestational diabetes mellitus; GWG, gestational weight gain; HCP, healthcare professional; RADIEL, Finnish gestational diabetes prevention; RCT, randomised controlled trial.

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including preeclampsia, requiring induction of labour, miscarriage, fetal macrosomia or delivery of a large-for-gestational age infant, congenital abnormalities, preterm delivery, caesarean section and perinatal death[6–8]. Obesity also independently directly affects these outcomes[9–15]. In later stages of pregnancy, women with obesity are four to nine times more likely to develop gestational diabetes mellitus (GDM)[16], and three to ten times more likely to develop preeclampsia[16–18], compared to women in the normal BMI range.

GDM is the most common obesity-related complication during pregnancy[19], and most strongly associated with future chronic disease for the mother and the offspring[20]. This review provides an overview of dietary interventions delivered during pregnancy for the prevention of GDM.

Excessive weight as a risk factor for gestational diabetes mellitus

GDM is hyperglycaemia that develops or is recognised for the first time during pregnancy, mainly in the second or third trimester, that does not include pre-pregnancy overt diabetes[21]. It is a multifactorial disease, which develops as a result of genetic, epigenetic and environmental factors. Among modifiable risk factors for GDM, prenatal maternal excess weight is the strongest[22]. The risk of GDM is almost 3-fold higher in women with a BMI of 30–34·9 kg/m^2, and 4-fold higher in women with a BMI of 35–39·9 kg/m^2, compared to women with BMI <30 kg/m^2[23]. In a recent systematic review and meta-analysis[22], the pooled estimates (adjusted OR) of GDM risk in women in the underweight, overweight and obese categories were 0·68, 2·01 and 3·98 respectively, and there was a dose–response relationship between increasing BMI and GDM risk, with GDM risk increasing 4 % per unit increase in BMI, in both unadjusted and adjusted models for confounders.

While evidence has consistently demonstrated that starting pregnancy with excess weight increases the risk of GDM, there seems to also be an association with gestational weight gain (GWG). Evidence from observational studies has shown that increased GWG is associated with adverse pregnancy outcomes, including GDM, as well as caesarean delivery, hypertensive disorders of pregnancy and large-for-gestational age infants[24–26]. More specifically, a greater rate of, and excessive GWG, especially in the first trimester, have been associated with 3-to-4-fold increased risk of GDM[27–29]. In 2009, the US Institute of Medicine issued guidelines for the appropriate amount of GWG, according to women's BMI at the beginning of pregnancy, including recommendations for rate of weight gain in each trimester[30]. These recommendations have not been formally adopted in the UK, and currently, there are no UK-specific guidelines on the ideal GWG[31]. For women with a BMI of 30 kg/m^2 and above, the National Institute for Health and Care Excellence recommends referral to a healthcare professional (HCP) for personalised lifestyle advice[31,32].

Since the publication of the National Institute for Health and Care Excellence guidance on weight management in pregnancy, systematic reviews[33–36], cohort studies[37–40] and randomised controlled trials (RCT)[41–44] have shown that GWG above or below the Institute of Medicine recommendations increased adverse pregnancy outcomes. More recently, a systematic review, meta-analysis and meta-regression of diverse international cohorts, looking at the association of GWG above or below Institute of Medicine thresholds with pregnancy outcomes, confirmed the earlier findings, although could not assess the impact on GDM, because of heterogeneity in the definitions used, and inconsistency in findings regarding GDM risk, and in treatments used[45]. Evidence from RCT has also previously suggested that dietary interventions to reduce overweight or obesity during pregnancy are not harmful to the mother or the fetus[34]. In view of the aforementioned, it remains debatable if weight maintenance for women with obesity during pregnancy should be recommended[46].

Interventions for the prevention of gestational diabetes mellitus

There has been a substantial amount of research evaluating interventions aiming at reducing the risk of GDM. In the UK, guidelines recommend that general healthy eating advice should be offered early in pregnancy at the booking appointment, but the content and structure of the advice is not specified for the purpose of preventing GDM[47]. Similarly, although physical activity recommendations are more specific than dietary recommendations[48], there is no advice about what information (if any) women should be given to prevent GDM. Several interventions have aimed at limiting GWG, often as a surrogate measure for clinical outcomes, based on the assumption that lower GWG will in turn improve maternal and neonatal outcomes, including preventing GDM[49,50]. In this review, we were specifically interested in the characteristics, content and effect of some of the most known and/or recent preventative dietary interventions, which we have summarised in Table 1, and commented on next.

Intervention content

Most dietary interventions[49,50] promoted general healthy eating advice according to national recommendations, with emphasis on restriction of sugar intake and increased fibre intake. In women with overweight or obesity, some, but not all interventions also encouraged reduced energy intake. The majority of dietary interventions have been combined with some physical activity advice or programme. The behavioural basis for the interventions is often not described, but where it is, interventions were informed by elements from the control and/or social cognitive theories, and involving goal-setting, self-monitoring of goals and weight, problem solving and in some cases, social support and motivational strategies.

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Table 1. Summary of characteristics of some known GDM prevention trials and their effects

	Participants	Interventions							Effect on GWG (kg intervention *v.* control)	Effect on GDM (% intervention *v.* control, noting with * when primary outcome)
						Sessions				
Study	Eligibility	Content	Provider	Mode	Level of personal contact	*N*	Frequency	Length per session		
Dodd 2014[42], Australia	BMI ≥25 kg/m^2 at antenatal booking Singleton pregnancy 10–20 weeks' gestation	**Control:** Standard care **Intervention:** Healthy eating advice based on national guidelines, especially to maintain balance of carbohydrates, fat and protein and reduce foods high in refined carbohydrates and saturated fat, increase fibre intake+ PA: increase amount of walking and incidental activity With opportunity to problem solve for barriers.	Research dietitian and trained research assistants	Individual	Face-to-face and telephone	One-off consultation/ planning session+ 2 phone sessions+ 2 follow-up visits for reinforced lifestyle advice (unclear if done as part of routine appointments)	Consultation/planning session within 2 weeks of randomisation+ 1 phone session at 22, and 1 at 24 weeks' gestation+ 1 visit at 28, and 1 at 36 weeks' gestation	Not reported	Between measurement at booking appointment and 36 weeks' gestation (or closest to birth): −0·04 (95 % CI−0·55, 0·48), adjusted	RR 1·21 (95 % CI 0·96, 1·52), adjusted
Petrella 2014[67], Italy	Pre-pregnancy BMI ≥25 kg/m^2 Aged ≥18 years Singleton pregnancy No previous GDM <20 weeks' gestation	**Control:** Simple nutritional booklet about lifestyle based on national guidelines for healthy eating in pregnancy **Intervention:** Therapeutic lifestyle changes group diet: 6276 kJ/day, with addition of 837 and 1255 kJ/day for women with obesity and overweight respectively, with primary focus on decreasing high-GI foods, and substituting them with alternatives, redistributing the number of meals along the day and with macronutrient content of 55 % of energy intake from carbohydrate (at least 225 g/day), 20 % protein, and 25 % fat (mostly unsaturated)+ Counselling session, including advice on appropriate GWG+ PA advice on developing a more active lifestyle, generally consistent with the advice for the general population.	N/A Dietitian in collaboration with gynaecologist	Individual Individual	N/A Face-to-face	N/A 5: Initial counselling session and follow-up appointments (unclear if part of routine care or extra)	N/A Counselling session at baseline, and then follow-up visits for adherence at 16, 20, 28 and 36 weeks' gestation	N/A Counselling session: 60 min Follow-up sessions: not reported	Between measurement at enrolment (about 12 weeks' gestation) and delivery: Intervention: 8·8(SD 6·5) Control: 10·4(SD 5·0) *P* value from *t*-test non-significant	Intervention: 23·3 % Control: 57·1 % *P* value from *t*-test = 0·009, R-square from adjusted logistic regression = 0·15; *P* = 0·014
Poston 2015[41], UK	15–18 weeks' gestation Aged >16 years BMI ≥30 kg/m^2 Singleton pregnancy	**Control:** Standard antenatal care **Intervention:** Healthy eating, not necessarily reducing energy intake, adjusted to individual diet and culture, swapping carbohydrate-rich foods with a medium-to-high GI, with lower-GI foods, and reducing saturated fat+ PA advice on incremental increases in walking at a moderate intensity, with additional options for women already engaging in some PA.	Health trainer	Individual	Primarily face-to-face, but also telephone or email if missed a session	8	Weekly	60 min	Between estimated weight before pregnancy and measured at delivery: –0·55 (95 % CI –1·08, –0·02), adjusted between estimated weight before pregnancy and measured at 27–28 weeks' gestation: –0·42 (95 % CI –0·75, –0·09), adjusted	RR* –1·2 (95 % CI –5·8, 3·8), adjusted

Table 1. (*Cont.*)

Study	Participants: Eligibility	Interventions: Content	Provider	Mode	Level of personal contact	Sessions: *N*	Sessions: Frequency	Sessions: Length per session	Effect on GWG (kg intervention *v.* control)	Effect on GDM (% intervention *v.* control, noting with * when primary outcome)
Herring 2016[55], USA	Aged ≥18 years Self-identification as African American <20 weeks' gestation First trimester BMI 25–45 kg/m^2 Medicaid recipient Cell phone ownership with unlimited text messaging Facebook member	**Control:** Standard care + Information on optimal GWG	N/A	Individual	N/A	N/A	N/A	N/A	Between first measured weight early in pregnancy and last measured before delivery: −3·1 (95 % CI −6·2, −0·1), adjusted	Intervention: 4 % Control: 4 % Fisher's exact $P = 1·00$
		Intervention: Technology-based behavioural lifestyle intervention: limiting sugary drinks to 1 cup/day, limiting junk and high-fat food to no more than 1/day, stick with 1 plate of food per meal, as well as increasing walking gradually to 5000 steps/day, and self-weighing weekly with encouragement to meet IOM recommendations Delivered through daily text messages tailored to each behavioural goal, plus self-monitoring text messages 3–4 times/week to enhance behavioural adherence, accompanied by feedback from the health coach. Participants also received raffle entries as motivator to respond to self-monitoring prompts+ Social media group providing a forum for support and additional behavioural skills training via links and to websites and videos+ Counselling phone calls to reinforce the skills and problem-solve.	Health coach	Individual	Face-to-face, telephone and text	8 adjunct to routine appointments: 1 baseline face-to-face, and the rest on the telephone	One-off face-to-face baseline session Phone sessions: weekly for the first 2 study weeks, and then twice a month thereafter	Baseline session: not reported Phone sessions: 15–20 min		
Koivusalo 2016[51], Finland	Planning pregnancy or <20 weeks' gestation Pre-pregnancy BMI ≥30 kg/m^2 and/or history of GDM Aged ≥18	**Control:** General information leaflets on diet and PA + Health education as part of usual care	Study nurses	Individual	Leaflets	3 during pregnancy, but for study assessments (in addition to antenatal appointments)	Every 3 months during pregnancy (but for study assessments)	Not reported	Between measured at <20 weeks' gestation and third trimester: −0·5 (95 % CI −1·1, 0·05); $P = 0·072$, unadjusted; $P = 0·039$ adjusted Between measured at <20 weeks' gestation and third trimester: −0·2 (95 % CI −1·1, 0·8); $P = 0·74$, unadjusted; $P = 0·37$, adjusted	Intervention: 13·9 % (95 % CI 8·7, 20·6) Control: 21·6 % (95 % CI 14·7, 29·8) Adjusted P* from logistic regression = 0·044
		Intervention during pregnancy: Advice to not gain weight during the first two trimesters if BMI ≥30+ Dietary advice based on national guidelines: optimising fruit and vegetable consumption, whole-grain products, low-fat dairy, vegetable fats, fish and low-fat meat, reducing sugary foods, following the plate model (half vegetables, quarter starchy foods, quarter protein foods), providing (6694–7531 kJ/day, 40–50 % of energy from carbohydrates, 30–40 % fat and 20–25 % protein)+ Group session with a dietitian+ Moderate PA with planning and updating an individual PA programme.	Study nurses and dietitians	Individual and group	Face-to-face	At least 3 (in addition to antenatal appointments): 1 group session+ 3 study visits, with additional visits if needed (e.g. if goals were not met)	Every 3 months during pregnancy	Group session: 120 min Individual sessions: not reported		

Bruno 2017[66], Italy	Pre-pregnancy BMI ≥25 kg/m^2 Aged >18 years Singleton pregnancy 9–12 weeks' gestation	**Control:** Moderate PA advice + General recommendations on diet based on national guidelines: avoid foods with high GI, reduce saturated fat, increase vegetable and fruit with low GI, but no specific indication on food quantities, energy intake, meal composition or meal distribution	Dietitian	Individual	Face-to-face	1 counselling session	One-off counselling session Study follow-up visits at 16, 20, 28 and 36 weeks' gestation	60 min	Between self-reported pre-pregnancy weight and measured at 28 weeks' gestation: Intervention: 7·2(SD 5·7) Control: 6·8(SD 5·5) *P* from *t*-test = 0·642	Intervention: 18·8 % Control: 37·1 %, adjusted *P** from logistic regression = 0·019
		Intervention: Moderate PA advice+ Personalised dietary intervention: low-GI diet, low saturated fat intake, 6276 kJ/day with extra 837 and 1255 kJ/day for women with obesity and overweight due to giving PA advice, based on plant foods, cereals, legumes and fish, with olive oil as the main source of fat, and no-to-moderate consumption of red wine. Goal was for 55 % of total energy from carbohydrates (80 % complex, 20 % simple, but minimum 225 g/day), 20 % protein and 25 % fat.	Dietitian	Individual	Face-to-face	1 initial counselling session+ 4 follow-up counselling sessions	Counselling at enrolment, and then at 16, 20, 28 and 36 weeks' gestation	Initial counselling: 60 min Follow-up counselling: not reported	Between self-reported pre-pregnancy weight and measured at 36 weeks' gestation: Intervention: 9·5(SD 6·4) Control: 9·1(SD 6·7) *P* from *t*-test = 0·749 Between self-reported pre-pregnancy and at delivery weight: Intervention: 10·1(SD 7·4) Control: 9·4(SD 6·8) *P* from *t*-test = 0·557	
Assaf-Balut 2017[58], Spain	8–12 weeks' gestation at first gestational visit, and 12–14 weeks' gestation at first study visit Aged ≥18 years Singleton pregnancy Acceptance and consent of participation in the study	**Control:** Mediterranean-style diet, with key recommendation to restrict consumption of dietary fat, including extra virgin olive oil and nuts+ Individualised dietary advice at each visit according to GWG (e.g. reduction in energy if excessive GWG)+ Walk at least 30 min/day	Midwives	Unclear, but suggestive of just individual	Face-to-face	4	Dietary advice 1 week after enrolment+ Nutritional reinforcement at standard routine care appointments: at 12–14, 24–28 and 36–38 weeks' gestation, and at delivery	Not reported	Between measured weight at 12–14 and 24–28 weeks' gestation: Intervention: 5·6(SD 2·8) Control: 5·2(SD 2·5) *P* from *t*-test = 0·052	RR* 0·75 (95 % CI 0·57, 0·98), adjusted
		Intervention: Mediterranean-style diet, with key recommendation to consume at least 40 ml of extra virgin olive oil, and a handful of pistachios (25–30 g) daily, provided by the study+ Individualised dietary advice at each visit according to GWG (e.g. reduction in energy if excessive GWG)+ Walk at least 30 min/day.	Dietitian	Individual and group	Face-to-face	4	Initial group session 1 week after enrolment+ Nutritional reinforcement during standard routine care appointments: at 12–14, 24–28 and 36–38 weeks' gestation	Group session: 60 min Nutritional reinforcement sessions: not reported	Between measured weight at 12–14 and 36–38 weeks' gestation: Intervention: 9·4(SD 4·3) Control: *P* from *t*-test = 9·9(SD 4·7)	

Table 1. (*Cont.*)

	Participants	Interventions							Effect on GWG (kg intervention *v.* control)	Effect on GDM (% intervention *v.* control, noting with * when primary outcome)
						Sessions				
Study	Eligibility	Content	Provider	Mode	Level of personal contact	*N*	Frequency	Length per session		
Simmons 2017[76], European countries, including the UK	Aged ≥18 years <20 weeks' gestation At risk of GDM because of pre-pregnancy BMI ≥29 kg/m^2	**Control:** Usual care							Between measured weight at <20 and 24–28 weeks' gestation: HE + PA *v.* UC: −1·19 (95 % CI −1·90, −0·49), adjusted HE *v.* UC: −0·64 (95 % CI −1·33, 0·06), adjusted PA *v.* UC: 0·12 (95 % CI −0·58, 0·82), adjusted Between measured weight at <20 and 24–28 weeks' gestation: HE + PA *v.* UC: −2·02 (95 % CI −3·58, −0·46), adjusted HE *v.* UC: −0·28 (95 % CI −1·67, 1·12), adjusted PA *v.* UC: 0·01 (95 % CI −1·38, 1·39), adjusted	Between <20 and 24–28 weeks' gestation: HE + PA *v.* UC: OR 1·10 (95 % CI 0·48, 2·49), adjusted HE *v.* UC: OR 1·48 (95 % CI 0·69, 3·15), adjusted PA *v.* UC: OR 1·21 (95 % CI 0·55, 2·67), adjusted Between <20 and 24–28 weeks' gestation: HE + PA *v.* UC: OR 0·80 (95 % CI 0·43, 1·49), adjusted HE *v.* UC: OR 1·33 (95 % CI 0·73, 2·40), adjusted PA *v.* UC: OR 0·86 (95 % CI 0·47, 1·58), adjusted
		Healthy eating: Advice to reduce sugary drinks and replace them with alternatives, eat more non-starchy vegetables, choose higher-fibre foods over low-fibre ones, watch portion size, increase intake of proteins, reduce fat intake by reducing foods such as fast food, fried foods and eat less carbohydrates by reducing intake of starchy foods+ Advice to achieve a maximum of 5 kg GWG for those with BMI 30 and above, or minimise further GWG if this was already exceeded	Lifestyle coach		Face-to-face and optional telephone	5 face-to-face sessions + ≤4 telephone sessions	At least 4 face-to-face sessions were expected to occur before 24–28 weeks' gestation, and the intervention was completed by 35 weeks' gestation	Face-to-face sessions: 30–45 min Telephone sessions: ≤20 min		
		PA: Advice to incorporate light and moderate-intensity PA into daily life, reduce sedentary time, incorporate resistance activities, increase the number of steps taken daily, be more active during the weekends+ Advice to achieve a maximum of 5 kg GWG for those with BMI 30 and above, or minimise further GWG if this was already exceeded	Lifestyle coach		Face-to-face and optional telephone Face-to-face and optional telephone	5 face-to-face sessions + ≤4 telephone sessions	At least 4 face-to-face sessions were expected to occur before 24–28 weeks' gestation, and the intervention was completed by 35 weeks' gestation	Face-to-face sessions: 30–45 min Telephone sessions: ≤20 min		
		Healthy eating + PA: Both healthy eating and PA advice as earlier+ Advice to achieve a maximum of 5 kg GWG for those with BMI 30 and above, or minimise further GWG if this was already exceeded.	Lifestyle coach			5 face-to-face sessions + ≤4 telephone sessions	At least 4 face-to-face sessions were expected to occur before 24–28 weeks' gestation and the intervention was completed by 35 weeks' gestation	Face-to-face sessions: 30–45 min Telephone sessions: ≤20 min		
Al Wattar 2019 [54], UK	Singleton pregnancy <18 weeks' gestation Aged ≥16 years High risk of pregnancy complications: any obesity, or raised serum TGL, or chronic hypertension	**Control:** Usual dietary advice as per national guidelines on antenatal care, weight management and hypertension in pregnancy							Unclear time points: −1·2 (95 % CI−2·2, −0·2), adjusted	OR* 0·65 (95 % CI 0·47, 0·91), adjusted *GDM was part of composite primary outcome
		Intervention: Dietary education for Mediterranean-style diet, high intake of nuts (30 g/day), and high intake of extra virgin olive oil as the main source of fat (0·5 l/week)+ Grocery shopping advice+ Cooking recipes for a healthy diet+ Advice for appropriate meal choices at restaurants+ Group sessions, with encouragement to involve partners and family+ Provision of nuts and olive oil throughout the study.	Dietitian or trained allied health professional	Individual and group	Face-to-face group, and telephone individual sessions	3 face-to-face+ 2 telephone	Face-to-face sessions at 18, 20 and 28 weeks' gestation, and telephone sessions at 24 and 32 weeks' gestation	Not reported		

Ding 2021[57], China	BMI ≥24 kg/m^2 at the start of pregnancy Aged <35 years <12 weeks' gestation Active on WeChat (a messaging smartphone application) Willing to be randomly assigned to one of the groups Able to follow the intervention plan No previous GDM	**Control:** Asked to follow the WeChat public account of the hospital: a free instant messaging smartphone application, through which participants were educated with general knowledge and skills about nutrition and weight management during pregnancy+ Basic medical care and health education	N/A	Individual	Smartphone application	N/A	N/A	N/A	Between self-reported pre-pregnancy weight and measured weight at 25 weeks' gestation: Intervention: 4·9(SD 3·1) Control: 6·9(SD 3·2) *P* from *t*-test <0·001 Between self-reported pre-pregnancy weight and measured weight at delivery: Intervention: 11·2(SD 4·9) Control: 13·4(SD 5·0) *P* from *t*-test = 0·002	Intervention: 24·0 % Control: 37·8 % *P** from χ^2 test = 0·029
		Intervention: Asked to follow the WeChat public account of the hospital: a free instant messaging smartphone application, through which participants were educated with general knowledge and skills about nutrition and weight management during pregnancy+ Enrolment into WeChat group: offering the ability to ask questions about diet at any time, and get answers from a dietitian, and receive messages from a dietitian about dietary guidelines for pregnancy+ Personalised nutrition counselling once a month based on the national guidelines for diagnosis and treatment of GDM. Diet advice included: no less than 6276 kJ/day at early pregnancy, and 7531 kJ/day at mid-pregnancy, general healthy eating principles with 50–60 % of energy intake from carbohydrates, <30 % from fat and 1·0–1·3 g/kg/day protein+ Asked to follow the WeChat official account of hospital to receive detailed pregnancy diet and exercise information, including a total of 90 messages about dietary guidelines in pregnancy+ Asked to initiate a daily PA plan (e.g. walk for at least 6000 steps/day)+ Basic medical care and health education.	Dietitians and clinical nutritionists	Individual	Face-to-face and smartphone application					
Ferrara 2020[56], USA	Pre-pregnancy BMI between 25 and 40 kg/m^2 Aged ≥18 years Singleton <13 weeks' gestation	**Control:** Usual antenatal care: periodic health education newsletters, including IOM GWG guidelines, and information on healthy eating and PA in pregnancy+ 4 study newsletters that focused on women's health and safety during pregnancy without addressing GWG	N/A	Individual	N/A (just printed information)	N/A	N/A	N/A	Between measured pre-pregnancy weight and last measured pregnancy weight: −2·19 (95 % CI −3·26, −1·12), adjusted	RR 1·01 (95 % CI 0·53, 1·94), adjusted
		Intervention: Usual antenatal care: periodic health education newsletters, including IOM GWG guidelines, and information on healthy eating and PA in pregnancy+ 4 study newsletters that focused on women's health and safety during pregnancy without addressing GWG+ Lifestyle intervention adapted by the Diabetes Prevention Programme, and mainly delivered by telehealth: daily self-weighing, healthy eating, PA (150 min moderate-to-vigorous intensity per week), stress management, with the goal to limit GWG.	Dietitian	Individual	Face-to-face, printed information and telephone	2 face-to-face sessions + 11 telephone sessions+ Optional maintenance telephone sessions about 6	13 weekly sessions and then once every 2 weeks optional telephone sessions for maintenance until 38 weeks' gestation	First face-to-face session: 52·9 min Last face-to-face session: 36·8 min Core telephone sessions: 25·6 min Maintenance telephone sessions: 20·5 min		

CI, confidence interval; GDM, gestational diabetes mellitus; GI, glycaemic index; GWG, gestational weight gain; HE, healthy eating; IOM, Institute of Medicine; N/A, not applicable; OR, odds ratio; PA, physical activity; RR, risk ratio; TGL, triglycerides; UC, usual care.

In the UK pregnancies better eating and activity trial[41], 1555 women with obesity, of multiple ethnicities residing in the UK, were offered from approximately 17 weeks' gestation, a complex intervention on behaviour change and self-monitoring of diet and physical activity, or standard antenatal care of lifestyle advice at the booking appointment. To improve glucose tolerance, women in the intervention group were encouraged to follow a healthy eating pattern, but to not necessarily restrict their energy intake. The dietary advice emphasised swapping carbohydrate-rich foods of medium-high glycaemic index with lower glycaemic index foods, to reduce glycaemic load of the diet, as well as reducing foods high in saturated fat. Physical activity advice focused on gradual increases in walking to reach moderate intensity, with options for additional physical activity/exercise. In the Finnish gestational diabetes prevention (RADIEL) study[51], women with a history of GDM and/or pre-pregnancy obesity were randomised to either individualised diet, physical activity and weight management counselling, or to receive leaflets with general information on diet, physical activity and weight control during pregnancy, as well as health education according to standard practice. In this study, intervention participants with obesity were advised to not gain weight during the first two trimesters. The dietary advice was based on the Nordic Nutrition Recommendations[52], and aimed to optimise participants' consumption of fruit and vegetables, berries, high-fibre foods, low-fat dairy products, unsaturated fats, fish and low-fat meat products, and to minimise the intake of sugary foods and drinks. Women were encouraged to follow the 'plate model', filling half of the plate with vegetables, one-quarter with complex carbohydrates (e.g. potato, rice, pasta) and one-quarter with protein foods (e.g. meat, fish, eggs, beans). The diet provided 6694–7531 kJ/day, with 40–50 % of energy coming from carbohydrates, 30–40 % from fat and 20–25 % from protein. Physical activity recommendations included 150 min of moderate-intensity activity per week and reduction in sedentary lifestyle. Both the diet and the activity plan in this study were monitored, and tailored to each woman's abilities, progress and preferences. For example, if a woman was struggling with physical activity, the focus would shift towards diet.

A few trials promoted a Mediterranean-style diet[53]. For example, ESTEEM (effect of simple, targeted diet in pregnant women with metabolic risk factors on pregnancy outcomes) was a multicentre RCT across five maternity units in the UK, in 1252 women with metabolic risk factors (obesity, chronic hypertension or hypertriglyceridaemia), which assessed whether a Mediterranean-style diet reduces adverse pregnancy outcomes compared to usual antenatal advice on diet, physical activity, weight management and hypertension in pregnancy[54]. The components of the diet included high intake of fruit and vegetables, non-refined grains and legumes, moderate-to-high consumption of fish, small-to-moderate intake of poultry and dairy products, low consumption of red and processed meat and minimal intake of sugary drinks, fast food and foods rich in animal fat. ESTEEM particularly emphasised increased intake of unsaturated fat from nuts (30 g/day) and extra virgin olive oil (0·5 l/week). The intervention package included dietary education sessions, advice on grocery shopping, ideas for recipes and healthy eating advice when eating out.

Intervention characteristics

Dietary interventions have been delivered mainly by experienced dietitians and nutritionists, or trained study nurses, and occasionally by trained health coaches or research staff. Most interventions commenced before 20 weeks' gestation, and were delivered until 34–37 weeks' gestation, or until delivery. The number of face-to-face visits has ranged from two to –eight per participant, either as part of, or in addition to routine antenatal appointments, usually supplemented with remote contacts (range two to eleven). The frequency of intervention delivery has been almost equally distributed among the studies, between every 2–3 months, monthly and weekly. Intervention sessions lasted roughly 60 min on average[49,50].

Interventions were delivered mostly through individual face-to-face sessions, but some studies delivered remote interventions, through telephone or mobile applications. For example, Herring *et al.*[55] delivered a telephone-based behavioural lifestyle intervention to run alongside routine antenatal appointments, including advice to reduce sugar intake, limit fast foods and foods high in fat, and control portion sizes, incorporate daily walking, and to weekly monitor weight gain to meet Institute of Medicine recommendations, supplemented with daily text messages for encouragement with the programme and enhancing self-efficacy. In the gestational weight gain and optimal wellness trial by Ferrara *et al.*[56], women in the intervention group received an adapted version of the National Diabetes Prevention Programme designed to be delivered as a mix of in-person and telephone sessions. More recently, an intervention by Ding *et al.*[57], using a mobile social media application, offered a free instant messaging platform for women during pregnancy, to interact with their HCP at any time regarding nutrition and weight management topics.

Beyond counselling, intervention packages included several materials, such as leaflets, fact sheets, newsletters, handbooks, recipe ideas, goal logbooks, diet, physical activity and weight monitoring charts and notebooks, text messages for self-monitoring and encouragement, pedometers, online websites for extra information and digital versatile discs with physical activity regimens. In the RADIEL study, participants also had access free of charge to public swimming pools, and/or guided exercise groups[51]. In the ESTEEM and St Carlos Mediterranean-style interventions, key foods, such as nuts and/or extra virgin olive oil, were provided to participants in addition to counselling[54,58].

Intervention effects on gestational diabetes mellitus

An individual participant data (IPD) meta-analysis of trials of diet and physical activity interventions in

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women with overweight or obesity in pregnancy[59] showed that the intervention groups gained less weight than usual care groups (from booking appointment until before delivery), with mean difference of −0·70 kg and 95 % CI −0·92, −0·48 kg, and relatively low heterogeneity (I^2 = 14·1 %), consistent across various subgroups of women based on age, parity, BMI, ethnicity and pre-pregnancy medical conditions. However, there was considerable variability in the intensity of the interventions and definitions of outcomes. The majority of trials failed to reduce GDM risk (OR 0·89, 95 % CI 0·72, 1·10). A potential benefit from lifestyle interventions in preventing GDM was shown only when aggregated and IPD data were combined, and not in the IPD meta-analysis alone, but the accuracy of this approach is doubtful[59,60].

In a recent Cochrane overview of systematic reviews and meta-analyses, quality of evidence from preventative lifestyle RCT for GDM was reported as low, due to variations in the definitions of GDM, type and intensity of interventions and controls, sparse data on compliance, heterogeneity in patient and study characteristics and selection criteria[50]. Overall, low quality of evidence from systematic reviews shows no benefit or harm from physical activity or exercise interventions alone, against routine antenatal care, on the risk of GDM (risk ratio 1·10, 95 % CI 0·66, 1·84)[50], although higher quality systematic reviews have demonstrated significant reductions in incidence of GDM[61,62]. The effect of dietary advice alone on GDM risk is also unclear. A small number of Mediterranean-style diets have shown a significant benefit compared to routine antenatal care (OR 0·66, 95 % CI 0·52, 0·82), with no heterogeneity[53]. However, overall, low quality of evidence again suggested that dietary interventions alone do not seem to confer a benefit or harm regarding GDM risk (risk ratio 0·60, 95 % CI 0·35, 1·04)[50]. Low-quality evidence has also shown unknown benefit or harm of low glycaemic index diets *v.* moderate-high glycaemic index diets on risk of GDM (risk ratio 0·91, 95 % CI 0·63, 1·31)[50]. Conversely, moderate-quality evidence suggested that a combination of diet and exercise can possibly reduce the risk of GDM (risk ratio 0·85, 95 % CI 0·71, 1·01), but it is unclear if these beneficial effects apply to all women or only to high-risk women (e.g. high BMI, age, high-risk ethnicity)[50]. In addition, many lifestyle interventions lack detailed reporting about the type, intensity, content, theoretical basis and setting of the intervention, as well as cost-effectiveness analysis, which prevents their delivery in a scalable way.

The mechanism behind the success of some dietary interventions over others in preventing GDM is unknown. A meta-analysis and meta-regression suggested that key aspects which confer benefit among successful interventions are: targeting a high-risk population based on risk evaluation models (including important GDM risk factors and not just BMI), early implementation of the intervention (e.g. before 20 weeks' gestation, or ideally, in the first trimester) and attenuation of GWG through intense diet and exercise programmes[63]. However, although pregnancy is a unique time when women are in frequent contact with their clinical care team, and are motivated to make lifestyle changes to protect the health of their baby, intensive lifestyle modifications, especially those requiring face-to-face counselling and multiple visits, may be hard to follow, can decrease treatment efficacy and may not be feasible in routine care[64]. The UK pregnancies better eating and activity trial with good attendance rates (seven of eight sessions) led to only a small difference in GWG between the groups (−0·42 kg from before pregnancy up to 28 weeks' gestation, intervention *v.* control), and an increase in exercise by 7·5 metabolic equivalent of task hours/week, with no differences in moderate or vigorous activity between the groups[41], while data have shown that an increase of 16 metabolic equivalent of task hours/week of exercise may be required as a minimum to reduce GDM, with increase in vigorous exercise when appropriate[65]. Trials that have shown effectiveness in GDM prevention so far have included intensive face-to-face dietetic support and/or provision of key foods to study participants, but they provide no indication of how these strategies could be delivered in routine antenatal care[51,54,58,66,67]. The RADIEL study reduced GDM incidence by 39 % in women at high risk, but required extra face-to-face visits and a group session to deliver standard healthy eating and physical activity advice. This may not be manageable in routine practice, given the amount of appointments women are already required to attend during pregnancy, and competing priorities they face (e.g. childcare, work)[51]. The ESTEEM and St Carlos trials implemented Mediterranean-style dietary advice supplemented with extra virgin olive oil and nuts, provided as part of the trial, from early or mid-pregnancy, and showed a similar reduction in GDM risk[54,58]. Nevertheless, wide scale implementation of a Mediterranean-style diet in certain countries such as the UK could be challenging. Studies outside pregnancy show that people have a favourable attitude towards this type of diet, but there are a number of barriers to adoption. The diet exists in many different versions, is perceived in various ways and knowledge of its composition is limited[68,69]. This diet may also not be acceptable to people of all ethnic backgrounds, and the cost of foods such as extra virgin olive oil is higher[70–72].

Data also support the effectiveness of technology-assisted interventions for weight control, offering convenience, and facilitating engagement, retention and delivery at high intensity, but at low cost[73–75]. For example, in women with established GDM, telehealth has been shown to increase efficiency and to improve perinatal outcomes[56]. Herring *et al.*[55], in a high-intensity preventative trial in women of African descent, with overweight and obesity, tested an inexpensive technology-assisted behavioural intervention requiring little health coaching, involving regular contact with HCP via text messaging and phone calls, as well as social support through a social media forum, and showed that the intervention significantly reduced GWG and prevalence of excess GWG, compared to usual care (also involving guidance on optimal GWG). The benefits in GWG did not translate into reduction in GDM incidence; however, this study was not statistically powered

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to detect such difference. Ding *et al.*[57] used social software to assist with delivery of the intervention, but this was still intense, as it involved interaction with HCP at any time for personalised counselling and information, in addition to general education, daily exercise plan and weekly messaging from HCP. In this study, the incidence of GDM was significantly lower in the intervention group (24 %) than in the control group (37·8 %). However, reported differences in rates of GDM between the two groups in this study were unadjusted for known confounders, which could have changed the direction or significance of the results.

In view of the aforementioned, lack of clarity about effective components and mechanisms of complex diet and/or physical activity interventions remains. What the results of some successful interventions suggest however could be that dietary modification with or without physical activity can have an effect on GDM risk, independent of GWG control, since the weight gain difference between the two trial arms was only −1·2 kg in the ESTEEM[54], and −0·5 kg in the RADIEL study[51], in favour of the intervention. But the optimum dietary composition is unknown. In the RADIEL study, there was only a small improvement reported in adherence to the diet recommendations in the intervention group compared with the control group, as indicated by a diet quality score[51]. In the Mediterranean dietary interventions, it was speculated that increased unsaturated fat and polyphenol consumption might have been beneficial with regards to insulin sensitivity and inflammation[54,58]. However, a reduction in dietary carbohydrate as a natural result of higher fat and protein consumption, under conditions when energy intake remains similar, may have also played a role. Indeed, successful interventions to date included some advice for reducing sugar consumption and/or moderating starchy foods, but detailed dietary data are not reported in most of them, so as to explore this. In the recent remote intervention by Ding *et al.*[57], both groups were consuming a diet high in carbohydrates (average of 283 and 277 g/day in the intervention and control groups, respectively), from baseline until the point of testing for GDM, with no difference between the groups, throwing doubt on the need for carbohydrate reduction, though again notably, analyses were not adjusted for confounders. The authors attributed the benefit in GDM risk to early implementation before 12 weeks' gestation, and to the higher than usual frequency of contact of women with their HCP, although they do not report engagement data. One RCT specifically aimed at reducing total carbohydrate intake as part of an intensive healthy eating intervention[76]. In this study, women were randomised to receive healthy eating alone, or physical activity advice alone, both, or usual care, and as part of the dietary advice, they were encouraged to eat more non-starchy vegetables, and reduce intake of both starchy carbohydrates and sugary foods and drinks. Women in any of the intervention arms did not significantly limit their GWG compared to usual care, before the time point of GDM diagnosis (<20 weeks' gestation until 24–28 weeks' gestation). This study was underpowered to detect difference in GDM, and although it resulted in significant reduction in total carbohydrate intake in favour of the healthy eating only group compared to usual care at 24–28 weeks' gestation, the degree of reduction was small (−4·8 portions/week, <1 portion/day). Thus, the effect of a reduced-carbohydrate diet as a preventative strategy for GDM remains to be investigated.

Conclusion

In conclusion, carrying or gaining excess weight during pregnancy increases the risk of hyperglycaemia and GDM. Several interventions to date have aimed to control GWG and blood glucose in women with overweight or obesity through changes in diet and/or physical activity but not all were powered to detect differences in GDM incidence. Dietary interventions varied in intensity, content as well as screening and diagnosis procedures, and definitions of outcomes. Only a small number of dietary interventions in women with overweight or obesity have been effective in reducing GDM incidence, and the mechanism mediating the effect, as well as the optimum dietary composition are still unknown. Implementation from as early as possible in pregnancy seems to be key to success. Greater intervention intensity (intensive dietetic support and/or provision of key foods, sometimes with support for increased physical activity) may have also contributed to improved outcomes, but incorporating this support into routine antenatal care for every woman living with overweight or obesity might not be feasible. Importantly, some of the successful interventions targeted women not only with obesity, but also other GDM and metabolic risk factors, such as previous GDM, hypertension and dyslipidaemia. New risk models based not solely on BMI, but also on other risk factors, could help identify women most likely to benefit from interventions, allowing targeting of resources and increasing the likelihood of intervention effectiveness. Future dietary interventions need to develop and test the effectiveness of programmes which have the possibility of being delivered at scale. One possibility might be to offer a reduced-carbohydrate approach, given evidence that it has helped people with type 2 diabetes or established GDM achieve weight and blood glucose control, but the feasibility and acceptability of this strategy from early pregnancy in women at risk of GDM needs to be determined.

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Conflict of Interest

None.

Authorship

M. M. conducted the literature review and drafted the manuscript for publication. N. M. A. and S. A. J. provided input to, and approved the final manuscript.

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