RESEARCH

Effects of interventions in pregnancy on maternal weight and obstetric outcomes: meta-analysis of randomised evidence

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S Thangaratinam *senior lecturer/consultant in obstetrics and maternal medicine*¹, E Rogozińska *researcher*¹, K Jolly *reader in public health*², S Glinkowski *researcher*³, T Roseboom *associate professor*^{4,5}, J W Tomlinson *MRC senior clinical fellow/reader in endocrinology*⁶, R Kunz *professor*⁷, B W Mol *professor*⁵, A Coomarasamy *professor*⁶, K S Khan *professor*¹

¹Women's Health Research Unit, Centre for Primary Care and Public Health, Barts and the London School of Medicine and Dentistry, Queen Mary University of London, London, UK; ²Department of Public Health, Epidemiology and Biostatistics, University of Birmingham, Birmingham; ³Arcana Institute, Krakow, Poland; ⁴Clinical Epidemiology Biostatistics and Bioinformatics, Academic Medical Centre, Amsterdam, Netherlands; ⁵Department of Obstetrics and Gynaecology, Academic Medical Centre, Amsterdam; ⁶School of Clinical and Experimental Medicine, University of Birmingham, Birmingham; ⁷University of Basel, Basel Institute for Clinical Epidemiology (BICE), Basel, Switzerland

Abstract

Objective To evaluate the effects of dietary and lifestyle interventions in pregnancy on maternal and fetal weight and to quantify the effects of these interventions on obstetric outcomes.

Design Systematic review and meta-analysis.

Data sources Major databases from inception to January 2012 without language restrictions.

Study selection Randomised controlled trials that evaluated any dietary or lifestyle interventions with potential to influence maternal weight during pregnancy and outcomes of pregnancy.

Data synthesis Results summarised as relative risks for dichotomous data and mean differences for continuous data.

Results We identified 44 relevant randomised controlled trials (7278 women) evaluating three categories of interventions: diet, physical activity, and a mixed approach. Overall, there was 1.42 kg reduction (95% confidence interval 0.95 to 1.89 kg) in gestational weight gain with any intervention compared with control. With all interventions combined, there were no significant differences in birth weight (mean difference -50 g, -100 to 0 g) and the incidence of large for gestational age (relative risk 0.85, 0.66 to 1.09) or small for gestational age (1.00, 0.78 to 1.28) babies between the groups, though by itself physical activity was associated with reduced birth weight (mean difference -60 g, -120 to -10 g). Interventions were associated with a reduced the risk of

pre-eclampsia (0.74, 0.60 to 0.92) and shoulder dystocia (0.39, 0.22 to 0.70), with no significant effect on other critically important outcomes. Dietary intervention resulted in the largest reduction in maternal gestational weight gain (3.84 kg, 2.45 to 5.22 kg), with improved pregnancy outcomes compared with other interventions. The overall evidence rating was low to very low for important outcomes such as pre-eclampsia, gestational diabetes, gestational hypertension, and preterm delivery.

Conclusions Dietary and lifestyle interventions in pregnancy can reduce maternal gestational weight gain and improve outcomes for both mother and baby. Among the interventions, those based on diet are the most effective and are associated with reductions in maternal gestational weight gain and improved obstetric outcomes.

Introduction

Obesity is a growing threat to women of childbearing age. Half the population is either overweight (body mass index (BMI) 25.0-29.9) or obese (BMI ≥30).¹ In Europe and the United States, 20-40% of women gain more than the recommended weight during pregnancy.² Increased maternal weight or excessive weight gain in pregnancy is associated with adverse pregnancy outcomes.³ Half the women who die during pregnancy, childbirth, or puerperium in the United Kingdom are either obese or overweight.⁴ For the offspring, maternal

Correspondence to: S Thangaratinam s.thangaratinam@qmul.ac.uk

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Appendix 1: Maternal and fetal clinical outcomes

Appendix 2: GRADE evidence profile

Appendix 3: Clinical characteristics of included studies

Appendix 4: Adverse outcomes

obesity is a major risk factor for childhood obesity, which persists into adulthood independent of other factors.⁵ Obesity costs the UK National Health Service (NHS) around £0.5bn a year and the UK economy a further £2.3bn in indirect costs.⁶ The antenatal period, with opportunities for regular contact with health professionals, is considered an ideal time to intervene as mothers are motivated to make changes that could optimise their outcome and that of the baby.⁷ There is a need to identify appropriate weight management interventions that are effective and safe in pregnancy. Existing reviews and guidelines are limited in their recommendations because of the small number of included studies.⁸⁻⁹ They have not been able to identify the best intervention that optimises the outcomes for the mother and baby.⁹⁻¹⁰ There is also a lack of consensus on what constitutes important outcomes. Guidelines from the Institute of Medicine (IOM) provide reference ranges for optimal weight gain in pregnancy for normal weight, overweight, and obese women based on observational evidence.¹¹ Given the potential importance of weight management interventions in pregnancy, we systematically reviewed the effects of dietary and lifestyle interventions on various outcomes ranked for their importance.

Methods

We carried out systematic reviews according to protocols developed using currently recommended review methods¹²⁻¹⁴ and ranked outcomes for importance using a two round Delphi survey.¹⁵

Identification of studies

We searched Medline, Embase, BIOSIS, LILACS, Science Citation Index, Cochrane Database of Systematic Reviews (CDSR), Cochrane Central Register of Controlled Trials (CENTRAL), Database of Abstracts of Reviews of Effects (DARE), Health Technology Assessment Database (HTA), and PsychInfo from inception to January 2012 to identify relevant citations. We searched for relevant unpublished studies and those reported in the grey literature in databases such as Inside Conferences, Systems for Information in Grey Literature (SIGLE), Dissertation Abstracts, and Clinical Trials.gov. Internet searches were also carried out with specialist search gateways (such as OMNI: www.omni.ac.uk), general search engines (such as Google), and meta-search engines (such as Copernic: www.copernic.com). The search term combination captured the concept “pregnancy and weight” incorporating MeSH, free text, and word variants. Language restrictions were not applied.

Study selection

The electronic searches were scrutinised and full manuscripts of all citations likely to meet the predefined selection criteria were selected. Independent reviewers (ER and SG) examined these manuscripts and made the final decisions regarding inclusion or exclusion. When disagreements occurred, they were resolved by consensus or arbitration with a third reviewer (ST). In cases of duplicate publication, we selected the most recent and complete versions. Randomised controlled trials that evaluated any dietary or lifestyle interventions with potential to influence maternal and fetal outcomes related to weight were included. Two independent reviewers (ER, SG) classified interventions as mainly diet based, physical activity based, or mixed approach (with both diet and physical activity components that might or might not be underpinned by behavioural theory). Any disagreements were resolved by discussion with a third reviewer (ST). We excluded studies on pregnant women who were underweight (BMI <18.5).

Study quality assessment and data extraction

Quality, defined as the extent to which an estimate of effect was likely to be correct or unbiased, was evaluated with accepted contemporary standards.¹⁶⁻¹⁷ The risk of bias in individual studies was assessed by considering six items: sequence generation, allocation concealment, blinding, incomplete outcome data, selective outcome reporting, and other potential sources of bias. This information provided data for one of the domains used in evidence rating (see below). Two independent reviewers (ER and SG) extracted data in duplicate using predesigned and piloted data extraction forms. We attempted to obtain missing information by contacting investigators.

Data synthesis

We calculated relative risks with 95% confidence intervals for dichotomous data. Continuous data were summarised as mean differences with standard deviations. We used the I^2 statistic to assess statistical heterogeneity between trials and explored possible causes if we detected substantial heterogeneity ($I^2 > 50\%$). Subgroup meta-analyses for the main outcomes were performed. For each outcome, the subgroups defined a priori were clinical characteristics such as BMI and diabetes in pregnancy; type of intervention; responders, defined as women with significant reduction in gestational weight gain with intervention; and study quality. A true subgroup effect was considered to be present when the difference in estimates between the subgroups was significant at $P < 0.005$. When any heterogeneity was not explained by subgroup analyses, we performed meta-analysis using a random effects model. Birth weight was analysed in kilograms and is reported in grams. Funnel plots were used to display small study effects when the intervention effects in smaller studies differed from the effects displayed by larger studies. We used Egger's test to test for funnel plot asymmetry.¹⁸ All analyses were carried out with Revman¹⁹ and Stata statistical software.²⁰

Prioritisation and rating of evidence

Our primary outcomes were weight related changes in the mother and baby. We prioritised the other maternal and fetal outcomes related to pregnancy and ranked them for importance by a two round Delphi survey of clinicians with expertise in this specialty.¹⁵ Nineteen clinicians (19/20, 95% response rate) participated in the first round and 16 (84%) in the second. The list of outcomes ranked as critically important to weight management in pregnancy is provided in appendix 1 on bmj.com.

We summarised the strength of evidence for key outcomes using the GRADE (grading of recommendations, assessment, development, and evaluation) methods.²¹ This system rates the confidence in the observed estimate into one of four levels (high, moderate, low, and very low) evaluating five domains (risk of bias (see above), (in-)consistency of the results (heterogeneity), (in-)directness of the evidence, (im-)precision of the results, and publication bias). Initially we assigned evidence from randomised trials as high quality and readjusted the level on the basis of deficiencies in the above domains. This lowered the rating of evidence from high to moderate to low or even very low, depending on the severity of the deficiency. The footnotes in appendix 2 on bmj.com provide an explanation as to how we downgraded evidence in the light of various deficiencies.

Safety of the interventions in pregnancy

We undertook the review of safety of interventions based on recommended methods, including those of Cochrane adverse

effects subgroup.^{22 23} We designed a separate search strategy to evaluate safety by including text words and indexing terms for adverse effects. We limited the search by including search filters for “adverse events”, “human studies”, and “study type” (excluding editorials and letters). We searched Medline and Embase from inception to March 2011. We included any relevant randomised studies, observational studies, case series, or case reports without any language restrictions. The number of adverse events reported in pregnant women and children were obtained for each intervention to compute a percentage of the total number of women and children in whom the occurrence of that particular adverse event, or confirmation of its absence, was reported. The adverse events were quantified as relative risks and 95% confidence intervals.

Results

Study selection

From 19 593 citations, we selected 215 full papers for assessment (fig 1). Forty four randomised trials (7278 women) reported the effects of dietary and lifestyle interventions in pregnancy. The interventions in the trials were broadly classified into three groups: those mainly based on diet (13 randomised trials)²⁴⁻³⁶ or physical activity (18 randomised trials)³⁷⁻⁵⁵ and a mixed approach with diet and physical activity components that might or might not be underpinned by behavioural counselling (13 randomised trials).^{7 56-67}

Characteristics of the included studies and interventions

The included trials studied the effect of interventions on women with any BMI,^{7 25-30 32 37-40 42-50 52 54-66} mostly obese and overweight women,^{31 33 53} or only obese women^{24 29 34-36 51 59 67} (clinical characteristics of all identified studies are in appendix 3 on bmj.com). Five randomised trials included pregnant women with a diagnosis of gestational diabetes mellitus^{28 31 34 57 58} and one included women with pre-existing diabetes.³² Typical dietary interventions included a balanced diet consisting of carbohydrates, proteins, and fat and maintenance of a food diary. Typical interventions based on physical activity included light intensity resistance training, weight bearing exercises, and walking for 30 minutes. The interventions in the mixed approach included counselling sessions, education concerning the potential benefit of diet and physical activity, and feedback on weight gain in pregnancy. The mixed approach used techniques of behavioural modification to give the women insight into controlling periods of emotional eating and preventing binge eating sessions. The quality of the studies varied (fig 2). One study was available only as an abstract, and data were not included in the meta-analysis.²⁴

Effect of intervention on maternal weight

Thirty four randomised trials (5481 women) evaluated the effect of interventions on maternal weight gain in pregnancy.^{7 25-28 31-39 42 43 45-48 50-54 56 59-63 65-67} Compared with control women, there was a reduction in weight gain of 1.42 kg with interventions (95% confidence interval 0.95 to 1.89 kg; $P<0.001$, $I^2=80\%$) (fig 3). The largest reduction in weight gain was observed with dietary intervention (3.84 kg, 2.45 to 5.22 kg; $P<0.001$, $I^2=92\%$) (table 1, fig 3). There was no significant difference between the two groups in their adherence to the Institute of Medicine (IOM) recommended gestational target weight gain (relative risk 0.85, 0.66 to 1.1).

Effect of intervention on fetal weight

Thirty one randomised trials (5278 newborns) evaluated the effect of the interventions on birth weight.^{26-28 30-40 42 44-50 52 53 57 59 61-63 65 66} Compared with controls, there was minimal reduction in the birth weight that was not significant (mean difference -50 g, 95% confidence interval -100 to 0 g) for all interventions (table 1, fig 4). There was a trend towards reduction in the risk of large for gestational age babies (defined as birth weight above the 90th centile or 4000 g) (relative risk 0.85, 0.66 to 1.09) with interventions (fig 5). The risk of small for gestational age babies (defined as birth weight below the 10th centile or 2500 g) was not altered (1.00, 0.78 to 1.28) with interventions (fig 5).

Effect of intervention on obstetric maternal outcomes

Thirty six randomised trials (n=6543 women) studied the effect of interventions on obstetric maternal outcomes.^{24 26 28-39 42 44-50 52-57 59 61-67} Fig 5 shows the summary of the effect of weight management interventions on pregnancy outcomes. The overall effect of interventions led to a reduction in pre-eclampsia by 26% (relative risk 0.74, 0.60 to 0.92; $P=0.006$, $I^2=31\%$). The summary estimate of interventions showed trends towards reduction in gestational diabetes (0.78, 0.57 to 1.08), gestational hypertension (0.89, 0.64 to 1.25), and preterm delivery (0.78, 0.60 to 1.02) that were not significant. Meta-analysis of the studies showed no difference between the groups in gestational age at delivery (mean difference 0.02 weeks, -0.08 to 0.11 weeks) and rates of caesarean section (0.93, 0.85 to 1.01), induction of labour (1.12, 1 to 1.26), and postpartum haemorrhage (0.90, 0.57 to 1.42).

Compared with the control, dietary interventions in pregnancy were associated with a 33% reduced risk of pre-eclampsia (0.67, 0.53 to 0.85; $P<0.001$, $I^2=0\%$) and a 61% reduced risk of gestational diabetes (0.39, 0.23 to 0.69; $P=0.001$, $I^2=21\%$) (fig 6). They were also associated with a significant reduction in gestational hypertension (0.30, 0.10 to 0.88; $P=0.03$, $I^2=0\%$) and preterm delivery (0.68, 0.48 to 0.96; $P=0.03$, $I^2=35\%$) (table 2). There were no differences in these outcomes with physical activity based and mixed approach interventions compared with the control. Visual analysis of the funnel plots showed no evidence of small study effects for weight related outcomes. There was some evidence for funnel asymmetry for pregnancy outcomes such as gestational diabetes ($P=0.034$) and caesarean section ($P=0.002$) and none for others.

Effect of interventions on fetal and neonatal outcomes

Fifteen randomised trials (n=3905 newborns) studied the effect of interventions on fetal and neonatal morbidity and mortality outcomes.^{28-31 34 35 37-39 46 50 53 57 63 67} Meta-analysis of the effect of interventions showed trends towards reduction in intrauterine death (relative risk 0.15, 0.02 to 1.20, $I^2=0\%$), birth trauma (0.36, 0.11 to 1.23, $I^2=0\%$) (fig 7), and hyperbilirubinaemia (0.84, 0.64 to 1.10; table 3). The overall risk of shoulder dystocia was reduced by 61% with all interventions compared with the control group (0.39, 0.22 to 0.70; $P=0.002$, $I^2=0\%$; table 3). There were no differences between the groups for respiratory distress syndrome (1.05, 0.48 to 2.28), admission to neonatal intensive care (1.00, 0.75 to 1.33), or infant hypoglycaemia (1.07, 0.85 to 1.35) (fig 7).

Subgroup and sensitivity analysis

Tables 4 and 5^{28 31 32 34 57 58} provides estimates of subgroup analyses for clinical characteristics and quality of the included studies for maternal and fetal outcomes. There was a significant difference between the subgroups for gestational weight gain based on the type of intervention ($P<0.001$). The responders, defined as women with significantly reduced gestational weight gain with intervention, showed a difference in reduction in pre-eclampsia ($P=0.009$) and birth weight ($P=0.002$) compared with the non-responders. There were no significant differences between the subgroups based on the BMI, diabetic status in pregnancy, and risk of bias for allocation concealment.

When we excluded studies on women with diabetes in pregnancy^{28 31 32 34 57 58} the sensitivity analysis consistently showed a overall reduction in gestational weight gain with interventions (mean difference -1.4 kg, 95% confidence interval -2.09 to -0.71 kg, $P<0.001$), including diet (-5.53 kg, -8.54 to -2.53 kg; $P<0.001$), physical activity (-0.72 kg, -1.2 to -0.25 kg, $P=0.003$), and mixed approach (-1.06 kg, -1.67 to -0.46 kg; $P<0.001$). There was no significant reduction in birth weight with intervention (-40 g, -100 to 10 g).^{26 27 30 33 35-40 42 44-50 52 53 59 61-63 65 66} There were no differences

between the groups in the incidence of babies who were small or large for gestational age or those with shoulder dystocia after we excluded women with diabetes. Dietary interventions in women without diabetes resulted in a significant reduction in preterm delivery (relative risk 0.26, 0.09 to 0.74) and gestational hypertension (0.30, 0.10 to 0.88). There was a trend towards a reduction in pre-eclampsia (0.82, 0.43 to 1.42) in these women with diet that was not significant.

Interventions in obese and overweight pregnant women showed a reduction in gestational weight gain (mean difference -2.1 kg, -3.46 to -0.75 kg; $P<0.002$, $I^2=88\%$). There was no significant reduction in fetal weight or other clinical outcomes. Dietary intervention in obese and overweight women significantly reduced the risk of pre-eclampsia (relative risk 0.63, 0.42 to 0.96), gestational diabetes (0.39, 0.23 to 0.69), and gestational hypertension (0.30, 0.10 to 0.88). This benefit was not observed for other outcomes or with other interventions. After we excluded women with diabetes, the beneficial effect observed with diet persisted for gestational weight gain (mean difference -7.73 kg, -6.05 to -9.40 kg; $P<0.001$, $I^2=41\%$) and gestational hypertension (relative risk 0.30, 0.10 to 0.88). There was no increase in the risk of small for gestational age babies, and there was no effect on any of the other maternal or fetal outcomes.

Rating the evidence

The Delphi survey of practicing clinicians determined the importance of the maternal and fetal outcomes.¹⁵ The overall evidence rating was moderate for reduction in gestational weight gain (see appendix 2 on bmj.com). The rating was moderate for evidence of no effect observed with interventions on the risk of babies who were small for gestational age. The rating for clinical outcomes such as pre-eclampsia, gestational diabetes, preterm delivery, gestational hypertension, admission to neonatal unit, and neonatal hypoglycaemia was low to very low. The evidence rating for the beneficial effect of diet was high for gestational hypertension, moderate for gestational diabetes, low for pre-eclampsia, and very low for preterm birth. Although clinicians judged thromboembolism, maternal admission to high dependency or intensive care unit, and long term neurological sequelae to the fetus as critically important outcomes, we did not identify evidence for these outcomes.¹⁵

Safety of the interventions

We included 26 studies after reviewing 14 832 citations to assess the safety of the interventions in pregnancy. Of the included studies, two were randomised controlled trials (277 women)^{40 64} and 24 were observational studies (19 cohort studies and five case-control studies, 468 581 women).⁶⁸⁻⁹¹ The studies evaluated the effects of dietary, physical activity, and other lifestyle interventions in pregnancy on maternal and fetal outcomes.

The two included randomised trials evaluated physical activity and did not show an increase in meconium staining of amniotic fluid (relative risk 0.62, 0.20 to 1.90), uterine atony (0.93, 0.22 to 3.89), or chorioamnionitis (3.69, 0.15 to 88.13). Eighteen studies observed the effect of diet on maternal and fetal outcomes. Most of the included studies evaluated the effect of severe reduction in energy intake in extreme conditions such as war or famine. There was an increase in the rate of neural tube defects and cleft lip and palate in babies of women with extreme forms of dieting and on diets with a high glycaemic index during pregnancy (see appendix 4 on bmj.com).⁸⁹ The risk of coronary artery disease, metabolic syndrome, breast cancer, and diabetes was increased in infants born to mothers whose diet had been severely restricted because of famine.⁷² There were no significant maternal or fetal adverse effects such as cord abnormalities, threatened miscarriage, meconium stained liquor, abnormal fetal heart rate pattern, maternal sepsis, or chorioamnionitis observed with physical activity during pregnancy.

Discussion

Summary of the findings

Dietary and lifestyle interventions in pregnancy are effective in reducing gestational weight gain without any adverse effect on the risk of babies small for gestational age. Compared with physical activity and a mixed approach, dietary interventions were associated with the greatest reduction in weight gain in pregnancy. Interventions also resulted in significant reduction in the risk of pre-eclampsia. There was an overall trend towards reduction in gestational diabetes, gestational hypertension, preterm birth, and intrauterine death with intervention compared with control. Diet in particular, significantly reduced the risk of pre-eclampsia, gestational diabetes, gestational hypertension, and preterm births compared with any other intervention. The interventions had less effect on outcomes related to fetal weight and other morbidity and mortality. Furthermore, there was no evidence that the interventions reduced the rates of caesarean section or induction of labour. The rating of evidence quality was moderate (see appendix 2 on bmj.com) for the lack of effect observed with interventions on size for gestational age. The quality of evidence for the benefit observed with interventions on gestational weight gain was moderate but low for clinical outcomes.

Strengths and limitations

Our systematic review was comprehensive in its scope and search. We conducted the review in line with contemporary recommendations and complied with the PRISMA (preferred reporting items for systematic reviews and meta-analyses) statement.⁹² Our search of literature aimed to minimise the risk of selection and publication bias. Most of the published reviews on effects of dietary and lifestyle interventions on maternal and fetal outcomes were limited to specific groups of women or types of intervention. There was no formal prioritisation of the importance of the clinical outcomes, and few assessed the quality of the evidence for the important outcomes. We undertook

rigorous quality assessment and formally prioritised the outcomes for clinical importance. Reliable data were identified on clinically important outcomes related to weight and pregnancy by the Delphi survey. We explored for sources of heterogeneity when required.

Appropriate subgroup analyses and sensitivity analyses planned *a priori* were undertaken for important factors such as BMI, diabetic status, maternal weight change with intervention, and study quality that could influence outcomes. We formally rated strength of evidence for key outcomes identified through Delphi survey. This enabled our confidence in the estimates of the important effects observed. Our careful scrutiny and presentation of evidence profiles provides the much needed clarity necessary to make judgments about effects.

The validity of a meta-analysis depends on the quality of the component studies, heterogeneity observed, and the risk of publication bias. The quality across various outcomes assessed by GRADE was moderate for the benefit observed with gestational weight gain but low for other important obstetric outcomes such as pre-eclampsia, gestational diabetes, gestational hypertension, and preterm delivery. This weakens the inferences for these outcomes. The reasons for low evidence rating were the significant heterogeneity observed in the effect size, deficiencies in the quality of the individual studies, and risk of publication and related biases.

We observed heterogeneity for beneficial effects of interventions on maternal weight gain that persisted after accounting for the type of intervention, BMI, and diabetic status. Further information is needed on characteristics of included women—such as age, ethnicity, socioeconomic status, parity, and underlying medical conditions—and characteristics of the interventions—such as frequency, duration, and intensity—that could influence the outcomes. We were limited in our ability to identify the optimal weight change in pregnancy with interventions that would minimise maternal and fetal complications. Furthermore, constraints in the available data limited assessment of baseline prognostic factors on the effectiveness of outcomes. Such questions were difficult to answer with extracted results from trial publications because patient level information was not available and subgroup effects (“treatment-covariate interactions”) were rarely reported in sufficient detail. Although the Delphi panel of clinicians identified long term neurological sequelae and metabolic syndrome of the fetuses exposed to the intervention, they were not reported in any of the studies.

Safety of the interventions

The beneficial effects observed in our review need balancing against potential adverse effects when evaluating clinical implications. The evidence of any adverse effects from diet in pregnancy was usually from observational studies on extremes of weight reduction diets or those on intake of food with a very high or low glycaemic index.⁸⁹ These findings do not apply to the interventions we reviewed. We also observed that reduction in weight gain in pregnancy was not associated with an increase in babies who were small for gestational age. Observational studies on physical activity in pregnancy did not show any significant adverse maternal or fetal outcome for activities of varying intensity.

Clinical and practical implications

Our findings suggest that interventions based on diet in pregnancy would reduce the gestational weight gain by 4 kg, on average, compared with 0.7 kg and 1.0 kg with physical

activity and a mixed approach, respectively. Dietary interventions were most effective in reducing complications such as pre-eclampsia, gestational diabetes, gestational hypertension, and preterm delivery. One of the main concerns of the mothers is the effect of dietary and lifestyle interventions on the weight of the fetus. There is no evidence that the interventions evaluated in our review or recommended in current clinical practice are associated with adverse maternal or fetal outcomes.

The diet based interventions effective in reducing weight gain in pregnancy included a balanced diet of 18–24 kJ/kg, a low glycaemic diet with unprocessed whole grains, fruits, beans and vegetables, and a healthy diet with a maximum of 30% fat, 15–20% protein, and 50–55% carbohydrate, with energy intake individualised to the needs of the mother. Provision of regular input on planned nutritional intake from early pregnancy through dedicated dietetic teams in primary and secondary care has the potential to improve outcomes. Overweight and obese women benefit the most and could be targeted in clinical practice.

Current research focuses mainly on mixed interventions with both diet and physical activity components. But interventions predominantly based on diet seemed to be more effective for weight related and clinical outcomes. With lack of individual data on important factors such as age, ethnicity, socioeconomic status, compliance, and other risk factors, we are limited in our explanation for the benefit observed with diet compared with other methods. There could be various reasons for this finding. Firstly, in a complex intervention, the net benefit gained might be linked to the vigour with which the components of the intervention are delivered. In “mixed approaches” the individual components might not be delivered to the same standard as in studies that focus on diet alone. Secondly, compliance might have been better in trials with a diet only intervention than other methods because of its relative simplicity and perceived safety in contrast with physical activity in pregnancy.^{93–94} Thirdly, specific components of the diet, such as fibre, might have benefits that are not evident with other interventions. Raised triglyceride concentrations in pregnancy are associated with the risk of pre-eclampsia.⁹⁵ There is a known reduction in the incidence of pre-eclampsia by up to 70% associated with a fall in the concentrations of triglycerides in women with the highest quarter of dietary fibre intake compared with the lowest quarter after adjustment for confounders.⁹⁶ The high fibre in the dietary intervention of the included studies could have influenced the beneficial effect observed with reduction in the rates of pre-eclampsia.

The economic evaluation undertaken by the National Institute for Health and Clinical Excellence on non-pharmacological interventions for weight management outside pregnancy reported that diet based interventions were cheaper than interventions based on physical activity.⁹⁷ With the clear benefit in gestational weight gain observed with dietary interventions in pregnancy, there is a potential for this strategy to be also cost effective compared with other methods.

Recommendations for future research

Synthesis of patient level data by individual patient data meta-analysis is needed to assess any differential effect of the benefits observed with interventions in various groups based on BMI, age, ethnicity, socioeconomic status, parity, and risk status in pregnancy. Availability of the raw data will substantially increase the power to detect baseline factors that truly modify the intervention effect⁹⁸ and will enable intervention effects to be quantified for clinically relevant groups.⁹⁹ In

addition, individual patient data meta-analysis will be able to assess whether the improvement in clinical outcomes is related to reduction in gestational weight gain alone or if there is any added benefit from the type of intervention resulting in weight change. It will also allow the magnitude of benefit from weight change in pregnancy to be quantified for both the mother and baby. This will allow us to implement those weight management interventions that show clear benefit with specific weight gain targets in pregnancy. This approach will also provide adequate power to generate valid, reliable answers and to populate the model for decision analytic modelling for health economic evaluation.

The paucity of descriptive information on the intensity and duration of intervention, means of provision, and patient compliance are factors that could potentially facilitate or hinder implementation. These gaps identify issues for further research. There is a need for good quality large prospective studies for the important clinical outcomes identified including long term effects on the mother and fetus.

Conclusion

Until now, the recommendations for weight management in pregnancy have mainly focused on obese and overweight women without an emphasis on a particular type of intervention. Dietary intervention is effective, safe, and potentially cost effective and dominates physical activity based intervention. The case for its introduction with a service evaluation alongside is underpinned by our review. Ongoing effectiveness trials should focus on clinically relevant outcomes captured by our Delphi survey. They should generate data for determining the most efficient means for improving outcomes with weight management strategies in pregnancy.

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- NHS Information Centre. Health survey for England 2006: CVD and risk factors adults, obesity and risk factors children. NHS Information Centre, 2008.
- Thangaratnam S, Jolly K. Obesity in pregnancy: a review of reviews on the effectiveness of interventions. *BJOG* 2010;117:1309-12.
- Ramachandran J, Bradford J, McLean J. Maternal obesity and pregnancy complications: a review. *Aust N Z J Obstet Gynaecol* 2008;48:228-45.
- Lewis G. The Confidential Enquiry into Maternal and Child Health (CEMACH). Saving mothers' lives: reviewing maternal deaths to make motherhood safer. The seventh report of the confidential enquiries into maternal deaths in the United Kingdom. CEMACH, 2007.
- Drake AJ, Reynolds RM. Impact of maternal obesity on offspring obesity and cardiometabolic disease risk. *Reproduction* 2010;140:387-98.
- National Audit Office. Tackling obesity in England. Stationery Office, 2001.
- Jackson RA, Stotland NE, Caughey AB, Gerbert B. Improving diet and exercise in pregnancy with Video Doctor counseling: a randomized trial. *Patient Educ Couns* 2011;83:203-9.
- NICE. Public health guidance 27. Dietary interventions and physical activity interventions for weight management before, during and after pregnancy. National Institute for Health and Clinical Excellence, 2010.
- Streuling I, Beyerlein A, von Kries. Can gestational weight gain be modified by increasing physical activity and diet counselling? A meta-analysis of interventional trials. *Am J Clin Nutr* 2010;92:678-87.
- Campbell F, Messina J, Johnson M, Guillaume L, Madan J, Goyder E. Systematic review of dietary and/or physical activity interventions for weight management in pregnancy. NICE Centre for Public Health Excellence, 2009.
- Rasmussen KM, Yaktine AL, eds. Weight gain during pregnancy: re-examining the guidelines. Committee to Reexamine Institute of Medicine Pregnancy Weight Guidelines 2009.
- Higgins JPT, Green S. Cochrane handbook for systematic reviews of interventions. Version 5.0.1. Cochrane Collaboration, 2008.
- Khan KS, ter Riet G, Glanville J, Sowden AJ, Kleijnen J. Undertaking systematic reviews of research on effectiveness. CRD's guidance for carrying out or commissioning reviews. 2nd ed. NHS Centre for Reviews and Dissemination, University of York, 2001.
- Khan KS, Kunz R, Kleijnen J, Antes G. Systematic reviews to support evidence-based medicine: how to review and apply findings of systematic reviews. *Br J Anaesth* 2003;91:767-8.
- Thangaratnam S, Rogozinska E, Jolly K, Glinkowski S, Duda W, Borowiack E, et al. Interventions to reduce or prevent obesity in pregnant women: a systematic review. *Health Technol Assess* (in press).
- Glasziou P, Chalmers I, Altman D, Bastian H, Boutron I, Brice A, et al. Taking healthcare interventions from trial to practice. *BMJ* 2010;341:c3852.
- Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Schunemann HJ. GRADE: What is "quality of evidence" and why is it important to clinicians? *BMJ* 2008;336:995-8.
- Sterne JAC, Egger M, Smith GD. Systematic reviews in health care: investigating and dealing with publication and other biases in meta-analysis. *BMJ* 2001;323:101-5.
- Review Manager (Computer program). Version 5.1. Nordic Cochrane Centre. Cochrane Collaboration, 2011.
- StataCorp. Stata Statistical Software: release 8. StataCorp LP, 2003.
- Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ* 2008;336:924-6.
- Cochrane Adverse Effects Sub-Group of the Cochrane Non-Randomised Study Methods Group. Including adverse effects in systematic reviews: interim recommendations. Cochrane Group, 2011.
- Loke YK, Price D, Herxheimer A. Systematic reviews of adverse effects: framework for a structured approach. *BMC Med Res Methodol* 2007;7:32.
- Badrawi H, Hassanein MK, Badraoui MH, Wafa YA, Shawky HA, Badrawi N. Pregnancy outcome in obese pregnant mothers. *J Perinat Med* 1992;20:203.
- Bechtel-Blackwell DA. Computer-assisted self-interview and nutrition education in pregnant teens. *Clin Nurs Res* 2002;11:450-62.
- Briley C, Flanagan NL, Lewis N. In-home prenatal nutrition intervention increased dietary iron intakes and reduced low birthweight in low-income African-American women. *J Am Diet Assoc* 2002;102:984-7.
- Clapp JF. Diet, exercise, and feto-placental growth. *Arch Gynecol Obstet* 1997;260:101-8.
- Crowther CA, Hillier JE, Moss JR, McPhee AJ, Jeffries WS, Robinson JS. Effect of treatment of gestational diabetes mellitus on pregnancy outcomes. *N Engl J Med* 2005;352:2477-86.
- Gomez TG, Delgado JG, Agudelo AA, Hurtado H. Diet effects on the perinatal result of obese pregnant patient. [Spanish]. *Rev Colomb Obstet Ginecol* 1994;45:313-6.
- Khouri J, Henriksen T, Christophersen B, Tonstad S. Effect of a cholesterol-lowering diet on maternal, cord, and neonatal lipids, and pregnancy outcome: a randomized clinical trial. *Am J Obstet Gynecol* 2005;193:1292-301.
- Landon MB, Spong CY, Thom E, Carpenter MW, Ramin SM, Casey B, et al. A multicenter, randomized trial of treatment for mild gestational diabetes. *N Engl J Med* 2009;361:1339-48.
- Ney D, Hollingsworth DR, Cousins L. Decreased insulin requirement and improved control of diabetes in pregnant women given a high-carbohydrate, high-fiber, low-fat diet. *Diabetes Care* 1982;5:529-33.
- Quinlivan JA, Lam LT, Fisher J. A randomised trial of a four-step multidisciplinary approach to the antenatal care of obese pregnant women. *Aust N Z J Obstet Gynaecol* 2011;51:141-6.
- Rae A, Bond D, Evans S, North F, Roberman B, Walters B. A randomised controlled trial of dietary energy restriction in the management of obese women with gestational diabetes. *Aust N Z J Obstet Gynaecol* 2000;40:416-22.
- Thornton YS, Smarkola C, Kopacz SM, Isohof SB. Perinatal outcomes in nutritionally monitored obese pregnant women: a randomized clinical trial. *J Natl Med Assoc* 2009;101:569-77.
- Wolff S, Legarth J, Vangsgaard K, Toubro S, Astrup A. A randomized trial of the effects of dietary counseling on gestational weight gain and glucose metabolism in obese pregnant women. *Int J Obes* 2008;32:495-501.
- Baciuk EP, Pereira RI, Cecatti JG, Braga AF, Cavalcante SR. Water aerobics in pregnancy: cardiovascular response, labor and neonatal outcomes. *Reprod Health* 2008;5:10.
- Barakat R, Lucia A, Ruiz JR. Resistance exercise training during pregnancy and newborn's birth size: a randomised controlled trial. *Int J Obes* 2009;33:1048-57.
- Barakat R, Cordero Y, Coterón J, Luaces M, Montejo R. Exercise during pregnancy improves maternal glucose screen at 24-28 weeks: a randomised controlled trial. *Br J Sports Med* 2011 Sep 26, epub ahead of print.
- Bell RJ, Palma SM. Antenatal exercise and birth-weight. *Aust N Z J Obstet Gynaecol* 2000;40:70-3.
- Cavalcante SR, Cecatti JG, Pereira RI, Baciuk EP, Bernardo AL, Silveira C. Water aerobics II: maternal body composition and perinatal outcomes after a program for low risk pregnant women. *Reprod Health* 2009;6:1.
- Clapp JF, III, Kim H, Burciu B, Lopez B. Beginning regular exercise in early pregnancy: effect on fetoplacental growth. *Am J Obstet Gynecol* 2000;183:1484-8.
- Erkkola R. The influence of physical exercise during pregnancy upon physical work capacity and circulatory parameters. *Scand J Clin Lab Invest* 1976;6:747-9.
- Erkkola R, Makela M. Heart volume and physical fitness of parturients. *Ann Clin Res* 1976;8:15-21.
- Garshasbi A, Faghih ZS. The effect of exercise on the intensity of low back pain in pregnant women. *Int J Gynaecol Obstet* 2005;88:271-5.

What is already known on this topic

- Excessive weight gain in pregnancy is associated with adverse maternal and fetal outcomes
- Interventions to manage weight in pregnancy have the potential to reduce adverse outcomes to mother and baby
- Interventions based on diet or physical activity, or both, in pregnancy could influence maternal and fetal weight and obstetric outcomes

What this study adds

- Diet and lifestyle interventions in pregnancy can reduce maternal weight gain in pregnancy
- There is no significant overall effect on outcomes related to fetal weight
- Diet based interventions are the most effective in reducing maternal gestational weight gain compared with other methods

- 46 Haakstad L, Bo K. Exercise in pregnant women and birth weight: a randomized controlled trial. *BMC Preg Childbirth* 2011;11:66.
- 47 Hopkins SA, Baldi JC, Cutfield WS, McCowan L, Hofman PL. Exercise training in pregnancy reduces offspring size without changes in maternal insulin sensitivity. *J Clin Endocrinol Metab* 2010;95:2080-8.
- 48 Khaledan A, Sh, Motahari Tabari NS, Ahmad Shirvani M. Effect of an aerobic exercise program on fetal growth in pregnant women. *HAYAT: J Faculty Nurs Midwifery* 2010;16:78.
- 49 Lee G, Challenger S, McNabb M, Sheridan M. Exercise in pregnancy. *Mod Midwife* 1996;6:28-33.
- 50 Marquez-Sterling S, Perry AC, Kaplan TA, Halberstein RA, Signorile JF. Physical and psychological changes with vigorous exercise in sedentary primigravidae. *Med Sci Sports Exerc* 2000;32:58-62.
- 51 Ong MJ, Guelfi KJ, Hunter T, Wallman KE, Fournier PA, Newnham JP. Supervised home-based exercise may attenuate the decline of glucose tolerance in obese pregnant women. *Diabetes Metab* 2009;35:418-21.
- 52 Prevedel T, Calderon I, DM, Adami H-O, RM. Maternal and perinatal effects of hydrotherapy in pregnancy. *Rev Bras Ginecol Obstet* 2003;25:53-9.
- 53 Santos IA, Stein R, Fuchs SC, Duncan BB, Ribeiro JP, Kroeff LR, et al. Aerobic exercise and submaximal functional capacity in overweight pregnant women: a randomized trial. *Obstet Gynecol* 2005;106:243-9.
- 54 Sedaghati P, Ziaee V, Ardjmand A. The effect of an ergometric training program on pregnant weight gain and low back pain. *Gazzetta Medica Italiana Archivio per le Scienze Mediche* 2007;166:209-13.
- 55 Yeo S, Steele NM, Chang MC, Leclaire SM, Ronis DL, Hayashi R. Effect of exercise on blood pressure in pregnant women with a high risk of gestational hypertensive disorders. *J Reprod Med* 2000;45:293-8.
- 56 Asbee SM, Jenkins TR, Butler JR, White J, Elliot M, Rutledge A. Preventing excessive weight gain during pregnancy through dietary and lifestyle counseling: a randomized controlled trial. *Obstet Gynecol* 2009;113:305-12.
- 57 Bung P, Artal R, Khodiguan N, Kjos S. Exercise in gestational diabetes. An optional therapeutic approach? *Diabetes* 1991;40(suppl 2):182-5.
- 58 Ferrara A, Hedderson MM, Albright CL, Ehrlich SF, Quesenberry CP, Peng TP, et al. A pregnancy and postpartum lifestyle intervention in women with gestational diabetes mellitus reduces diabetes risk factors. A feasibility randomized control trial. *Diabetes Care* 2011;34:1519-25.
- 59 Guelinckx I, Devlieger R, Mullie P, Vansant G. Effect of lifestyle intervention on dietary habits, physical activity, and gestational weight gain in obese pregnant women: a randomized controlled trial. *Am J Clin Nutr* 2010;91:373-80.
- 60 Huang TT, Yeh CY, Tsai YC. A diet and physical activity intervention for preventing weight retention among Taiwanese childbearing women: a randomised controlled trial. *Midwifery* 2011;27:257-64.
- 61 Hui A, Back L, Ludwig S, Gardiner P, Sevenhuysen G, Dean H, et al. Lifestyle intervention on diet and exercise reduced excessive gestational weight gain in pregnant women under a randomised controlled trial. *BJOG* 2011;119:70-7.
- 62 Hui AL, Ludwig SM, Gardiner P, Sevenhuysen G, Murray R, Morris M, et al. Community-based exercise and dietary intervention during pregnancy: a pilot study. *Can J Diabetes* 2006;30:169-75.
- 63 Jeffries K, Shub A, Walker SP, Hiscock R, Permezel M. Reducing excessive weight gain in pregnancy: a randomised controlled trial. *Med J Aust* 2009;191:429-33.
- 64 Kulpa PJ, White BM, Visscher R. Aerobic exercise in pregnancy. *Am J Obstet Gynecol* 1987;156:1395-403.
- 65 Phelan S, Phipps MG, Abrams B, Darroch F, Schaffner A, Wing RR. Randomized trial of a behavioral intervention to prevent excessive gestational weight gain: the Fit for Delivery Study. *Am J Clin Nutr* 2011;93:772-9.
- 66 Polley BA, Wing RR, Sims CJ. Randomized controlled trial to prevent excessive weight gain in pregnant women. *Int J Obes* 2002;26:1494-502.
- 67 Vinter CA, Jensen DM, Ovesen P, Beck-Nielsen H, Jorgensen JS. The LiP (Lifestyle in Pregnancy) study: a randomized controlled trial of lifestyle intervention in 360 obese pregnant women. *Diabetes Care* 2011;34:2502-7.
- 68 Carmichael SL, Shaw GM, Schaffer DM, Laurent C, Selvin S. Dieting behaviors and risk of neural tube defects. *Am J Epidemiol* 2003;158:1127-31.
- 69 Clapp JF, III. The course of labor after endurance exercise during pregnancy. *Am J Obstet Gynecol* 1990;163:1799-805.
- 70 Clapp JF, III, Capeless EL. Neonatal morphometrics after endurance exercise during pregnancy. *Am Obstet Gynecol* 1990;163:1805-11.
- 71 Dale E, Mullinax KM, Bryan DH. Exercise during pregnancy: effects on the fetus. *C J Appl Sport Sci* 1982;7:98-103.
- 72 De Rooij SR, Painter RC, Holleman F, Bossuyt PM, Roseboom TJ. The metabolic syndrome in adults prenatally exposed to the Dutch famine. *Am J Clin Nutr* 2007;86:1219-24.
- 73 Gregory PB, Rush D. Iatrogenic caloric restriction in pregnancy and birthweight. *Am J Perinatol* 1987;4:365-71.
- 74 Hatch MC, Shu XO, McLean DE, Levin B, Begg M, Reuss L, et al. Maternal exercise during pregnancy, physical fitness, and fetal growth. *Am J Epidemiol* 1993;137:1105-14.
- 75 Knudsen VK, Orozova-Bekkevold IM, Mikkelsen TB, Wolff S, Olsen SF. Major dietary patterns in pregnancy and fetal growth. *Eur J Clin Nutr* 2008;62:463-70.
- 76 Lenders CM, Hediger ML, Scholl TO, Khoo CS, Slap GB, Stallings VA. Effect of high-sugar intake by low-income pregnant adolescents on infant birth weight. *J Adolesc Health* 1994;15:596-602.
- 77 Lenders CM, Hediger ML, Scholl TO, Khoo CS, Slap GB, Stallings VA. Gestational age and infant size at birth are associated with dietary sugar intake among pregnant adolescents. *J Nutr* 1997;127:1113-7.
- 78 Lumey LH, Stein AD, Kahn HS, Romijn JA. Lipid profiles in middle-aged men and women after famine exposure during gestation: the Dutch Hunger Winter Families Study. *Am J Clin Nutr* 2009;89:1737-43.
- 79 Magann EF, Evans SF, Weitz B, Newnham J. Antepartum, intrapartum, and neonatal significance of exercise on healthy low-risk pregnant working women. *Obstet Gynecol* 2002;99:466-72.
- 80 Neugebauer R, Hoek HW, Susser E. Prenatal exposure to wartime famine and development of antisocial personality disorder in early adulthood. *JAMA* 1999;282:455-62.
- 81 Ravelli AC, van der Meulen JH, Michels RP, Osmond C, Barker DJ, Hales CN, et al. Glucose tolerance in adults after prenatal exposure to famine. *Lancet* 1998;351:173-7.
- 82 Ravelli GP, Stein ZA, Susser MW. Obesity in young men after famine exposure in utero and early infancy. *N Engl J Med* 1976;295:349-53.
- 83 Roseboom TJ, van der Meulen JH, Osmond C, Barker DJ, Ravelli AC, Bleker OP. Plasma lipid profiles in adults after prenatal exposure to the Dutch famine. *Am J Clin Nutr* 2000;72:1101-6.
- 84 Roseboom TJ, van der Meulen JH, Osmond C, Barker DJ, Ravelli AC, Schroeder-Tanka JM, et al. Coronary heart disease after prenatal exposure to the Dutch famine, 1944-45. *Heart* 2000;84:595-8.
- 85 Schramm WF, Stockbauer JW, Hoffman HJ. Exercise, employment, other daily activities, and adverse pregnancy outcomes. *Am J Epidemiol* 1996;143:211-8.
- 86 Stanner SA, K Bulmer, C Andrés, O E Lantseva, V Borodina, V V Poteen, et al. Does malnutrition in utero determine diabetes and coronary heart disease in adulthood? Results from the Leningrad siege study, a cross sectional study. *BMJ* 1997;315:1342-8.
- 87 Stein AD, Kahn HS, Rundle A, Zybert PA, van der Pal-de Bruin, Lumey LH. Anthropometric measures in middle age after exposure to famine during gestation: evidence from the Dutch famine. *Am J Clin Nutr* 2007;85:869-76.
- 88 Vujkovic M, Ocke MC, Van Der Spek PJ, Yazdanpanah N, Steegers EA, Steegers-Theunissen RP. Maternal western dietary patterns and the risk of developing a cleft lip with or without a cleft palate. *Obstet Gynecol* 2007;110:378-84.
- 89 Yazdy MM, Liu S, Mitchell AA, Werler MM. Maternal dietary glycemic intake and the risk of neural tube defects. *Am J Epidemiol* 2010;171:407-14.
- 90 Painter RC, De R, Sr., Bossuyt PM, Osmond C, Barker DJ, Bleker OP, et al. A possible link between prenatal exposure to famine and breast cancer: a preliminary study. *Am J Hum Biol* 2006;18:853-6.
- 91 De Rooij SR, Painter RC, Phillips DI, Osmond C, Tanck MW, Bossuyt PM, et al. Cortisol responses to psychological stress in adults after prenatal exposure to the Dutch famine. *Psychoneuroendocrinology* 2006;31:1257-65.
- 92 Moher D, Liberati A, Tetzlaff J, Altman DG, for the PRISMA group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ* 2009;339:b2535.
- 93 Clarke PE, Gross H. Women's behaviour, beliefs and information sources about physical exercise in pregnancy. *Midwifery* 2009;20:133-41.
- 94 Gross H, Bee PE. Perceptions of effective advice in pregnancy. The case of activity. *Clin Eff Nurs* 2004;8:161-9.
- 95 Ray JG, Diamond P, Singh G, Bell CM. Brief overview of maternal triglycerides as a risk factor for pre-eclampsia. *BJOG* 2006;113:379-86.
- 96 Qiu C, Coughlin KB, Frederick IO, Sorensen TK, Williams MA. Dietary fiber intake in early pregnancy and risk of subsequent preeclampsia. *Am J Hypertens* 2008;21:903-9.
- 97 NICE clinical guideline 43. Obesity. NICE, 2006. www.nice.org.uk/guidance/CG43.
- 98 Lambert PC, Sutton RJ, Abrams KR, Jones DR. A comparison of summary patient-level covariates in meta-regression with individual patient data meta-analysis. *Clin Epidemiol* 2002;55:86-94.
- 99 Thomson SG, Higgins JP. Treating individuals 4: can meta-analysis help target interventions at individuals most likely to benefit? *Lancet* 2005;365:341-6.

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Tables

Table 1 | Effect of dietary and lifestyle interventions in pregnancy on primary outcomes (weight gain in pregnancy and birth weight) and secondary weight related outcomes ranked as critically important by Delphi survey (except for exceeding IOM recommendations)

	No of studies	No of participants	Summary estimate (95% CI)	P value	I ² (%)
Dietary intervention					
Weight gain in pregnancy (kg)	10 ^{25-28 31-36}	2560	-3.84* (-5.22 to -2.45)	<0.001	92
Birth weight (g)	10 ^{26-28 30-36}	2861	-60* (-190 to 80)	0.41	84
Small for gestational age	3 ^{28 30 31}	2252	1.02† (0.75 to 1.37)	0.91	0
Large for gestational age	5 ^{28 29 31 34 35}	2378	0.78† (0.51 to 1.19)	0.26	63
Exceeds IOM recommendations	0	—	—	—	—
Physical activity					
Weight gain in pregnancy (kg)	14 ^{37-39 42 43 45-48 50-54}	1057	-0.72* (-1.20 to -0.25)	0.003	30
Birth weight (g)	14 ^{37-40 42 44-50 52 53}	1369	-60* (-120 to -10)	0.02	0
Small for gestational age	4 ^{37 38 46 53}	409	1.28† (0.52 to 3.15)	0.60	0
Large for gestational age	4 ^{38 39 46 52}	355	0.52† (0.25 to 1.09)	0.08	0
Exceeds IOM recommendations	1 ⁴⁶	74	0.33† (0.11 to 0.98)	0.05	NA
Mixed approach					
Weight gain in pregnancy (kg)	10 ^{7 56 59-63 65-67}	1864	-1.06* (-1.67 to -0.46)	<0.001	36
Birth weight (g)	7 ^{57 59 61-63 65 66}	1048	10* (-50 to 70)	0.86	0
Small for gestational age	4 ^{58 63 65 66}	891	0.88† (0.53 to 1.44)	0.60	0
Large for gestational age	9 ^{57-59 61 62 63 65-67}	1500	1.05† (0.79 to 1.40)	0.72	0
Exceeds IOM recommendations	4 ^{61 63 65 66}	899	0.89† (0.71 to 1.13)	0.33	56
All interventions					
Weight gain in pregnancy (kg)	34	5481	-1.42* (-1.89 to -0.95)	<0.001	80
Birth weight (g)	31	5278	-50* (-100 to 0)	0.08	57
Small for gestational age	11	3552	1.00† (0.78 to 1.28)	0.99	0
Large for gestational age	18	4233	0.85† (0.66 to 1.09)	0.21	38
Exceeds IOM recommendations	5	873	0.85† (0.66 to 1.11)	0.21	60

IOM=Institute of Medicine; NA=not applicable.

*Mean difference.

†Relative risk.

Table 2| Effect of dietary and lifestyle interventions in pregnancy on secondary maternal outcomes (ranked as critically important by Delphi survey, except for vaginal delivery and gestational age at birth). Summary estimates are relative risks unless stated otherwise

	No of studies	No of participants	Summary estimate (95% CI)	P value	I ² (%)
Dietary intervention					
Gestational diabetes mellitus	3 ^{33 35 36}	409	0.39 (0.23 to 0.69)	0.001	21
Pre-eclampsia	6 ^{28 30 31 34-36}	2624	0.67 (0.53 to 0.85)	<0.001	0
Gestational hypertension	2 ^{35 36}	282	0.30 (0.10 to 0.88)	0.03	0
Preterm delivery	4 ^{26 30 31 35}	1474	0.68 (0.48 to 0.96)	0.03	35
Caesarean section	5 ^{29 30 31 35 36}	2273	0.93 (0.84 to 1.04)	0.19	49
Vaginal delivery	2 ^{31 34}	472	0.97 (0.89 to 1.07)	0.56	0
Induction of labour	4 ^{28 31 34 35}	2277	1.12 (0.99 to 1.27)	0.07	60
Postpartum haemorrhage	2 ^{28 35}	1232	0.90 (0.57 to 1.42)	0.64	0
Gestational age at delivery (weeks)	6 ^{28 30-32 34 35}	2625	-0.05* (-0.18 to 0.08)	0.42	71
Physical activity					
Gestational diabetes mellitus	0	—	—	—	—
Pre-eclampsia	0	—	—	—	—
Gestational hypertension	0	—	—	—	—
Preterm delivery	5 ^{37 38 46 52 53}	450	1.22 (0.51 to 2.90)	0.65	0
Caesarean section	5 ^{37 39 48-50}	542	0.88 (0.66 to 1.17)	0.38	0
Vaginal delivery	3 ^{37 39 49}	488	1.02 (0.93 to 1.11)	0.70	0
Induction of labour	0	—	—	—	—
Postpartum haemorrhage	0	—	—	—	—
Gestational age at delivery (weeks)	11 ^{37-39 42 44-49 54}	1250	0.03* (-0.14 to 0.20)	0.74	0
Mixed approach					
Gestational diabetes mellitus	6 ^{51 62 63 65-67}	1233	1.18 (0.78 to 1.77)	0.44	0
Pre-eclampsia	4 ^{59 63 65 66}	718	1.16 (0.70 to 1.90)	0.57	39
Gestational hypertension	4 ^{59 63 65 66}	779	1.08 (0.75 to 1.55)	0.69	42
Preterm delivery	4 ^{57 63 65 66}	728	0.90 (0.55 to 1.47)	0.68	7
Caesarean section	8 ^{56 57 59 61 63 65-67}	1407	0.94 (0.79 to 1.13)	0.53	10
Vaginal delivery	1 ⁵⁷	34	1.25 (0.88 to 1.78)	0.21	NA
Induction of labour	1 ⁵⁹	85	1.17 (0.78 to 1.75)	0.44	NA
Postpartum haemorrhage	0	—	—	—	—
Gestational age at delivery (weeks)	6 ^{57 59 61 62 65 66}	813	0.20* (-0.02 to 0.42)	0.07	1
All interventions					
Gestational diabetes mellitus	9	1642	0.78 (0.57 to 1.08)	0.13	29
Pre-eclampsia	10	3342	0.74 (0.60 to 0.92)	0.006	31
Gestational hypertension	6	1061	0.89 (0.64 to 1.25)	0.51	50
Preterm delivery	13	2652	0.78 (0.60 to 1.02)	0.07	0
Caesarean section	18	4222	0.93 (0.85 to 1.01)	0.10	3
Vaginal delivery	6	994	1.00 (0.94 to 1.07)	0.91	0
Induction of labour	5	2362	1.12 (1.00 to 1.26)	0.05	47
Postpartum haemorrhage	2	1232	0.90 (0.57 to 1.42)	0.64	0
Gestational age at delivery (weeks)	23	4688	0.02* (-0.08 to 0.11)	0.72	33

NA=not applicable.

*Mean difference.

Table 3| Effect of dietary and lifestyle interventions in pregnancy* on secondary fetal and neonatal outcomes (ranked as critically important by Delphi survey, except for infant hyperbilirubinaemia). Summary estimates are relative risks unless stated otherwise

	No of studies	No of participants	Relative risk (95% CI)	P value	I ² (%)
Dietary intervention					
Intrauterine death	2 ^{28 30}	1320	0.15 (0.02 to 1.20)	0.07	0
Admission to neonatal intensive care unit	2 ^{28 31}	1962	0.98 (0.66 to 1.47)	0.93	77
Shoulder dystocia	3 ^{28 31 34}	2082	0.38 (0.21 to 0.69)	0.001	0
Birth trauma	2 ^{28 31}	1961	0.36 (0.11 to 1.23)	0.10	0
Respiratory distress syndrome	2 ^{28 31}	1962	1.05 (0.48 to 2.28)	0.91	58
Infant hypoglycaemia	3 ^{28 31 34}	1877	1.05 (0.83 to 1.33)	0.69	41
Infant hyperbilirubinaemia	2 ^{28 31}	1898	0.84 (0.64 to 1.10)	0.19	0
Mixed approach					
Intrauterine death	0	—	—	—	—
Admission to neonatal intensive care unit	1 ⁶⁷	304	0.98 (0.56 to 1.71)	0.94	NA
Shoulder dystocia	1 ⁶³	235	0.90 (0.06 to 14.14)	0.94	NA
Birth trauma	0	—	—	—	—
Respiratory distress syndrome	0	—	—	—	—
Infant hypoglycaemia	2 ^{57 63}	269	2.35 (0.47 to 11.76)	0.3	0
Infant hyperbilirubinaemia	0	—	—	—	—
All interventions					
Intrauterine death	2	1320	0.15 (0.02 to 1.20)	0.07	0
Admission to neonatal intensive care unit	3	2266	1.00 (0.75 to 1.33)	1.00	58
Shoulder dystocia	4	2317	0.39 (0.22 to 0.70)	0.002	0
Birth trauma	2	1961	0.36 (0.11 to 1.23)	0.10	0
Respiratory distress syndrome	2	1962	1.05 (0.48 to 2.28)	0.91	58
Infant hypoglycaemia	5	2146	1.07 (0.85 to 1.35)	0.55	10
Infant hyperbilirubinaemia	2	1898	0.84 (0.64 to 1.10)	0.19	0

*No randomised studies evaluated effect of physical activity for above outcomes.

NA=not applicable.

Table 4| Subgroup analyses for trial methods and clinical characteristics for maternal outcomes in evaluation of dietary and lifestyle interventions in pregnancy

	Gestational weight gain (kg)			Pre-eclampsia		
Subgroup	No of studies	Mean difference (95% CI)	P value for interaction	No of studies	Relative risk (95% CI)	P value for interaction
Intervention type:						
Diet	10	−3.84 (−5.22 to −2.45)	<0.001	6	0.67 (0.53 to 0.85)	0.05
Physical activity	14	−0.72 (−1.20 to −0.25)		0	—	
Mixed	10	−1.06 (−1.67 to −0.46)		4	1.16 (0.70 to 1.90)	
Diabetic status:						
Women with diabetes	4	−1.85 (−2.44 to −1.26)	0.33	3	0.65 (0.50 to 0.84)	0.06
Normal women	30	−1.4 (−2.09 to −0.71)		7	1.01 (0.68 to 1.50)	
BMI:						
Obese and overweight	11*†	−2.41 (−4.04 to -0.77)	0.05	7†	0.81 (0.58 to 1.14)	0.49
Any weight	25*†	−0.63 (−1.24 to -0.02)		4†	0.70 (0.53 to 0.92)	
Maternal weight change with intervention:						
Significantly reduced	—	—	—	4	0.61 (0.47 to 0.79)	0.009
No significant change	—	—	—	6	1.12 (0.77 to 1.61)	
Risk of bias (allocation concealment):						
High risk	28	−0.89 (−1.61 to −0.17)	0.07	7	0.73 (0.56 to 0.93)	0.76
Low risk	6	−2.14 (−3.28 to −1.01)		3	0.78 (0.53 to 1.16)	

*Polley et al⁶⁶ data presented separately for normal weight women and overweight women.

†Phelan 2011 et al⁶⁵ data presented separately for normal weight women and overweight women.

Table 5| Subgroup analyses for trial methods and clinical characteristics for fetal outcomes in evaluation of dietary and lifestyle interventions in pregnancy

Subgroup	Birth weight (g)			Large for gestational age			Small for gestational age		
	No of studies	Mean difference (95% CI)	P value for interaction	No of studies	Relative risk (95% CI)	P value for interaction	No of studies	Relative risk (95% CI)	P value for interaction
Intervention type:									
Diet	10	-60 (-190 to 80)	0.22	5	0.78 (0.51 to 1.19)	0.16	3	1.02 (0.75 to 1.37)	0.76
Physical activity	14	-60 (-120 to -10)		4	0.52 (0.25 to 1.09)		4	1.28 (0.52 to 3.15)	
Mixed	7	10 (-50 to 70)		9	1.05 (0.79 to 1.40)		4	0.88 (0.53 to 1.44)	
Diabetic status:									
Women with diabetes	5	-60 (-170 to 50)	0.80	13	0.97(0.73 to 1.27)	0.34	3	1.03 (0.75 to 1.41)	0.77
Normal women	26	-40 (-100 to 10)		5	0.76 (0.50 to 1.15)		8	0.95 (0.64 to 1.42)	
BMI:									
Obese and overweight	9*	-20 (-90 to 50)	0.43	7†	1.05 (0.68 to 1.63)	0.13	4*†	1.17 (0.77 to 1.80)	0.35
Any weight	23*	-60 (-130 to 10)		12†	0.71 (0.55 to 0.91)		9*†	0.92 (0.68 to 1.24)	
Maternal weight change with intervention:									
Significantly reduced	7	-170 (-300 to -40)	0.002	5‡	0.79 (0.50 to 1.25)	0.70	2‡	1.03 (0.74 to 1.42)	0.78
No significant change	24	-10 (-50 to -30)		12‡	0.88 (0.66 to 1.17)		8‡	0.95 (0.64 to 1.42)	
Risk of bias (allocation concealment):									
High risk	26	-60 (-120 to 0)	0.33	15	0.82 (0.63 to 1.08)	0.66	7	0.89 (0.63 to 1.25)	0.35
Low risk	5	0 (-90 to 80)		3	0.96 (0.51 to 1.80)		4	1.13 (0.79 to 1.62)	

*Polley et al⁶⁶ data presented separately for normal weight women and overweight women.

†Phelan 2011 et al⁶⁵ data presented separately for normal weight women and overweight women.

‡Ferrara 2011 et al⁵⁸ did not provide data for gestational weight gain.

Figures

Fig 1 Identification of studies in systematic review of effects of dietary and lifestyle interventions in pregnancy on maternal and fetal outcomes

Fig 2 Quality of randomised controlled trials included in systematic review of dietary and lifestyle interventions in pregnancy on maternal and fetal outcomes

Fig 3 Mean difference in gestational weight gain (kg) with dietary and lifestyle interventions in pregnancy

Fig 4 Mean difference in birth weight (g) with dietary and lifestyle interventions in pregnancy

Fig 5 Relative risk of effect on size for gestational age with dietary and lifestyle interventions in pregnancy

Fig 6 Relative risk of effects of weight management interventions in pregnancy on maternal outcomes

Fig 7 Relative risk of effects of weight management interventions in pregnancy on fetal and neonatal outcomes