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Effectiveness of multimodal nutrition interventions during pregnancy to achieve 2009 Institute of Medicine gestational weight gain guidelines: a systematic review and meta-analysis

Andrew R. Beauchesne[a,b], Kelly Copeland Cara[b,c], Jiawen Chen[d], Qisi Yao[e], Laura Paige Penkert[b,c], Wenfang Yang[a] and Mei Chung[a,b,c]

[a]Department of Obstetrics and Gynecology, Maternal & Child Health Center, The First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi, PR China;[b]School of Medicine, Tufts University, Boston, MA, USA; [c]Friedman School of Nutrition Science and Policy, Tufts University, Boston, MA, USA; [d]Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA; [e]Department of Nutrition and Food Sciences, College of Health Sciences, University of Rhode Island, Kingston, RI, USA

ABSTRACT

Background: In 2009, the Institute of Medicine (IOM) published a revision to its 1990 recommendations on gestational weight gain (GWG). The objective of this review is to update a previous systematic review and meta-analysis to evaluate the effectiveness of nutrition interventions in achieving recommended GWG.

Methods: We conducted updated literature searches in MEDLINE® (2012 through 2019), Web of Science (2012 to 6 February 2017), Embase (2016 through 2019), and Cochrane Central Register of Controlled Trials (2012 through 2019). Literature published before January 2012 was identified from a published systematic review. We included controlled trials conducted in the U.S. or Canada among generally healthy pregnant women that compared nutrition interventions with or without exercise to controls (e.g., usual care) and reported total GWG or rate of GWG based on the 2009 IOM GWG guidelines. Two independent investigators conducted screening, data extraction, and risk-of-bias (ROB) assessment. Random-effects meta-analyses were conducted when data were sufficient.

Results: Eighteen unique studies were included, of which 11 were conducted in women with overweight or obesity. Nutrition interventions, compared to controls, had a similar effect on total GWG (mean difference = −1.24 kg; 95% CI [−2.65, 0.18]; I^2=67.6%) but significantly decreased second and third trimester rate of GWG (−0.07 kg/week; 95% CI [−0.12, −0.03]; I^2=54.7%). Nutrition interventions also reduced the risk of exceeding IOM's rate of GWG targets (pooled RR = 0.71; 95% CI [0.55, 0.92]; I^2=86.3%). Meta-analyses showed no significant differences in achieving IOM's total GWG or any secondary outcome (e.g., preterm birth or small/large for gestational age) between groups. Most studies were assessed as having some or high ROB in at least two domains.

Conclusion: Multimodal nutrition interventions designed to meet the 2009 IOM's GWG targets may decrease the rate of GWG over the second and third trimesters but may not decrease total GWG.

KEY MESSAGES

Excessive gestational weight gain is associated with higher risk of many adverse maternal and fetal outcomes and represents a public health concern in the United States and Canada.

Nutrition interventions designed to meet the 2009 IOM GWG guidelines may decrease the rates of GWG over the second and third trimesters but may not be effective at reducing total GWG.

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Introduction

Pre-pregnancy body mass index (BMI) and gestational weight gain (GWG) are important determinants for pregnancy and neonatal outcomes. The Centers for Disease Control and Prevention (CDC) reported that only 32% of women in the United States achieved appropriate GWG, whereas 48% of women had excessive GWG and 20% of women had inadequate GWG

CONTACT Wenfang Yang wenfang.yang@xjtu.edu.cn Department of Obstetrics and Gynecology, Maternal & Child Health Center, The First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi, PR China

Supplemental data for this article can be accessed here.

[1]. Both excessive and inadequate GWG are associated with a number of adverse maternal and infant outcomes [2]. In pregnant women, excessive GWG is associated with hypertensive disorders [3], gestational diabetes [4], caesarean section [3], complications at delivery [5, 6], and post-partum weight retention [7]. In infants, excessive GWG is associated with fetal macrosomia and large for gestational age [2], future overweight and obesity [8], morbidity [6], and mortality [9]. Large for gestational age infants are at higher risk for perinatal [10] and long-term adverse health outcomes [11,12]. According to national CDC survey data, the prevalence of overweight or obesity among U.S. women of childbearing age increased from 22.8% in 1976 to 53.5% in 2014 [13]. In 2010, nearly 56% of pregnant women with overweight and 59% with obesity exceeded the recommended weight gain during pregnancy [14]. Compared to women with normal weight, excessive GWG may put women with overweight and obesity at even higher risk for hypertensive disorders in pregnancy as well as caesarean delivery [6]. Inadequate GWG, particularly among women who are underweight, is associated with increased risk of delivering an infant with low birthweight or small for gestational age [2].

In 1990, the Institute of Medicine (IOM) published recommendations on GWG [15]. In 2009, the IOM published a revision to the 1990 guidelines [16]. The revised guidelines redefined the BMI categories based on cut-off points developed by the World Health Organization [17] and the National Heart, Lung, and Blood Institute [18]. Similar to the 1990 guidelines, the new guidelines provide ranges of recommended GWG for women with pre-pregnancy weight status categories of underweight, normal weight, overweight, and obese; however, both the BMI cut-off points for each weight category and the corresponding recommended GWG targets were revised. For example, the BMI cut-off points for underweight and normal pre-pregnancy weight status were down-adjusted by 1.1–1.3 kg/m^2, so underweight, normal weight, overweight, and obese weight status are defined as BMI $<$18.5 kg/m^2, 18.5–24.9 kg/m^2, 25–29.9 kg/m^2, and $\geq$30.0 kg/m^2, respectively, to align with the commonly used BMI cut-offs for adults [19]. Further, the recommended weight gain for women with obesity was changed from "at least 15" pounds to 11–20 pounds (5–9.1 kg). The recommended second and third trimester rate of GWG range for women with underweight, normal weight, overweight, and obese weight status are 0.44–0.58, 0.35–0.50, 0.23–0.33, and 0.17–0.27 kg/week, respectively. The report also calls for relevant agencies and organisations to adopt these new guidelines and provide counseling on diet and physical activity to pregnant women. The rationale for this approach was to assist pregnant women in achieving GWG associated with "a favorable pregnancy outcome" in all pre-pregnancy BMI categories while reducing the risk of small- or large-for-gestational-age infants and other adverse outcomes for mothers and infants.

Numerous intervention trials designed to meet the 2009 IOM GWG guidelines have since been published. Therefore, we conducted a systematic review to evaluate the effectiveness of nutrition interventions with or without exercise during pregnancy in achieving GWG within the recommended ranges according to the 2009 IOM GWG guidelines [16].

Methods

We followed methods outlined in the Cochrane Handbook for Systematic Reviews of Intervention [20]. A prospectively developed study protocol was registered on PROSPERO (CRD42017038526).

Data sources and searches

We identified and screened literature prior to 2012 from a published systematic review examining the effects of interventions in pregnancy on maternal weight and obstetric outcomes [21]. For literature published in 2012 and beyond, we implemented searches in Ovid MEDLINE® (gateway.ovid.com; 2012 through 2019), Web of Science (webofknowledge.com; 2012 to 6 February 2017), Embase (embase.com; 2016 through 2019), and Cochrane Central Register of Controlled Trials (gateway.ovid.com; 2012 through 2019). Because intervention details and study locations are often not reported in the abstracts and are not well indexed in various electronic databases, our search strategies were intentionally designed broadly to capture all controlled trials among pregnant women and reporting body weight, weight gain, weight retention, or body mass index (BMI) as an outcome. The searches were limited to English publications and human studies. Details of the search strategies are presented in the supplementary online material.

Study selection

After removing duplicated citations across multiple databases in Endnote, we uploaded the citations to Rayyan (web application, https://rayyan.qcri.org) for double independent abstract screening. All potentially

Table 1. Study eligibility criteria.

	Inclusion	Exclusion
Populations	• Generally healthy pregnant women • Less than 20% of participants receiving insulin or other medication • U.S. and Canadian populations	• Greater than 20% of participants with diabetes mellitus receiving insulin therapy • Women with abnormal glucose intolerance or gestational diabetes • Women with HIV • Women who used *in vitro* fertilisation
Interventions	• Lifestyle intervention, including diet, physical activity and counselling • Diet or dietary counselling as a component in the intervention group • Intervention delivered directly to pregnant women • Intervention using the 2009 Institute of Medicine (IOM) guidelines for gestational weight gain targets	• Drug or supplement • Caesarean section • Exercise only • Intervention to healthcare staff or caretakers • Intervention starting during 3rd trimester • Post-partum studies
Comparators	Any	None
Outcomes	• Primary: [1] total gestational weight gain (37 weeks or at delivery minus baseline), [2] rate of gestational weight gain in 2nd and 3rd trimester • Secondary: [1] caesarean delivery, [2] postpartum weight retention, [3] preterm birth, [4] small- or large-for-gestational age, [5] childhood obesity, and [6] neonatal death / infant death	• Studies that did not report any of the primary outcomes
Study designs	• Randomised or non-randomised clinical trials • Follow-up of RCTs • Cluster RCTs • Secondary analysis of RCTs	• Observational studies • Single-arm trials • Studies without a concurrent control group

relevant full-length articles were retrieved for double independent full-text screening based on the final inclusion and exclusion criteria described in Table 1. In brief, we included randomised controlled trials (RCTs) or non-randomised controlled clinical trials (CCTs) of generally healthy pregnant women (less than 20% of participants receiving insulin or other medication) who resided in the United States (U.S.) or Canada and received either nutrition interventions based on the 2009 IOM guidelines (the "intervention group") or controls (e.g., standard obstetric care). We operationalised the definition of "nutrition interventions" of interest to include any intervention with a dietary component (e.g., diet education or prescription) delivered directly to pregnant women. We excluded studies with interventions using dietary supplements as the sole intervention, targeting healthcare staff and key persons, starting from or after the third trimester, or not following the 2009 IOM guidelines for GWG targets. The primary outcomes of the present systematic review were total gestational weight gain (defined as the difference in weight from at least 37 weeks gestation up to delivery) or rate of weight gain (defined as weekly gestational weight gain during the second or third trimester). Studies that did not report any of the primary outcomes of interest were excluded. Secondary outcomes of interest were caesarean delivery, postpartum weight retention, preterm birth, small- or large-for-gestational age, childhood obesity, and neonatal death. The following study populations were excluded: women with HIV, gestational diabetes, or abnormal glucose intolerance, or women who used *in vitro* fertilisation (IVF). Because the 2009 IOM report states the guidelines are intended for use among women in the U.S. and countries with similar population characteristics and availability of health care [16], only studies conducted in the U.S. and Canada were included. Discrepancies in inclusion or exclusion decisions were resolved by consensus between the two reviewers or adjudicated by a third reviewer or the entire research team.

Data extraction

From all included studies, we extracted information on study design (RCT or CCT), study location, sample size, participants' baseline characteristics (i.e., health status, age, anthropometric measurement), intervention component(s) (i.e., dietary, exercise, or other component), intervention duration, comparison group components (e.g., standard care), and which outcomes of interest were assessed. For anthropometric measurements, we extracted mean (±SD) BMI and the percentage of study participants with normal weight, overweight, or obese weight status as defined within each study. Data were extracted by one reviewer and checked by a second reviewer.

Due to a wide variety of intervention components reported in the studies, we grouped similar intervention components into categories (diet, exercise, and other) for facilitating the comparisons within and across studies. We further grouped components into the subcategories outlined in Table 2 and defined each subcategory using intervention descriptions

Table 2. Intervention component definitions.

Dietary components	Definition
Diet education/info	Online, recorded, printed, or in-person educational materials, lectures, or counselling sessions on dietary guidelines, food quantity, calories, dietary adherence, or other dietary advice beyond that provided in standard prenatal care (e.g., individual dietary counselling session with a dietician, group lecture on grocery shopping, and meal planning)
Diet prescription	Instructions or recommendations on all or some dietary intake, including quantity or type of ingredients, foods, food substitutions, recipes, or meal plans (e.g., providing structured meal plan tailored to meet individual preferences [tastes, allergies, intolerances, etc.])
Food or supplement	Food items or supplements that were provided to participants as part of the intervention (e.g., providing women with meal replacement bars)
Diet tracker	A record, log, device, or software application that tracks various components of dietary intake, including specific types of foods, quantity of foods, nutrition information, or calories (e.g., food log, calorie counter, food item check-list); dietary assessment tools (e.g., 24-hour recall), unless used by the participant for self-monitoring purposes, were not considered
Diet goal-setting	Interventions (including diet prescriptions) with goal-setting regarding diet, such as encouraging or limiting specific foods, limiting quantities of foods, or encouraging specific foods over other foods (e.g., written recommendations to limit sugar-sweetened beverages to 1 cup per day); goals regarding weight gain were not considered unless specific dietary goals were described
Other diet	Other dietary intervention components (e.g., reminders to use diet goal-setting tool)
Exercise components	
Exercise education/info	Online, recorded, printed, or in-person educational materials, lectures, or counselling sessions on exercise recommendations, exercise types, exercise adherence, or other exercise advice beyond that provided in standard prenatal care (e.g., individual health coach calls to encourage incremental increase in walking, group lecture on the health benefits of exercise)
Exercise prescription	Instructions or recommendations on quantity or type of exercise or physical activity, number of daily steps, or number of active calories (e.g., recommending 90 min of walking weekly)
Exercise class	Interventions that offered an in-person, virtual, or recorded exercise class of any frequency or duration (e.g., weekly aerobics class)
Exercise tracker	A record, log, device, or software application that tracks forms of exercise and physical activity (e.g., exercise log, pedometer)
Exercise goal-setting	Interventions (including exercise prescriptions) with goal-setting regarding exercise, such as encouraging or number of steps per day or number of days per week (e.g., a walking goal of 5,000 steps daily); goals regarding weight gain were not considered unless specific exercise goals were described
Other exercise	Other exercise intervention components (e.g., reminders to use physical activity goal-setting tool)
Other components	
Other education/info	Online, recorded, printed, or in-person educational materials, lectures, counselling sessions or other educational resources beyond that provided in standard prenatal care and covering such topics outside the realm of diet or exercise as behavioural and social support strategies, smart shopping, problem-solving, mindfulness, pregnancy, goal-setting, relapse prevention, positive self-talk, local resources, frequently asked questions, online group forum support, pregnancy-related risks of overweight or obese, or healthy lifestyle (e.g., online module discussing IOM gestational weight gain recommendations, lecture on good sleep hygiene)
Weight tracker	Home scale, app, or log to track weight (e.g., daily weight log); tracking weight at study visits
Other	Any intervention component beyond the standard of care that isn't included in previously described component (e.g., email or text message notifications for sessions and appointments, behaviour change goal-setting, blogging tools, group support meetings)
Standard or usual care	Standard pregnancy-related care offered by a prenatal provider; clinically indicated meetings with nutritionists, counsellors, or other providers; routine health education about pregnancy, optimal weight gain, and/or basic nutrition or exercise during pregnancy (e.g., overweight or obese patients receiving counselling by registered dietitian at prenatal visit, a packet of information on physical activity and nutrition during pregnancy from Health Canada)

provided in the included studies. To help illustrate meaningful differences between intervention and control groups, we defined interventions with multiple components (e.g., diet education/info, exercise education/info) as features beyond standard prenatal care. Definitions were created by two investigators and reviewed by the entire research team. Study interventions were then coded by one investigator using the created definitions and were independently checked by a second team member. Intervention components for each included study are described in Table 3.

We extracted number of events by group for the following categorical outcomes: total GWG and rate of GWG above, below, or within IOM recommendations; caesarean delivery; preterm birth; postpartum weight retention; small-for-gestational-age (SGA); and large-for-gestational-age (LGA). We extracted continuous data by group for total GWG, rate of GWG, and postpartum weight retention. To identify variations among included studies, we also extracted any specified outcome definitions and data from stratified analyses (e.g., weight status, race, ethnicity, socioeconomic status), if available. For articles that reported adjusted measures of effect, we focussed on models controlling for the greatest number of confounders and extracted data on confounders, effect estimates, and confidence intervals (CIs).

Risk-of-Bias assessment

Two independent team members assessed risk of bias (ROB) for the primary outcomes of the present

Table 3. Intervention components of included studies.

Author (Year) Reference	Arm	Dietary Components						Exercise Components						Other Components			
		Dietary Education/ Info.	Diet Prescription	Food or Supplement	Diet Tracker	Diet Goal-setting	Other	Exercise Education/ Info.	Exercise Prescription	Exercise Class	Exercise Tracker	Exercise Goal-setting	Other	Other Education/ Info.	Weight Tracker	Other	Standard or usual care
Cahill *et al.* (2018) [38]	I	X				X	X	X					X		X	X	X
	C															X	X
Epel *et al.* (2019) [39]	I	X					X	X						X		X	X
	C																X
Gallagher *et al.* (2018) [29]	I	X	X		X			X			X			X		X	X
	C																X
Harden *et al.* (2014) [25] Study 1 *	I	X			X	X	X			X	X	X	X		X	X	X
	C	X			X	X				X	X	X			X		X
Harden *et al.* (2014) [25] Study 2 *	I	X			X	X	X			X	X	X	X		X	X	X
	C	X			X	X				X	X	X			X		X
Herring *et al.* (2016 and 2017) [26,40]	I	X	X		X		X	X	X			X	X	X	X	X	X
	C																X
Hui *et al.* (2012) [32]	I	X	X		X	X		X	X	X	X						X
	C																X
Hui *et al.* (2014) [31]	I	X	X		X	X		X	X	X	X						X
	C																X
Liu *et al.* (2015) [27]	I	X	X		X			X	X		X			X	X		X
	C																X
Olson *et al.* (2018) [30]	I1	X			X	X		X			X	X		X	X	X	X
	I2	X			X	X		X			X	X		X	X	X	X
	C	X						X						X		X	X
Peccei *et al.* (2017) [24]*	I	XX	XX				X	XX	X		X	X		X	X	X	X
	C	X	X					X	X		X						X
Phelan *et al.* (2018) [33,34]	I	X	X	X	X			X			X	X		X	X		X
	C													X			X
Redman *et al.* (2017) [28]	I**	X	X				X	X			X			X	X	X	X
	C																X
Thomson *et al.* (2016) [35]	I	X				X		X				X		X		X	
	C	X												X		X	
Trak-Fellermeier *et al.* (2019) [36]	I	X	X			X		X	X			X					X
	C													X			X
	C																X
Vesco *et al.* (2014 and 2016) [37,41]	I	X	X		X	X			X		X	X		X			X
	C	X															X

I: Intervention arm; C: Control arm.
*No comparison group without a dietary component for Peccei *et al.* 2017 and Harden *et al.* 2014 (Study 1 and Study 2).
**Represents two intervention groups that were identical except for remote versus in-person delivery of the intervention.
X indicates inclusion of the corresponding intervention component.
XX indicates greater intensity of intervention component in intervention group than comparison group.

systematic review using the Cochrane Collaboration's ROB 2.0 tool [22]. Assessments of low risk, some concerns, and high risk were rated for each ROB domain. Disagreements were resolved by consensus among team members.

Meta-Analysis

In light of heterogeneity in intervention design, strength, and delivery across included studies, we conducted random-effects meta-analyses when three or more studies reported the same outcome [23]. For outcomes assessed by fewer than three trials, results were synthesised qualitatively only. Studies without a true control group (i.e., where the control group also received a nutrition intervention) [24,25] were excluded from all meta-analyses, and those without adequate quantitative data for certain outcomes (e.g., no variance reported [25–27] or results only reported for intervention group [27]) were excluded from meta-analyses of those outcomes. To avoid double-counting control participants in one trial with two modes of intervention delivery (in-person and remote) that measured rate of GWG, separate meta-analyses were conducted to assess each intervention arm separately compared to the control group [28]. Pooled effects sizes and confidence intervals were similar, so we present only results from the meta-analysis of the in-person delivery mode. A few studies reported results stratified by participants' weight status at baseline (i.e., normal, overweight, obese) [29,30] or by a defined BMI threshold (i.e., pre-pregnancy BMI $<=24.9$ or $>=25\,kg/m^2$) [31]. Since there were not enough studies to conduct separate subgroup analyses by baseline weight status, results for these subgroups were combined for analyses of count (events) data. For continuous data, stratified results were left unaltered in our analyses since individual data were not available.

For categorical outcomes (such as total GWG above or below IOM recommendation, caesarean delivery, preterm birth, and small- or large-for-gestational-age), we combined reported adjusted effect estimates (i.e., adjusted risk ratios, odds ratios, or incidence rate ratio) and calculated risk ratios (when adjusted effect estimates were not reported) in the meta-analyses. We noted the covariates adjusted (as reported in the original studies) in the legends of the forest plots. For continuous outcomes (i.e., total GWG and rate of GWG outcomes), we used reported or calculated net change (the difference between the two within-group changes from baseline) as the effect size in the meta-analyses. When post-intervention sample sizes were not reported, we used baseline sample sizes in the analyses. When standard deviation (SD) of the within-group change was not reported, we calculated SD from the reported standard errors or CIs.

We used both the Cochran's Q statistic (considered significant when $p<0.10$) and the I^2index to quantify the extent of statistical heterogeneity. I^2values of 25%, 50%, and 75% were defined as small, moderate, and large heterogeneity, respectively. Stata SE software (version 15.1; Stata Corp., College Station, TX) was used for all calculations and meta-analyses (*metan* command). Two-tailed *p*-values ≤ 0.05 were considered statistically significant.

Results

The literature search and study selection process are summarized in Figure 1. Briefly, a total of 11,437 abstracts were identified by our literature searches. We screened a total of 393 full-text articles, and finally included 18 articles reporting 16 studies (14 RCTs and two non-randomised trials) that met the eligibility criteria of the present systematic review [24–41]. The 16 included studies were published between 2012 and 2019 (Table 4). Sample sizes ranged from 16 to 1,722. Eleven studies were conducted exclusively in women with overweight or obesity, while the remaining studies either did not report weight status or included women with normal weight. Regarding study duration, some studies reported the mean start and end of the intervention by gestational age while others reported the number of planned intervention weeks or the number of days participants had access to intervention resources. One study did not report details on intervention duration [24]. Most of the studies in this review ($n=9$) reported total GWG as a primary study outcome of the original trials [24,25,27,30,31,33,35,37,39]. Other primary outcomes reported by the individual studies were the proportion of women with excessive GWG, rate of GWG, post-pregnancy weight retention, and infant body composition. None of the included studies assessed childhood obesity, neonatal death, or infant death.

As shown in Table 3, all study interventions included both dietary and exercise components; however, the type of dietary or exercise components differed among the studies. Dietary education or information was included in all 16 study intervention groups, while most studies also included diet trackers ($n=10$), diet prescriptions ($n=10$), and/or dietary goal-setting ($n=9$) as part of the intervention. Just one study (reported in two publications) provided

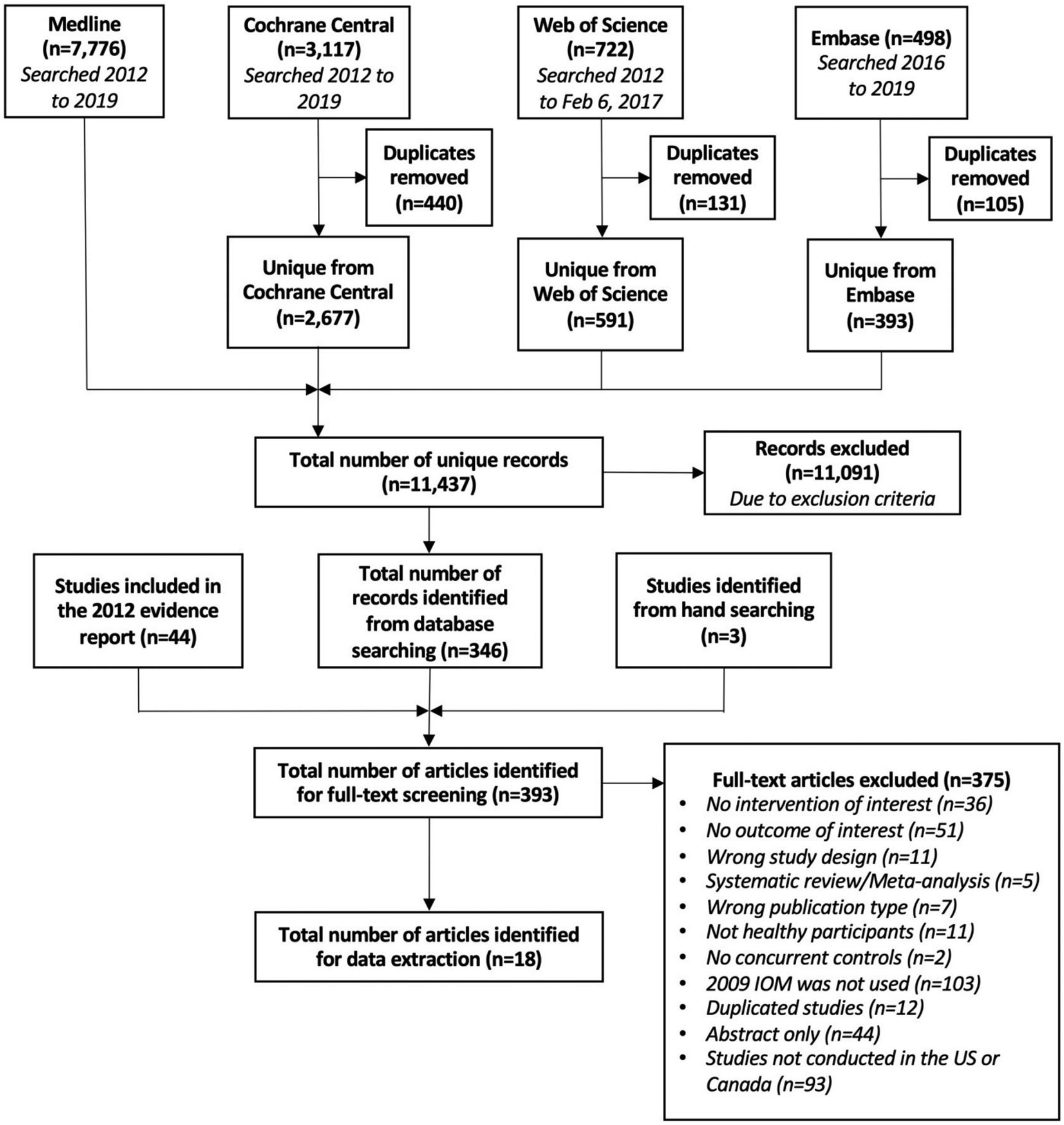

Figure 1. Literature search and study selection process.

foods or supplements to participants in the intervention group [33,34]. Exercise education or information was included in all studies except one [37]. Most studies provided exercise trackers ($n = 10$), exercise goal-setting ($n = 9$), and/or exercise prescriptions ($n = 7$), while few provided exercise classes ($n = 4$). All studies reported that both intervention and control groups received standard or usual prenatal care except one [35]. The control groups of three studies (reported in two publications [24,25]) included dietary or exercise components beyond what would be expected in standard prenatal care, albeit to a lesser intensity than the intervention groups. These additional components were usually limited to education or information on diet or exercise. Nonetheless, these studies were excluded from meta-analyses due to a lack of true controls.

Primary outcomes

Total gestational weight gain

Five trials reporting total GWG outcome (kilograms [kg]) were included in the meta-analysis [26,27,30–32]. Study control groups had mean total GWG ranging from 12.3 to 16.2 kg (in a subgroup of women with normal pre-pregnancy weight status). One trial including 56 total participants found those in the nutrition intervention group gained significantly less weight compared to the control group (−3.10 kg, 95% CI [−6.15, −0.05]) [26]. Similarly, a second trial including

Table 4. Characteristics of included trials assessing the effect of nutrition interventions on infant and maternal outcomes[a].

Author, (Year) Reference; Location	Study design; N randomised	Definition used for total GWG	Mean age at baseline (SD) [range]	Percent normal weight (%)	Percent overweight (%)	Percent obese (%)	Mean BMI in kg/m^2 (SD)	Mean intervention duration (SD)	Outcomes reported	Primary outcomes of the original trial
Cahill *et al.* (2018) [38]; St. Louis, Missouri, U.S.	RCT; 267	NA	Intervention: 24.7 (4.9) Control: 26.0 (4.9)	0	Intervention: 31.6 Control: 38.8	Intervention: 67.7 Control: 61.2	Intervention: 32.8 (5.1) Control: 31.9 (4.9)	NR	Rate of GWG; CD; PB; SGA; LGA	EGWG
Epel *et al.* (2019) [39]; San Francisco, U.S.	Non-randomised trial; 220	Difference between weight at last prenatal visit before delivery and self-reported pre-pregnancy weight	Intervention: 27.8 (5.7); Control: 28.0 (6.0); [18-45]	0	Intervention: 51 Control: 58 (includes normal weight and overweight)	Intervention: 49 Control: 45	NR	8 weeks	Total GWG; PWR	Total GWG
Gallagher *et al.* (2018) [29]; New York, U.S.	RCT; 210	NA	Intervention: 33.8 (4.0); Control: 33.8 (4.7); [≥18]	0	Intervention: 62 Control: 57	Intervention: 38 Control: 43	Intervention: 30.1 (4.1) Control: 30.7 (5.0)	Randomisation at 14.9 (0.8) GW to delivery at 35 ∼ 36.5 weeks	Rate of GWG; CD; PB; SGA; LGA	Infant body composition
Harden *et al.* (2014) [25]Study 1; Roanoke, Virginia, U.S.	RCT; 16	NA	21.9 (4.8) [21-35]	0	0	100	37.6 (6.6)	24 weeks	Rate of GWG	Rate of GWG
Harden *et al.* (2014) [25]Study 2; Roanoke, Virginia, U.S.	RCT; 51	Total weight gained from first prenatal visit until weight before delivery or last known weight >37 GW	25 (5.2) [18-45]	NR	NR	NR	30.6 (8.04)	24 weeks	Total GWG	Total GWG
Herring *et al.* (2016 and 2017) [26,40]; Philadelphia, U.S.	RCT; 66	Difference between last measured weight recorded before delivery and first measured weight in early pregnancy	Intervention: 25.9 (4.9)]; Control 25.0 (5.7); [≥18]	0	36	64	Intervention: 33.5 (5.8) Control: 32.2 (5.4)	Randomisation at 12.5 (3.7) GW to delivery	Total GWG; CD; SGA; LGA [26] PWR [40]	EGWG
Hui *et al.* (2012) [32]; Winnipeg, Canada	RCT; 224	Difference between pre-pregnancy weight and body weight at delivery room	Intervention: 30.1 (5.2); Control: 28.7 (5.9)	NA	NR	NR	Intervention: 24.9 (5.4) Control: 25.7 (5.1)	16 weeks	Total GWG; CD; LGA	EGWG
Hui *et al.* (2014) [31]; Winnipeg, Canada	RCT; 113	Difference between pre-pregnancy weight and body weight at delivery room	BMI ≤ 24.9: intervention 31 (3), control 29 (6); BMI ≥ 25: intervention 31 (4), control 32 (5)	50.4	49.6 (includes overweight and obese)	49.6 (includes overweight and obese)	BMI ≤24.9: Intervention 21.6 (2.2); Control 22.6 (1.9) BMI ≥25: Intervention 29.5 (5.1); Control 29.7 (1.3)	16 weeks	Total GWG; CD; LGA	Total GWG
Liu *et al.* (2015) [27]; Columbia, South Carolina, U.S.	Non-randomised trial; 54[b]	Delivery room weight minus pre-pregnancy weight	Intevention: 25.1 (4.2); control: 27.4 (4.9); [20-40]	0	Intervention: 81.3 Control: 57.9	Intervention: 18.7 Control: 42.1	Intervention: 28.6 (3.5) Control: 29.8 (3.1)	Baseline at ≤ 18 GW to 36 GW	Total GWG; CD; PB; SGA; LGA; PWR; Rate of GWG	Total GWG; Rate of GWG
	RCT; 1,722	Difference between first weight	NR [18-35]	53.4	46.6 (overweight or class 1 obese)	46.6 (overweight or class 1 obese)	Median (25th, 75th percentile):	Median = 28 weeks		Total GWG

(*continued*)

Table 4. Continued.

Author, (Year) Reference; Location	Study design; N randomised	Definition used for total GWG	Mean age at baseline (SD) [range]	Percent normal weight (%)	Percent overweight (%)	Percent obese (%)	Mean BMI in kg/m^2 (SD)	Mean intervention duration (SD)	Outcomes reported	Primary outcomes of the original trial
Olson *et al.* (2018) [30]; Rochester, New York, U.S.		at < 14 GW and the last weight at ≥37 GW					Intervention = 24.7 (22.0, 28.6) Control = 24.7 (21.9, 28.3)		Total GWG; Rate of GWG; CD; PB	
Peccei *et al.* (2017) [24]; Revere, Massachusetts, U.S.	RCT; 300	Difference between patient's first documented prenatal weight (<16 GW) and last documented weight before delivery	NR [18-49]	0	~42.67	~57.3	25-40	NR; Eligible participants were < 16 GW, and intervention continued to 6 months postpartum	Total GWG; CD; SGA; LGA	Total GWG
Phelan *et al.* (2018) [33,34]; San Luis Obispo, California and Providence, Rhode Island, U.S.	RCT; 264	NA	30.3 (5.42) [≥18] Intervention: 30.7 (5.3); Control 29.7 (5.5)	0	All: 39.7 Intervention: 41.9 Control: 37.5	All: 60.3 Intervention: 58.1 Control: 62.5	All: 32.5 (5.3) Intervention: 32.3 (5.2) Control: 32.6 (5.3)	9-16 GW to delivery	Rate of GWG; PWR [33] Rate of GWG; CD; PB; SGA; LGA [34]	Total GWG measured at 35-36 GW; Rate of GWG; PWR [33] Rate of GWG [34]
Redman *et al.* (2017) [28]; Baton Rouge, Louisiana, U.S.	RCT; 54	NA	Intervention (in-person): 29.2 (4.8) Intervention (remote): 29.0 (4.2) Control: 29.5 (5.1)	0	Intervention (in-person): 44 Intervention (remote): 42 Control: 53	Intervention (in-person): 56 Intervention (remote): 58 Control: 47	NR	10.4-13.4 GW to delivery	Rate of GWG	Total GWG
Thomson *et al.* (2016) [35]; Mississippi, U.S.	RCT; 105	Difference between self-reported final pregnancy weight captured at postnatal month visit and self-reported pre-pregnancy weight	Intervention: 22.7 (4.69); Control: 23.3 (4.58)	Intervention: 20.5 Control: 27.9	Intervention: 25.6 Control: 20.9	Intervention: 46.2 Control: 41.9	NR	17.7 (2.43) GW to delivery	Total GWG; CD; PB; SGA; LGA	Total GWG
Trak-Fellermeier *et al.* (2019) [36]; San Juan, Puerto Rico, U.S.	RCT; 31	Difference between last pre-delivery weight and enrolment weight	Intervention: 30.0 (5.3); Control: 25.6 (4.8)	0	Intervention: 46.7 Control: 12.5	Intervention: 53.3 Control: 87.5	Intervention: 34.6 (8.0) Control: 36.0 (7.0)	Baseline at 8-16 GW to 35-36 GW and 6 days.	Total GWG; CD; SGA; LGA; PB	Rate of GWG (average weekly GWG from baseline to 36 weeks)
Vesco *et al.* (2014 and 2016) [37,41]; Portland, Oregon, U.S.	RCT; 114	NA	31.8 (4.8) [19.1-45.2]	NA	NA	100	36.7 (4.9)	16 weeks	Rate of GWG; CD; PB; SGA; LGA [37] PWR [41]	Total GWG from randomisation to 2 weeks postpartum

CD: Caesarean delivery; EGWG: Excessive gestational weight gain; PB: Preterm birth; PWR: Postpartum weight retention; GW: Gestational weeks; Rate of GWG: Rate of weight gain in 2nd and 3rd trimester; SLGA: Small- or large-for-gestational-age; Total GWG: Total gestational weight gain.
aParticipants from all studies were generally healthy. None of the included studies assessed childhood obesity or neonatal/infant death.
bFor non-randomised trials, n represented total sample size at baseline.

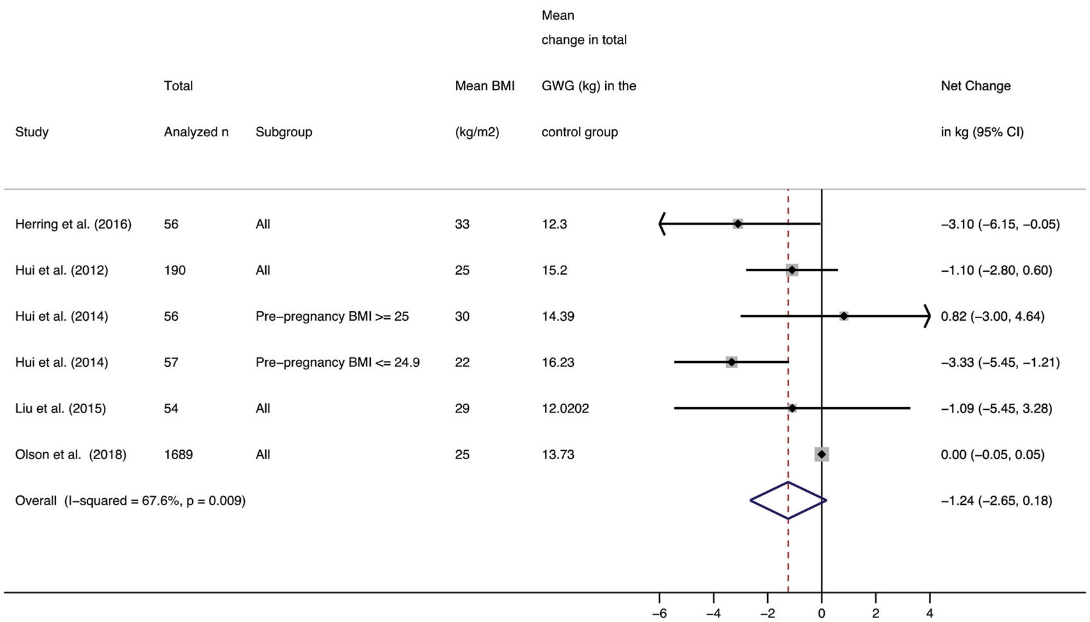

Figure 2. Random-effect meta-analysis of 5 RCTs comparing the effects of nutrition interventions on total GWG (kg) to controls.

57 participants with pre-pregnancy BMI less than 25 kg/m^2 found those participants in the nutrition intervention group gained significantly less weight compared to the control group (−3.33 kg, 95% CI [−5.45, −1.21]) [31]; however, in this trial, total GWG was similar between the intervention and control groups among the 56 participants with pre-pregnancy BMI greater or equal to 25 kg/m^2 (0.82 kg, 95% CI [−3.00, 4.64]). None of the other three trials found significant differences in total GWG between the two groups. The random-effects model meta-analysis of these five RCTs showed no significant difference in total GWG between nutrition intervention and control groups (pooled net change = −1.24 kg; 95% CI [−2.65, 0.18], $p = .09$) with moderate heterogeneity (I^2 = 67.6%, $p = .009$) (Figure 2).

Altogether, eight trials reporting the percentage of participants with total GWG above ($n = 7$), below ($n = 3$), or within ($n = 4$) IOM recommendations were included in the meta-analysis [26,27,30–32,35,36,39]. Two trials found that nutrition interventions significantly reduced the risk of total GWG above IOM guideline targets compared to the control groups [26,32], while the other five trials did not show significant differences between groups. The random-effects model meta-analysis of these seven trials showed no significant difference between nutrition interventions and controls (pooled RR = 0.89, 95% CI [0.73, 1.08], $p = .23$) with large heterogeneity (I^2 = 66.2%, $p = .007$) (Figure 4). Similarly, the random-effects model meta-analyses of total GWG below ($n = 3$ trials) and within ($n = 4$ trials) IOM's total GWG targets showed no significant differences in the risks between nutrition intervention and control groups (below: pooled RR = 1.58, 95% CI [0.96, 2.59], $p = .07$; within: pooled RR = 0.75, 95% CI [0.45, 1.23], $p = .25$) with no significant heterogeneity (below: I^2 = 0.0%, $p = .863$; within: I^2 = 13.2%, $p = .327$) (Figure 3).

Rate of gestational weight gain

Six trials reporting rate of GWG (kilograms per week [kg/wk]) during the second ($n = 2$) or third trimester ($n = 2$), or both second and third trimesters combined ($n = 6$) [27–29,34,37,38], were included in the meta-analysis. Study control groups had mean rates of GWG ranging from 0.25 to 0.49 kg/wk during the second and third trimesters combined. Five of the six trials found that pregnant women in the nutrition intervention groups had significantly lower rates of GWG during the second and third trimesters compared to those in the control groups (mean rate of GWG ranged from −0.04 to −0.18 kg/week) [28,29,34,37,38]. The other trial showed no significant difference between groups [27]. The random-effects model meta-analysis of these six trials showed that nutrition interventions had lower rates of GWG during second and third trimesters (combined) compared to controls (pooled net change = −0.08 kg/week, 95% CI [−0.12, −0.04, $p < .001$]) with moderate significant heterogeneity (I^2 = 45.9%, $p = .086$) (Figure 4). The meta-analysis of two trials showed that participants in the nutrition intervention groups had a significantly lower rate of

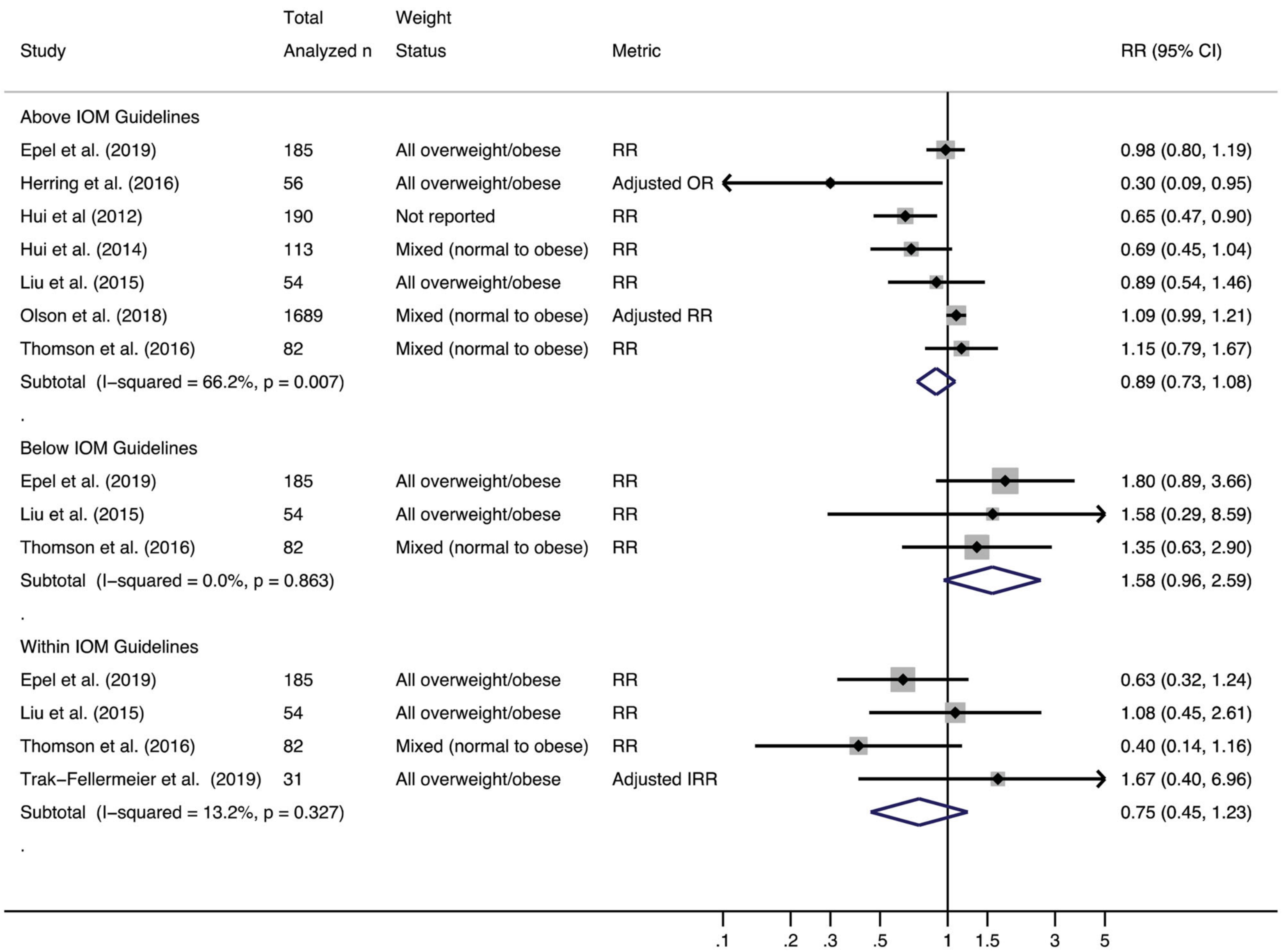

Figure 3. Random-effect meta-analysis of 7 trials comparing the effects of nutrition interventions on the percentage of participants reaching IOM's total GWG targets to controls. Legends: Adjusted OR: odds ratio controlled for early pregnancy BMI, parity, maternal age, and length of gestation; Adjusted RR: risk ratio controlled for gestational age at delivery, BMI, income, and two timing of weight measurement variables; Adjusted IRR: incidence rate ratio controlled for age and baseline BMI; RR: relative risk; CI: confidence interval; IOM: Institute of Medicine.

GWG during the second trimester compared to those in the control groups (pooled net change = −0.12 kg/week, 95% CI [−0.17, −0.07], $p < .001$) with low but non-significant heterogeneity (I^2 = 24.8%, $p = .264$). However, the same two trials did not find significant differences between group rates of GWG during the third trimester (pooled net change = −0.04 kg/week, 95% CI [−0.08, 0.01], $p = .12$) with no heterogeneity (I^2 = 0.0%, $p = .472$) (Figure 4).

Six trials reporting the percentage of participants with a rate of GWG above ($n = 5$), within ($n = 2$), or below ($n = 1$) IOM recommendations were included in the meta-analysis [28–30,36–38]. Four trials found that pregnant women receiving nutrition interventions had significantly reduced risk of exceeding IOM's rate of GWG targets compared to control groups (RR = 0.48 to 0.81) [28,29,37,38]; however, the largest trial found no significant difference between groups (adjusted RR = 1.0 [95% CI 0.94, 1.07]) [30]. This inconsistency resulted in large heterogeneity in the random effects meta-analysis (I^2 = 86.3%, $p < .001$). The meta-analysis of these five trials found that pregnant women receiving nutrition interventions had significantly lower risk of exceeding IOM's rate of GWG targets compared to control groups (pooled RR = 0.71, 95% CI [0.55, 0.92], $p = .01$) (Figure 5). One of the trials reported that the number of participants with rates of GWG below or within IOM recommendations was significantly higher in the nutrition intervention group compared to the control group (RR = 3.11 and 3.45, respectively) [37]. A meta-analysis combining results from two trials [36, 37] reporting on the number of participants with rates of GWG within IOM recommendations showed no significant differences between nutrition intervention and control groups (pooled RR = 2.57, 95% CI [0.89, 7.39], $p = .08$) (Figure 5).

Studies not included in Meta-Analysis

Three trials reported in two publications were excluded from meta-analysis because the control group received dietary (e.g., dietary education, dietary

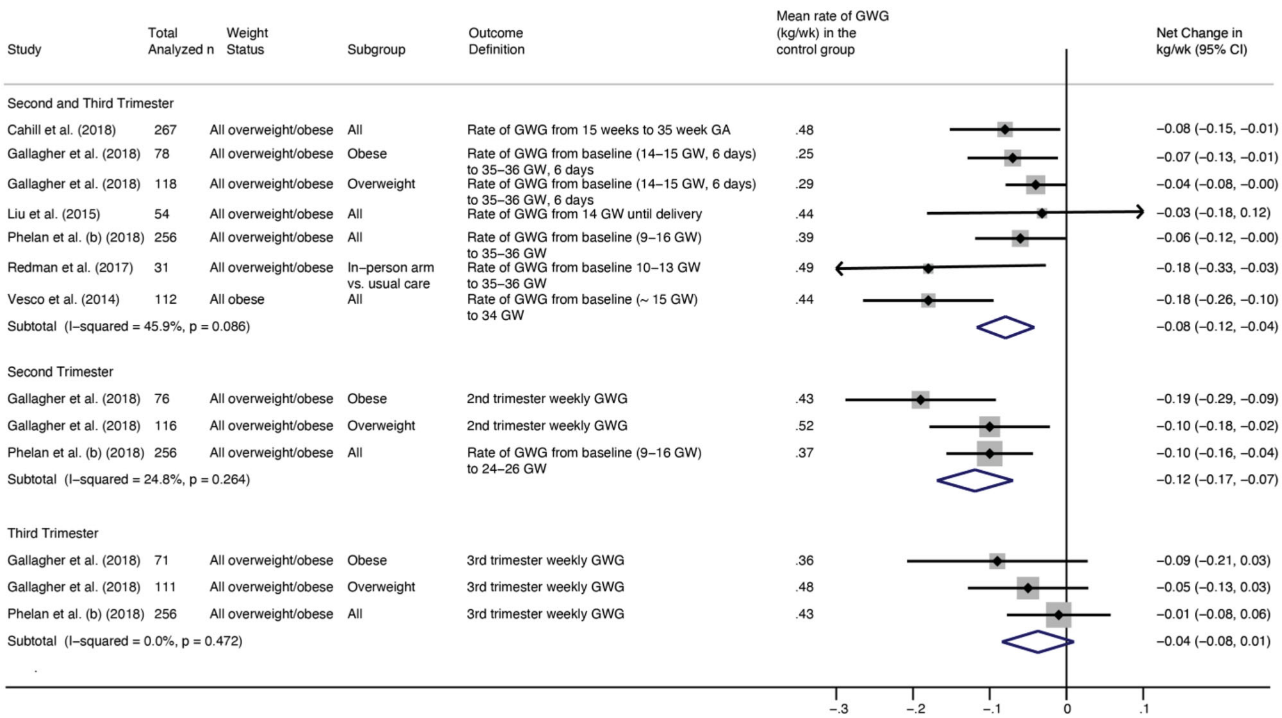

Figure 4. Random-effect meta-analysis of 6 trials comparing the effects of nutrition interventions on the net change in rate of GWG (kg/week) to controls.

counselling, goal setting) or exercise components beyond what would be expected in standard care [24,25]. An RCT including 300 women found no significant difference in the proportion of women with total GWG within IOM guidelines in the nutrition intervention group (34.2%) compared to the control group (27.5%) (odds ratio = 1.4, 95% CI [0.8, 2.4]) [24]. However, subgroup analyses found women in the intervention group with overweight status gained significantly less weight compared to women with overweight status in the control group (difference = −5.3 pounds, 95% CI [−10.0, −0.6]). The second RCT including 16 women found those in the nutrition intervention group had a lower rate of GWG compared to controls during the second trimester (gestation weeks ~12 to 24: 0.18 kg/week vs. 0.50 kg/week) but a higher rate of GWG during the third trimester (gestation weeks ~24–32: 0.40 kg/week vs. 0.36 kg/week) [25]. These rates were calculated from provided total GWG measures by group and therefore do not allow for standard deviation calculations or tests of significance. Lastly, an RCT including 51 women found no significant difference in the proportion of women with total GWG within IOM guidelines between nutrition intervention (36%) and control groups (13%) ($p = .06$) [25].

Risk of bias

Summary risk-of-bias (ROB) assessments for our primary outcomes, total GWG and rate of GWG, are shown in Figure 6. Individual study ROB assessments are provided in supplemental online materials.

For the total GWG outcome, over 50% of studies had some or high ROB due to the randomisation process, including issues regarding concealment of allocation sequence. Over 75% of studies had some ROB due to measurement in the outcome, including issues with blinding of participants and outcome assessors. Additionally, 100% of studies had some ROB in selection of the reported results, usually due to lack of a prespecified analysis plan. Lastly, 100% of studies had low ROB due to deviations from intended interventions.

For the rate of GWG outcome, over 50% of studies had some or high ROB due to the randomisation process, and 100% of studies had some ROB in selection of the reported results. Notably, 100% of studies had low ROB in deviations from intended interventions and missing outcome data.

Secondary outcomes

Meta-analyses were conducted for the caesarean delivery outcome (11 trials [26,27,29–32,34–38]), preterm birth outcome (eight trials [27,29,30,34–38]), small-for-gestational-age (SGA) outcome (eight trials [26,27,29,34–38]), large-for-gestational-age (LGA) outcome (10 trials [26,27,29,31,32,34–38]), and postpartum weight retention as a continuous outcome (three trials [33,39,41]). The random-effects model meta-analyses did not show significant differences in the risks of

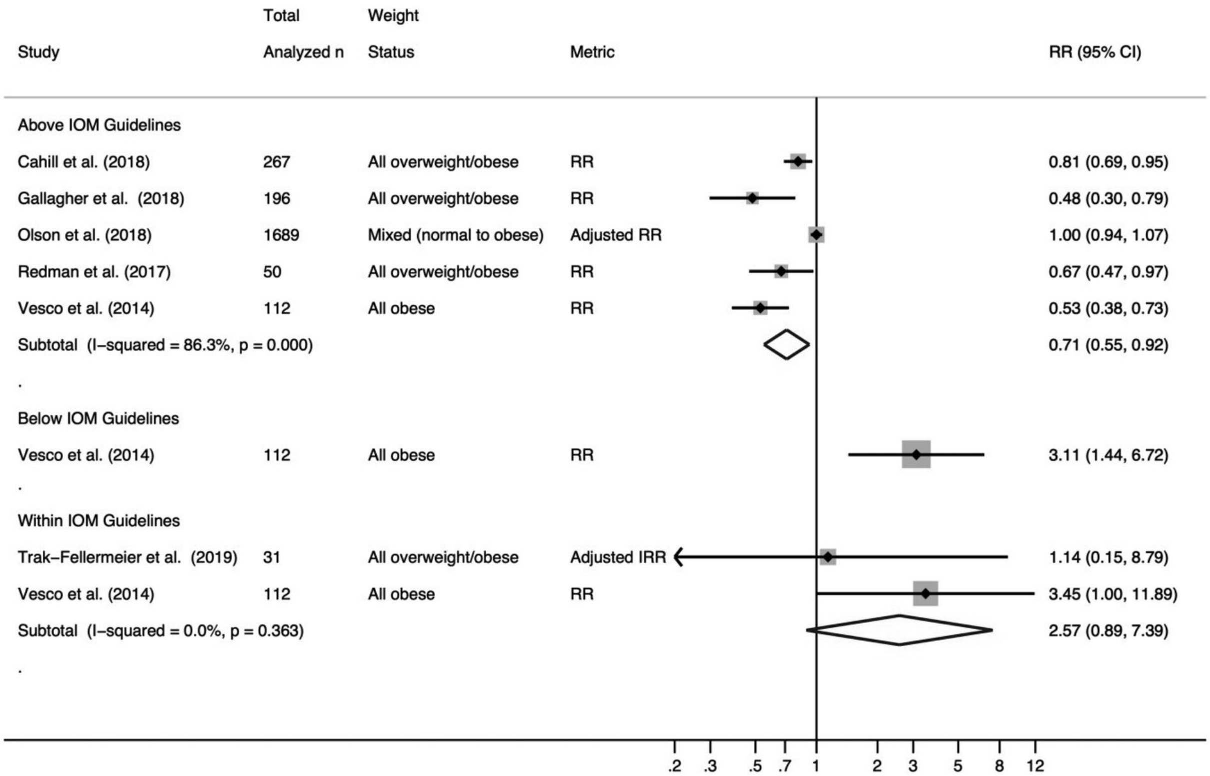

Figure 5. Random-effect meta-analysis of 6 trials comparing the effects of nutrition interventions on the percentage of participants reaching IOM's rate of GWG guideline targets to controls. Legends: Adjusted RR: risk ratio controlled for gestational age at delivery; BMI: income, and two timing of weight measurement variables; Adjusted IRR: incidence rate ratio controlled for age and baseline BMI; RR: relative risk; CI: confidence interval; IOM: Institute of Medicine.

caesarean delivery, preterm birth, SGA, LGA, or postpartum weight retention between intervention and control groups (pooled RR ranged from −0.23 to 1.10) (Figures 7–11).

Two trials reported on postpartum weight retention as a categorical outcome [27,33], so no meta-analysis was performed. One of these two studies found no significant difference between groups in the number of women at or below pre-pregnancy weight (by self report or by measurement at enrolment) at 12 months postpartum ($p = .56$ and $p = .99$, respectively) [33]. In the other trial, data on postpartum weight retention were reported for 14 of 16 participants randomised to the nutrition intervention group with no data reported for the control group [27]. At 12 weeks postpartum, those in the intervention group retained an average of 2.6 (SD = 12.6) pounds above their pre-pregnancy weight, 50% were at or below their pre-pregnancy weight, and 36% were 5 pounds or more above their pre-pregnancy weight [27].

Discussion

Results of our systematic review and meta-analyses suggest that multimodal nutrition interventions that were designed to help women meet the 2009 IOM's GWG guideline targets significantly decreased the rates of GWG during the second and third trimesters among generally healthy women; however, there was no significant difference in total GWG compared to usual care. Additionally, most women in the included studies of this systematic review, regardless of intervention group and pre-pregnancy weight status, exceeded the gestational weight gain recommended in the 2009 IOM GWG guidelines. Overall, the quality of the body of evidence is only moderate primarily due to potential biases relating to randomisation and outcome assessment and reporting. Results from our meta-analyses also suggest, compared to usual care, nutrition interventions had similar effects on secondary outcomes including caesarean delivery, preterm birth, SGA,LGA, and postpartum weight retention.

There are numerous possible reasons for the significant difference in rate of GWG during second and third trimesters, but not total GWG, found in this review. One obvious possible reason is that studies did not implement nutrition interventions until several weeks into pregnancy. The lack of intervention during the first or even part of the second trimester may have only allowed for a significant effect in weight

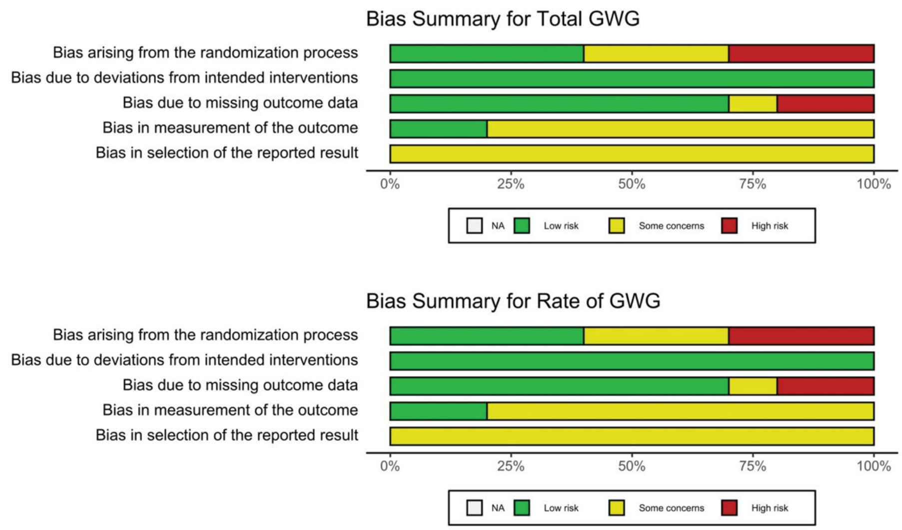

Figure 6. Summary ROB assessment for total GWG ($n = 9$, top) and rate of GWG ($n = 7$, bottom) outcomes.

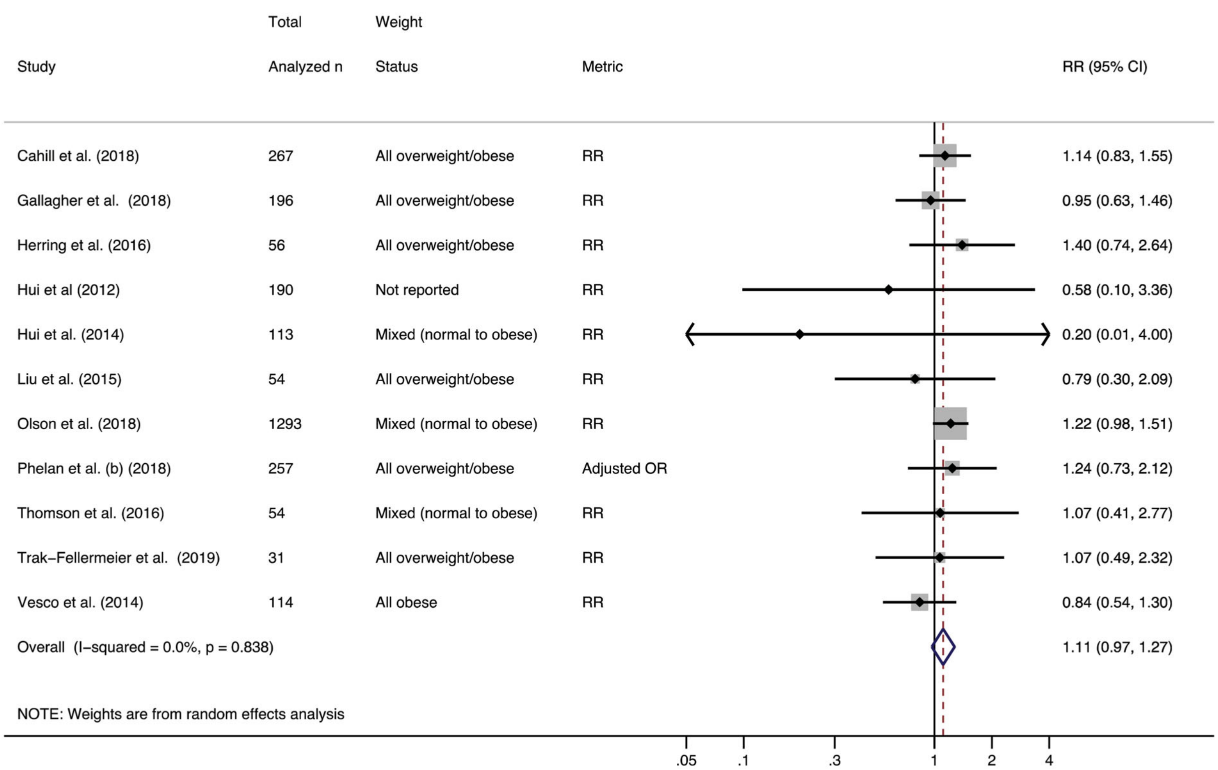

Figure 7. Random-effect meta-analysis of 11 trials comparing the effects of nutrition interventions on caesarean delivery to controls.

gain during the second and third trimester, but the effect was not great enough to reflect a difference in total GWG, which includes weight gained during the first trimester before implementation of intervention. Further, adherence may be highest near the beginning of the intervention, resulting in lower GWG in the second trimester. Last, fewer studies assessed rate of GWG than total GWG. These studies may have had more intensive interventions compared to other included studies.

Our results are consistent with a meta-analysis of individual patient data from seven randomised trials, including four studies from the present review, that assessed the effect of lifestyle interventions with a dietary component on GWG [42]. Similar to our findings, the authors reported the rate of GWG was lower

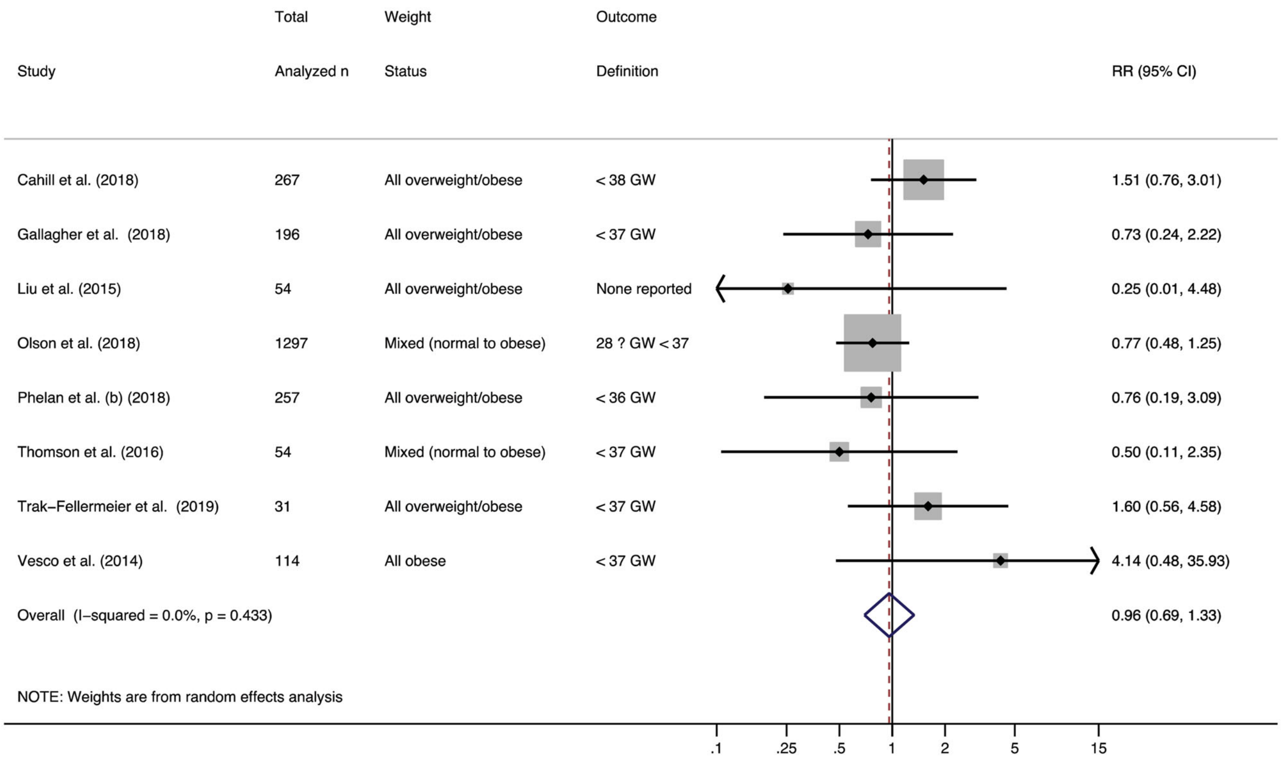

Figure 8. Random-effect meta-analysis of 8 trials comparing the effects of nutrition interventions on preterm birth to controls.

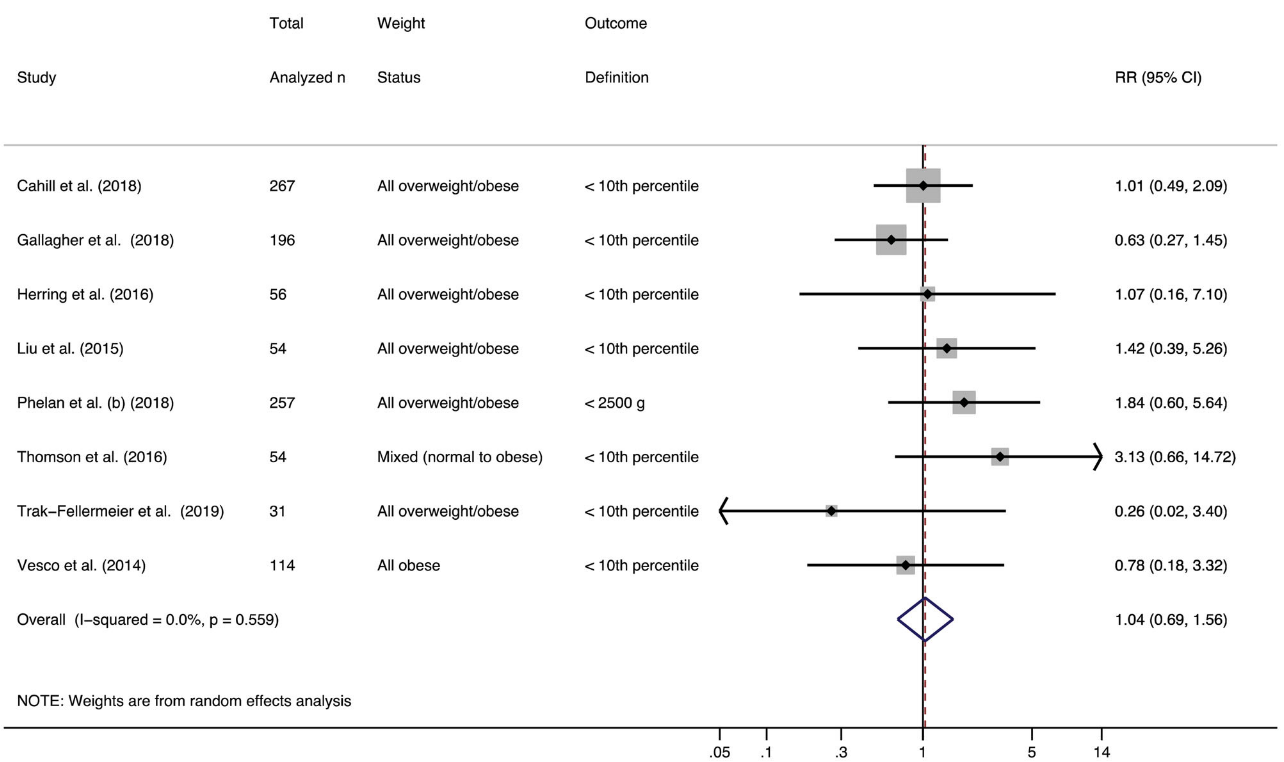

Figure 9. Random-effect meta-analysis of 8 trials comparing the effects of nutrition interventions on small-for-gestational-age (SGA) to controls.

in the intervention than control groups, and the interventions had a greater effect on rate of GWG during the second trimester than the third trimester. In contrast to our results, they found the intervention groups had significantly lower total GWG compared to control groups. This difference in conclusions may

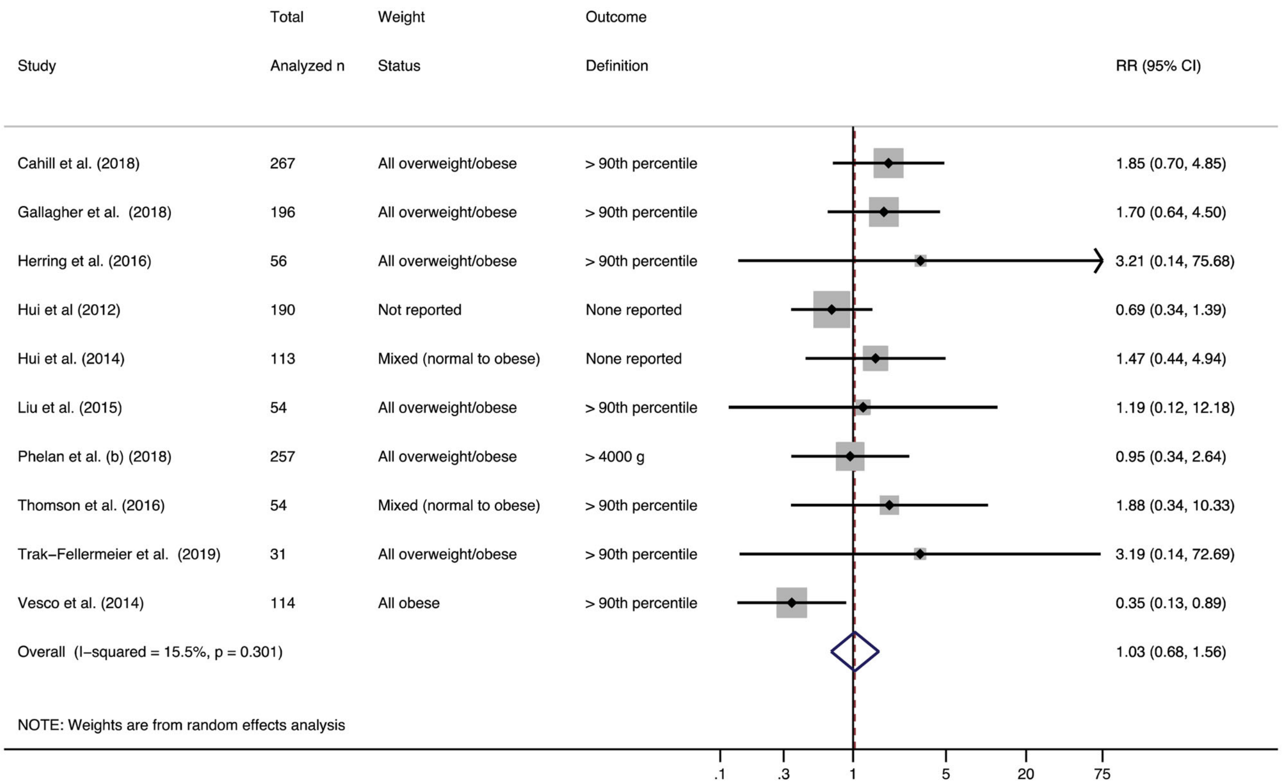

Figure 10. Random-effect meta-analysis of 10 trials comparing the effects of nutrition interventions on large-for-gestational-age (LGA) to controls.

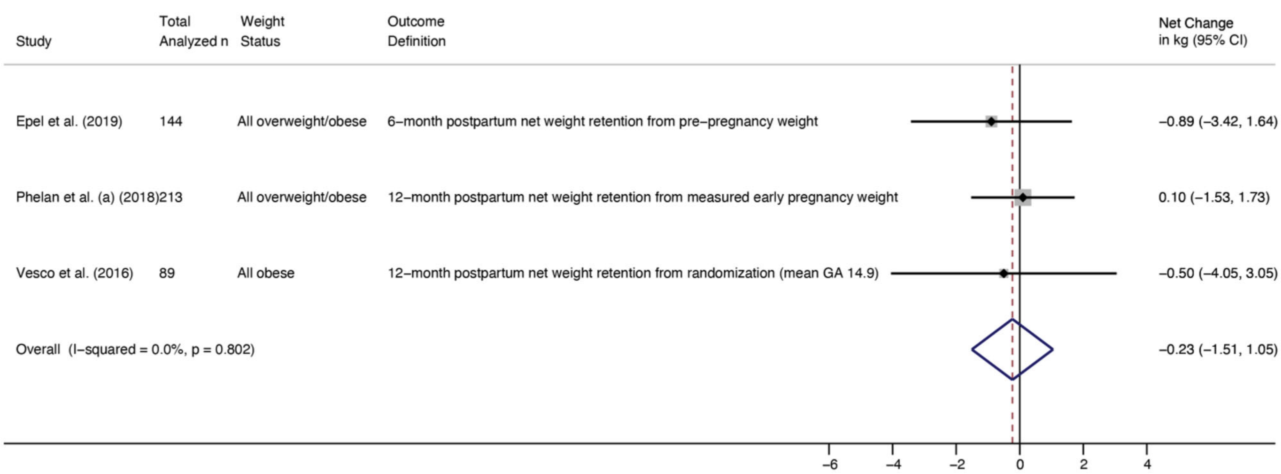

Figure 11. Random-effect meta-analysis of 3 trials comparing the effects of nutrition interventions on postpartum weight retention to controls.

stem from higher statistical power in their meta-analyses which utilised individual participant data. Another possible explanation is the difference in inclusion criteria: they included studies measuring total GWG from baseline to just 35–36 weeks gestation, while we used a cut-off of at least 37 weeks gestation with many of our included studies measuring total GWG up to 40 weeks gestation or time of delivery. Therefore, our analyses captured more time overall leaving room for intervention participants' weight gain to possibly catch up to that of control participants. Our findings that rate of GWG measured in separate trimesters was significantly different in the second but not the third trimester support this reasoning. In a second systematic review and meta-analysis, researchers found a significant difference in total GWG between dietary intervention and control groups [21]. Differences in inclusion criteria, especially including studies that may not have followed the 2009 IOM guidelines, may partially account for the discrepancy in this findings with the current systematic review.

Most gestational weight gain occurs during the second and third trimester of pregnancy [15]. Therefore, interventions that reduce the rate of weight gain during these trimesters may be beneficial in reducing overall gestational weight gain and the risk of pregnancy complications, including those that typically develop during the latter two trimesters (e.g. gestational diabetes, large for gestational age). However, our results did not show a significant difference in secondary outcomes between intervention and control groups. Some of our null results are consistent with a prior systematic review of a broader range of nutrition interventions showing no significant effect of intervention on rates of caesarean delivery, neonates large for gestational age, or preterm birth [21]. Excessive GWG has been shown to be associated with many adverse maternal outcomes, including postpartum weight retention [7], large for gestational age [2], caesarean delivery [3], and cardiovascular and cerebrovascular diseases [43]. The effects of nutrition intervention on some outcomes, such as caesarean delivery, may depend on the degree of weight gain that is achieved. Alternatively, moderate weight control during pregnancy may have an effect on the birthweight of the newborn but not necessarily the occurrence of SGA or LGA, which represent the extreme ends of newborn weight status.

Our review had a few notable strengths. We included studies with only interventions designed to meet the 2009 IOM GWG guideline targets, and thus can evaluate the impact of the 2009 IOM GWG guidelines on clinical or public health practice. All original studies, except for one, in our review investigated total GWG or rates of GWG as their primary study outcome. Therefore, the availability of outcome data was consistently high with most studies having low risk of bias due to missing outcome data. Since included studies used different dietary or exercise components, we followed the approach to synthesizing evidence on “complex multicomponent health care interventions” recommended by the Agency for Healthcare Research and Quality (AHRQ) [44]. Finally, our risk-of-bias assessment focussed on the effect of assignment to intervention (i.e., intention-to-treat) rather than the effect of adhering to intervention. Based on our assessment, all studies showed low risk of bias for deviations from intended intervention (i.e., contamination), and intention-to-treat or modified intention-to-treat analyses were conducted across all studies.

There are several limitations in our review. Our search strategy was limited to English publications; however, we believe no important publications were missed since our criteria included studies conducted in the U.S. and Canada. Most included studies were single-blinded or unblinded due to study design limitations. Most studies had small sample sizes and generalisability is limited. Further, the included studies may not be adequately powered to assess the effect of nutrition intervention on secondary outcomes, including caesarean delivery, neonates large for gestational age, or preterm birth. Several meta-analyses demonstrated moderate or high heterogeneity of outcomes among included studies resulting in large uncertainties (i.e., wide confidence intervals). Furthermore, few trials reported outcomes by subgroup (i.e., weight status, race) which limited the possibility of investigating heterogeneity or assessing the effect of interventions among specific populations that may benefit differently from interventions designed to improve GWG. Lastly, our review did not assess the effect of nutrition interventions on several clinically meaningful maternal and obstetric outcomes where assessment requires large studies, including preeclampsia and gestational diabetes mellitus. The 2009 IOM GWG guidelines removed these outcome from consideration due to a “lack of sufficient evidence that GWG was a cause of these conditions” [16].

In pregnant women and other populations, a dose response relationship of nutrition intervention intensity and weight-related outcomes has been observed [45–47]. It is possible that nutrition interventions of included studies are not intensive enough to meet the IOM GWG guideline targets. Although the absolute net change in the rate of GWG was found to be small in the present review, more intensive nutrition interventions that start earlier in pregnancy or in prenatal care have the potential to help reach the 2009 IOM GWG recommended targets.

The quality of future studies may be improved by increasing sample sizes, reporting clear and appropriate randomisation processes, and prospectively selecting outcome measures. Additionally, research investigating the intensity of nutrition interventions on GWG and clinical outcomes of interest may help identify the most cost-effective intervention strategies. Once identified, large prospective cohort and intervention studies are needed to examine the effectiveness of meeting the 2009 IOM GWG targets on clinically relevant maternal and obstetric outcomes to fill the gaps in evidence for informing clinical and public health guideline developments.

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Disclosure statement

All authors declare no conflicts of interest.

ORCID

Kelly Copeland Cara http://orcid.org/0000-0003-1491-9539
Qisi Yao http://orcid.org/0000-0002-5786-0613
Mei Chung http://orcid.org/0000-0002-5583-2870

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