Macronutrient composition and gestational weight gain: a systematic review 1,2

Myrine J Tielemans,3,8 Audry H Garcia,5,8 André Peralta Santos,3,8 Wichor M Bramer,4 Nellija Luksa,3 Mateus J Luvizotto,3 Eduardo Moreira,3 Geriolda Topi,3 Estef AL de Jonge,3 Thirsa L Visser,3 Trudy Voortman,3 Janine F Felix,3 Eric AP Steegers,3 Jessica C Kiefte-de Jong,3,6,7 and Oscar H Franco3

Department of 3Epidemiology, 4Medical Library, and Departments of 5Obstetrics and Gynecology and 6Pediatrics, Erasmus Medical Center, University Medical Center, Rotterdam, Netherlands; and 7Department of Global Public Health, Leiden University College the Hague, The Hague, Netherlands

ABSTRACT

Background: Abnormal gestational weight gain is associated with unfavorable pregnancy outcomes. Several risk factors have been identified, but the effect of macronutrient intake during pregnancy on gestational weight gain has not been systematically evaluated in both high-income countries and low- and middle-income countries.

Objective: We conducted a systematic review of the literature in 8 different databases (until 12 August 2015) to assess whether energy intake and macronutrient intake (i.e., protein, fat, and carbohydrate) during pregnancy were associated with gestational weight gain (following Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines).

Results: Of 7623 identified references, we included 56 articles (46 observational studies and 10 trials, 28 of which were in high-income countries and 28 of which were in low- and middle-income countries). Eleven of the included articles were of high quality (20%). Results of 5 intervention and 7 high-quality observational studies suggested that higher energy intake during pregnancy is associated with higher gestational weight gain (n = 52). Results from observational studies were inconsistent for protein intake (n = 29) and carbohydrate intake (n = 18). Maternal fat intake (n = 25) might be associated with gestational weight gain as suggested by observational studies, although the direction of this association might depend on specific types of fat (e.g., saturated fat). Macronutrient intake was not consistently associated with the prevalence of inadequate or excessive gestational weight gain. Associations were comparable for high-income countries and low- and middle-income countries.

Conclusions: The current literature provides evidence that energy intake is associated with gestational weight gain, but the roles of individual macronutrients are inconsistent. However, there is a need for higher-quality research because the majority of these studies were of low quality.

Keywords: energy intake, gestational weight gain, macronutrients, pregnancy, systematic review

INTRODUCTION

Gestational weight gain (GWG)9 varies considerably in women worldwide (1, 2), and abnormal weight gain (i.e., too little or too much) has been associated with unfavorable pregnancy and birth outcomes. Too little GWG (3) increases risks of low birth weight and preterm birth (4); the latter disorder was ranked seventh in the leading causes of global years of life lost (5). In contrast, excessive GWG (3) is associated with risks of gestational diabetes, cesarean delivery, giving birth to a large-for-gestational-age newborn, and postpartum weight retention (6–8). Furthermore, excessive GWG has been linked to childhood obesity in the offspring (9), which is associated with increased risk of chronic diseases in later life (10).

Hence, it is important to identify modifiable factors associated with abnormal GWG. Such a modifiable factor could be dietary intake during pregnancy (11). Several national and international dietary guidelines recommend higher energy intake but do not have specific recommendations for the macronutrient composition in pregnancy (12), whereas other guidelines recommend slightly higher protein intake in addition to higher energy intake (13). Nevertheless, the effects of different dietary components during pregnancy on GWG have not been fully elucidated. Several studies have reported that energy intake was associated with higher GWG in high-income countries (14), but it is unclear whether weight gain during pregnancy is affected by specific sources of energy (e.g., energy from protein, carbohydrates, or fat). In addition, maternal nutrition might be differently associated with GWG in low- and middle-income countries than in high-income countries because maternal protein-energy malnutrition is prevalent in many low- and middle-income countries (15, 16).

1Supported by Nestlé Nutrition (Nestec Ltd.), Metagenics Inc., and AXA (MJT, AHG, EALdJ, TV, JCK-dJ, and OHF).
2 Supplemental Material (Search Strategy and Quality Score) and Supplemental Tables 1–8 are available from the “Online Supporting Material” link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.
3 These authors contributed equally to this work.
4 Supported by Nestlé Nutrition (Nestec Ltd.), Metagenics Inc., and AXA (MJT, AHG, EALdJ, TV, JCK-dJ, and OHF).
5 Abbreviations used: GI, glycemic index; GWG, gestational weight gain; RCT, randomized controlled trial.

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In nonpregnant adult populations, weight gain is mainly determined by a positive energy balance, largely irrespective of the source of energy (17). However, weight gain during pregnancy is a result of complex processes in both the mother and fetus and includes, for example, fetal weight gain, placental weight development, maternal fat accumulation, and changes in extracellular volume (18). Therefore, the relation between macronutrient intake and weight gain may be more complex during pregnancy and may be different from that in nonpregnant subjects.

Previous systematic reviews on this topic have mainly focused on the effects of dietary factors in high-income countries (14) or were restricted to a specific type of study design (e.g., randomized controlled studies on dietary and lifestyle interventions) (19). Therefore, we aimed to conduct a systematic review that would provide a full overview of the effects of macronutrient intake on GWG worldwide. We systematically reviewed the association between energy and macronutrient intakes and weight gain during pregnancy in both observational and intervention studies in low-, middle-, and high-income countries.

METHODS

A systematic review of the literature was performed to assess the association between energy and macronutrient intakes with weight gain during pregnancy. This review was performed according to a predefined protocol and reported in concordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (20).

Search strategy and selection criteria

We searched for articles without restrictions to the language and publication date in the following electronic databases: Embase (via https://www.embase.com), MEDLINE (via OvidSP; http://ovidsp.tx.ovid.com/sp-3.17.0a/ovidweb.cgi), Cochrane central (via Wiley; http://onlinelibrary.wiley.com/cochranelibrary/search), Web-of-Science (https://apps.webofknowledge.com), CINAHL (via EBSCOHost; https://health.ebsco.com/products/cinahl-complete/allied-health-nursing), and PsycINFO (via OvidSP; http://ovidsp.tx.ovid.com/sp-3.17.0a/ovidweb.cgi). Additional articles were retrieved from PubMed, where the subset “as supplied by publisher” contains the most-recent unindexed articles, and from Google Scholar. The search was last run on 12 August 2015 and was designed by an experienced medical information specialist. The search strategy combined controlled vocabulary terms (in MEDLINE, Embase, CINAHL, and PsycINFO) and free-text words in the title or abstract related to the exposure (e.g., nutrition, diet, or food), outcome (e.g., weight gain, weight change, or change in BMI), and studied population (e.g., pregnancy, pregnant women, or maternal). The complete search strategy for all databases is provided in Supplemental Material: Search Strategy.

To minimize publication bias, we used the following 3 strategies: 1) we did not restrict to the language of publication; 2) we applied a broad search strategy that focused on all nutritional exposures in relation to pregnancy and weight gain; and 3) we searched through trial registries [clinicaltrials.gov and the International Clinical Trials Registry Platform (http://apps.who.int/trialsearch/)] to identify unpublished relevant intervention trials.

Study selection

Randomized controlled trials (RCTs), intervention studies, cohort studies, and case-control studies were eligible for inclusion if the recruited participants were women with a singleton pregnancy either healthy or diseased. Studies were included if protein, fat, carbohydrate, or energy intake was measured or supplemented as the exposure or intervention and if the reported outcome was GWG (measured or self-reported) or the adequacy of GWG. In addition, we included studies that measured weight shortly after childbirth. The selection criteria (Population, Intervention or exposure, Comparison, Outcome, and Study design) are presented in Table 1.

We excluded studies if they included only mothers who had given birth to newborns with birth defects because birth defects might disproportionately contribute to GWG or to extremely preterm newborns (born <28 wk of gestation) because of the short follow-up period. We excluded studies that were restricted to adolescents, and we included studies in which the mean age of the total population was <18 y because, during adolescence, additional energy is needed for the adolescents’ own growth. Intervention studies in which the exclusive effects of macronutrients could not be determined were excluded (e.g., when the intervention was combined with micronutrients or physical activity). We also did not include studies on dietary counseling when actual dietary intake was not measured.

Two independent reviewers screened the titles and abstracts. The retrieved full-text articles were also evaluated by 2 independent reviewers and included if the selection criteria matched. To solve disagreements during the selection process, a third reviewer was contacted. In case of multiple articles including the same participants, we included the article that provided the most information or which was published most recently. Non-English articles were preferably evaluated by native speakers in the presence of one of the authors.

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>PICOS criteria, macronutrient composition, and gestational weight gain: a systematic review¹</td>
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<tr>
<td>PICOS criteria</td>
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<tr>
<td>Population</td>
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<td>Intervention/exposure</td>
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<td>Comparison</td>
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<td>Outcome</td>
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<td>Study design</td>
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¹PICOS, Population, Intervention or exposure, Comparison, Outcome, and Study design.
Reference lists of the 20% most recently published articles and of related systematic reviews were screened to identify relevant articles. Additional articles were identified through hand searches of related articles.

Data extraction

We extracted the data with the use of a predesigned template. The following information was extracted: 1) details of the study (e.g., study design, starting year of the study, country in which the study was performed, number of participants, inclusion and exclusion criteria, and source of funding); 2) data on study participants (e.g., age, ethnicity, and comorbidities); 3) pregnancy-related aspects (e.g., complications and parity); 4) type of dietary exposure (energy or macronutrient intake); 5) details of measurement methods of diet and GWG (e.g., method used, number of measurements, absolute GWG or adequacy of GWG, measured or self-reported, and pregnancy period covered); and 6) statistical analyses (e.g., statistical method, crude and adjusted effect estimates, 95% CIs, SDs, SEs, P values, and covariates). The extracted data were checked by a second reviewer in a random sample of 20% of the studies included.

We stratified the studies by the income level of the country in which each study was performed on the basis of the World Bank list of economies (21) because differences in maternal nutritional status might affect the association between maternal macronutrient intake and GWG (15).

Assessment of study quality

The quality of each study was assessed with the use of a predefined scoring system (Supplemental Material: Quality Score). This quality score was developed on the basis of existing scoring frameworks (22–24). We assigned a quality score to each article on the basis of 5 items, namely the study design, population size, exposure measurement (or, in intervention studies, the adequacy of blinding), outcome measurement, and adjustment for confounders and energy adjustment (or, in intervention studies, the adequacy of random assignment). Each item received points from zero to 2, which led to a maximum of 10 points that represented the highest quality. Studies were considered of high quality when the quality score was ≥7. One reviewer ascribed a quality score to all studies, and a second reviewer checked the assigned quality scores in a random sample of the studies included. Quality scores were checked randomly for 17 studies (31%), and both reviewers agreed on 96% of the assigned scores on the individual items of the quality score.

RESULTS

Study selection

For this systematic review, we identified 7623 distinctive references in the electronic databases. We excluded 7141 references on the basis of their titles and abstracts, and we retrieved full texts of the remaining 482 articles. After a critical evaluation, 433 references did not meet the selection criteria and were excluded. Seven full texts were identified by a reference check (n = 4) or by a hand search (n = 3). No additional studies were identified via trial registries. We included 56 studies in this systematic review of which 50 articles were written in English. Other languages of included studies were French (25), German (26), Italian (27), Polish (28), and Portuguese (29, 30). Figure 1 shows the flowchart of the selection process.

Characteristics of studies included

The characteristics of the included studies and population characteristics are presented in Table 2. The 56 articles included 78,362 participants (ranging from 20 to 46,262 participants/study) with an age range of 12–46 y. Most studies included
# TABLE 2
Study characteristics, macronutrient composition, and GWG: a systematic review (*n* = 56 studies)\(^1\)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Study design</th>
<th><em>n</em></th>
<th>Age, (y)</th>
<th>Population characteristics</th>
<th>Dietary intake</th>
<th>Dietary assessment or intervention (T)</th>
<th>GWG assessment (T)</th>
<th>Quality score</th>
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<td>High-income countries</td>
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<td>Althuizen et al., 2009 (34)</td>
<td>Netherlands</td>
<td>Longitudinal</td>
<td>144</td>
<td>31 (NR)</td>
<td>Women with term childbirth</td>
<td>Energy Total fat Saturated fat</td>
<td>FFQ (T3)</td>
<td>GWG and adequacy of GWG (SR weight T3 minus SR prepregnancy weight)(^3)</td>
<td>4</td>
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<tr>
<td>Ancri et al., 1977 (46)</td>
<td>United States</td>
<td>Longitudinal</td>
<td>98</td>
<td>12–32</td>
<td>Healthy women</td>
<td>Energy Protein</td>
<td>24hR (T3)</td>
<td>Measured and estimated GWG (weight T3 minus weight T2)(^4)</td>
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<tr>
<td>Anderson et al., 1986 (35)</td>
<td>United Kingdom</td>
<td>Longitudinal</td>
<td>49</td>
<td>28 (20–38)</td>
<td>Healthy women without obstetric complications</td>
<td>Energy Protein Total fat Carbohydrate Energy</td>
<td>Weighed FR (T3)</td>
<td>Adequacy of GWG (measured weight T3 minus SR prepregnancy weight)(^5)</td>
<td>4</td>
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<tr>
<td>Bellati et al., 1995 (27)</td>
<td>Italy</td>
<td>Longitudinal</td>
<td>100</td>
<td>NR (NR)</td>
<td>Healthy women without pregnancy complications</td>
<td>Energy</td>
<td>24hR (T2 or T3)</td>
<td>GWG (assessment method and covered period NR)</td>
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<td>Bergmann et al., 1997 (36)</td>
<td>Germany</td>
<td>Longitudinal</td>
<td>156</td>
<td>≤21 to ≥27</td>
<td>Healthy women with childbirth ≥35 wk of gestation</td>
<td>Energy</td>
<td>Weighed FR (T1, T2, and T3)</td>
<td>Measured GWG (weight T3 minus weight T1 minus birth weight and placental weight)</td>
<td>7</td>
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<tr>
<td>Blumfield et al., 2015 (56)</td>
<td>Australia</td>
<td>Longitudinal</td>
<td>134</td>
<td>29 (18–41)</td>
<td>Pregnant women from general population</td>
<td>Energy Protein Total fat Saturated fat Monounsaturated fat Polyunsaturated fat Carbohydrate Energy</td>
<td>FFQ (T1 or T2 and T2 or T3)</td>
<td>GWG and adequacy of GWG (measured weight T3 minus SR prepregnancy weight)(^6)</td>
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<td>Bompiani and Botta, 1986 (33)</td>
<td>Italy</td>
<td>Intervention</td>
<td>20</td>
<td>NR (NR)</td>
<td>Women with type 2 diabetes mellitus</td>
<td>Low-energy diet vs. control diet (NR)(^7)</td>
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<td>GWG (assessment method and covered period NR)</td>
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<td>Chasan-Taber et al., 2008 (47)</td>
<td>United States</td>
<td>Longitudinal</td>
<td>454</td>
<td>16–39</td>
<td>Healthy women with term childbirth</td>
<td>Energy</td>
<td>FFQ (T2 or T3)</td>
<td>GWG (measured weight T3 minus SR prepregnancy weight)</td>
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<td>Guillard et al., 2013 (37)</td>
<td>Netherlands</td>
<td>Longitudinal</td>
<td>6959</td>
<td>30 (NR)(^8)</td>
<td>Pregnant women from general population</td>
<td>Energy Protein Total fat Carbohydrate Energy</td>
<td>FFQ (T1 or T2)</td>
<td>Adequacy of GWG (measured weight T3 minus SR prepregnancy weight)(^6)</td>
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<td>Heery et al., 2015 (38)</td>
<td>Ireland</td>
<td>Longitudinal</td>
<td>799</td>
<td>31 (18–44)</td>
<td>Pregnant women from general population</td>
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<td>GWG and adequacy of GWG (last measured weight minus SR prepregnancy weight)(^6)</td>
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<tr>
<th>Reference</th>
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<th>GWG assessment (T)</th>
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<td>Lagiou et al., 2004 (48)</td>
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<td>Energy, Protein, Fat (source) Carbohydrate</td>
<td>FFQ (T2)</td>
<td>GWG (measured weight T2 minus SR prepregnancy weight)</td>
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<td>Langhoff-Roos et al., 1987 (39)</td>
<td>Sweden</td>
<td>Longitudinal</td>
<td>50</td>
<td>29 (21–40)</td>
<td>Healthy women with term childbirth</td>
<td>Energy</td>
<td>FR (T2 and T3)</td>
<td>GWG (measured weight T3 minus SR prepregnancy weight)</td>
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<td>Longitudinal</td>
<td>39</td>
<td>NR (NR)</td>
<td>Healthy women</td>
<td>Energy, Protein, Total fat Carbohydrate, Monounsaturated fat, Polyunsaturated fat</td>
<td>FR (T3)</td>
<td>GWG (assessment method and covered period NR)</td>
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<td>Maslova et al., 2015 (40)</td>
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<td>Longitudinal</td>
<td>46,262</td>
<td>30–31 (NR)</td>
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<td>FFQ (T2)</td>
<td>GWG (SR weight T3 minus SR weight T1)</td>
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<td>Montpetit et al., 2012 (50)</td>
<td>Canada</td>
<td>Longitudinal</td>
<td>59</td>
<td>32 (18–40)</td>
<td>Healthy women of high socio-economic position; Women with term childbirth</td>
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<td>GWG (measured weight T3 minus SR prepregnancy weight)</td>
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<td>Longitudinal</td>
<td>194</td>
<td>28–29 (NR)</td>
<td>Women with term childbirth</td>
<td>Energy, Protein, Total fat Carbohydrate, Monounsaturated fat, Polyunsaturated fat</td>
<td>FFQ (T1 or T2 and T3)</td>
<td>Adequacy of GWG (measured weight T3 minus measured weight T1 or T2)</td>
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<td>Ostachowska-Gasior and Janik, 2003 (28)</td>
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<td>Longitudinal</td>
<td>27</td>
<td>NR (19–34)</td>
<td>NR</td>
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<td>Adequacy of GWG (measured weight T3 minus SR prepregnancy weight)</td>
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<tr>
<td>Papoz et al., 1980 (25)</td>
<td>France</td>
<td>Longitudinal</td>
<td>156</td>
<td>25 (16–42)</td>
<td>Women with preterm or term childbirth</td>
<td>Energy, Protein, Total fat Carbohydrate, Dietary interview by dietitian (T1, T2, and T3)</td>
<td>GWG (measured weight T3 minus SR prepregnancy weight, unclear which period of GWG is covered)</td>
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<td>Picone et al., 1982 (51)</td>
<td>United States</td>
<td>Longitudinal</td>
<td>60</td>
<td>23 (NR)</td>
<td>Healthy women</td>
<td>Energy, Protein, Total fat Carbohydrate</td>
<td>24hR (NR)</td>
<td>Adequacy of GWG (measured weight T3 minus SR prepregnancy weight)</td>
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<td>Rae et al., 2000 (32)</td>
<td>Australia</td>
<td>Intervention</td>
<td>124</td>
<td>30–31 (NR)</td>
<td>Obese women with gestational diabetes mellitus</td>
<td>Energy</td>
<td>FR (NR)</td>
<td>GWG (weight T3 minus weight when intervention was started; assessment method NR)</td>
<td>6</td>
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MACRONUTRIENT INTAKE AND GESTATIONAL WEIGHT GAIN

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<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Study design</th>
<th>n</th>
<th>Age, y</th>
<th>Population characteristics</th>
<th>Dietary intake</th>
<th>Dietary assessment or intervention (T)</th>
<th>GWG assessment (T)</th>
<th>Quality score</th>
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<td>Renault et al., 2015</td>
<td>Denmark</td>
<td>Longitudinal embedded in intervention</td>
<td>366</td>
<td>31 (&gt;18)</td>
<td>Obese women (BMI ≥ 30 kg/m²)</td>
<td>Protein (source)</td>
<td>FFQ (T1 or T2)</td>
<td>GWG (measured weight T3 minus SR prepregnancy weight)</td>
<td>6</td>
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<td>Scholl et al., 1993</td>
<td>United States</td>
<td>Longitudinal</td>
<td>790</td>
<td>19 (12-29)</td>
<td>Healthy women with preterm or term childbirth</td>
<td>Protein (source)</td>
<td>24hR (T2 and T3)</td>
<td>Adequacy of GWG (measured T3, first measurement NR)</td>
<td>8</td>
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<tr>
<td>Shin et al., 2014</td>
<td>United States</td>
<td>Longitudinal</td>
<td>490</td>
<td>NR (16-43)</td>
<td>Pregnant women from general population</td>
<td>Protein, Polyunsaturated fat, Energy</td>
<td>24hR (T1, T2, or T3)</td>
<td>Adequacy of GWG (measured weight (T1, T2, or T3) minus SR prepregnancy weight)</td>
<td>6</td>
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<td>Sloan et al., 2001</td>
<td>United States</td>
<td>Longitudinal</td>
<td>2087</td>
<td>22 (NR)</td>
<td>Women with term childbirth</td>
<td>Protein</td>
<td>24hR (T1 or T2)</td>
<td>GWG (assessment method and period NR)</td>
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<td>Stuebe et al., 2009</td>
<td>United States</td>
<td>Longitudinal</td>
<td>1388</td>
<td>NR (24 to 35)</td>
<td>Women with childbirth ≥ 34 wk of gestation</td>
<td>Protein, Total fat, Saturated fat</td>
<td>FFQ (T1 or T2 and T3)</td>
<td>Adequacy of GWG (last measured weight minus SR prepregnancy weight)</td>
<td>7</td>
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<td>Uusitalo et al., 2009</td>
<td>Finland</td>
<td>Longitudinal</td>
<td>3360</td>
<td>29 (24 to 35)</td>
<td>Women in families with newborn infants carrying increased human leukocyte antigen–conferred susceptibility to type 1 diabetes</td>
<td>Protein</td>
<td>FFQ (postpartum)</td>
<td>GWG (measured weight T3 minus measured weight T1)</td>
<td>8</td>
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<tr>
<td>Viegas et al., 1982</td>
<td>United Kingdom</td>
<td>Intervention</td>
<td>142</td>
<td>25 (NR)</td>
<td>Asian women</td>
<td>Energy supplementation¹³</td>
<td>Consumed supplements (T2 and T3) recorded</td>
<td>Measured GWG (T3 minus T2)</td>
<td>6</td>
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<td>Viegas et al., 1982</td>
<td>United Kingdom</td>
<td>Intervention</td>
<td>128</td>
<td>23–25 (NR)</td>
<td>Asian women</td>
<td>Energy supplementation¹³</td>
<td>Consumed supplements (T3) recorded</td>
<td>Measured GWG (T3 minus T2)</td>
<td>6</td>
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<td>Low- and middle-income countries</td>
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<td>Adair et al., 1984</td>
<td>Taiwan</td>
<td>Intervention</td>
<td>125</td>
<td>26–27 (19–30)</td>
<td>Women with inadequate protein consumption and of low socioeconomic position</td>
<td>Energy supplementation¹³</td>
<td>Supplementation vs. no supplementation (T1, T2, and T3)</td>
<td>Measured GWG (weight T3 minus prepregnancy weight)</td>
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<th>GWG assessment (T)</th>
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<tr>
<td>Ali et al., 2002 (63)</td>
<td>India</td>
<td>Longitudinal</td>
<td>150</td>
<td>NR (NR)</td>
<td>Healthy women without pregnancy complications</td>
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<td>NR</td>
<td>GWG assessment method and covered period NR</td>
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<td>Begum et al., 1991 (64)</td>
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<td>25 (20–29)</td>
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<td>Brazil</td>
<td>Longitudinal</td>
<td>224</td>
<td>NR (18–40)</td>
<td>Healthy women</td>
<td>Energy</td>
<td>FFQ (T1, T2, and T3)</td>
<td>Measured GWG (weight differences T1, T2, and T3)</td>
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<td>Changamire et al., 2014 (61)</td>
<td>Tanzania</td>
<td>Longitudinal embedded in intervention</td>
<td>6889</td>
<td>25 (≥18)</td>
<td>HIV-negative women</td>
<td>Energy</td>
<td>24hR (T3)</td>
<td>Measured GWG (difference in weight during T3)</td>
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<td>Costa et al., 2011 (30)</td>
<td>Brazil</td>
<td>Case-control</td>
<td>200</td>
<td>24–25 (22–28)</td>
<td>Healthy normal-weight women with term childbirth</td>
<td>Energy</td>
<td>FFQ (postpartum)</td>
<td>Adequacy of GWG (measured weight T3 minus prepregnancy weight)</td>
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<td>Das, 1976 (65)</td>
<td>India</td>
<td>Longitudinal</td>
<td>60</td>
<td>23 (16–40)</td>
<td>Healthy (underprivileged) women</td>
<td>Energy</td>
<td>24hR (T1, T2, and T3)</td>
<td>Measured GWG (weight T3 minus weight T1 or T2)</td>
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<td>Longitudinal</td>
<td>570</td>
<td>25 (≥14)</td>
<td>Women with childbirth ≥34 wk of gestation</td>
<td>Energy</td>
<td>FFQ (T2 or T3)</td>
<td>Adequacy of GWG (reported weight T3 minus SR prepregnancy weight)</td>
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<td>Ebrahimi et al., 2015 (66)</td>
<td>Iran</td>
<td>Longitudinal</td>
<td>308</td>
<td>27 (18–35)</td>
<td>Pregnant women from urban area</td>
<td>Energy</td>
<td>2-d 24hR (NR)</td>
<td>Adequacy of GWG (measured and estimated weight T3 minus measured prepregnancy weight)</td>
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<td>Ho et al., 2005 (31)</td>
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<td>Longitudinal</td>
<td>62</td>
<td>35 (NR)</td>
<td>Women with gestational diabetes mellitus</td>
<td>Energy</td>
<td>FR (NR)</td>
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<td>Hsu et al., 2013 (67)</td>
<td>Taiwan</td>
<td>Longitudinal</td>
<td>451</td>
<td>29 (15–41)</td>
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<td>Intervention</td>
<td>29</td>
<td>22–24 (20–30)</td>
<td>Healthy women</td>
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<td>Supplementation vs. no supplementation (T3)</td>
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<td>Jaruratanasirikul et al., 2009 (69)</td>
<td>Thailand</td>
<td>Longitudinal</td>
<td>236</td>
<td>27 (17–42)</td>
<td>Women with childbirth ≥34 wk of gestation</td>
<td>Energy, Protein, Total fat Carbohydrate</td>
<td>24hR (NR) and FFQ (NR)</td>
<td>Adequacy of GWG (measured weight T3 minus SR prepregnancy weight) 15</td>
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<td>Kardjati et al., 1990 (70)</td>
<td>Indonesia</td>
<td>Longitudinal nested in intervention</td>
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<td>26 (NR)</td>
<td>Underprivileged women</td>
<td>Energy supplementation 13</td>
<td>FR (T2 and T3)</td>
<td>Measured GWG 17 (specific period NR, weight measured with intervals ≥2 wk)</td>
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<td>Iran</td>
<td>Intervention</td>
<td>53</td>
<td>26 (NR)</td>
<td>Healthy women with term childbirth</td>
<td>Energy supplementation 13</td>
<td>Energy-protein supplementation vs. no supplementation (T2 and T3)</td>
<td>Measured GWG (weight T3 minus weight T2)</td>
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<td>Lechtig et al., 1978 (58)</td>
<td>Guatemala</td>
<td>Longitudinal nested in intervention</td>
<td>135</td>
<td>26 (14–46)</td>
<td>Underprivileged women</td>
<td>Energy (provided through supplementation) 19</td>
<td>Daily measurement of individual supplementation (NR)</td>
<td>Adequacy of GWG (weight T3 minus T2) 19</td>
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<td>Martins and Benicio, 2011 (59)</td>
<td>Brazil</td>
<td>Longitudinal</td>
<td>82</td>
<td>26 (&gt;18)</td>
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<td>Saturated fat</td>
<td>24hR (T1, T2, and T3)</td>
<td>Measured postpartum weight retention (weight ≥15 d postpartum minus weight T1 or T2)</td>
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<td>1104</td>
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<td>Supplementation vs. no supplementation (T2 and T3)</td>
<td>Measured GWG (weight T3 minus weight T1 or T2)</td>
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<td>Bangladesh</td>
<td>Longitudinal</td>
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<td>25–26 (NR)</td>
<td>NR</td>
<td>Energy supplementation 13</td>
<td>Supplementation vs. no supplementation (NR)</td>
<td>Measured GWG and adequacy of GWG (covered period NR) 20</td>
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<td>Popa et al., 2014 (80)</td>
<td>Romania</td>
<td>Longitudinal</td>
<td>382</td>
<td>28 (NR)</td>
<td>Women without obstetrical complications</td>
<td>Energy, Protein, Total fat Carbohydrate</td>
<td>FFQ (postpartum)</td>
<td>Adequacy of GWG (measured last weight minus measured first weight) 16</td>
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<td>Qureshi et al., 1973 (74)</td>
<td>India</td>
<td>Intervention</td>
<td>76</td>
<td>NR (20–35)</td>
<td>Women with term childbirth</td>
<td>Energy supplementation 13</td>
<td>NR</td>
<td>Measured GWG (T3 minus T2)</td>
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<td>Rodrigues et al., 2008 (60)</td>
<td>Brazil</td>
<td>Longitudinal</td>
<td>222</td>
<td>26 (18–41)</td>
<td>Healthy women</td>
<td>Energy, Protein, Total fat Carbohydrate</td>
<td>FFQ (T1)</td>
<td>Measured GWG (T3 minus T1)</td>
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<td>Saowakontha et al., 1992</td>
<td>Thailand</td>
<td>Longitudinal</td>
<td>Rural: 130 Urban: 52</td>
<td>Women with preterm or term childbirth</td>
<td>Energy, Protein Total fat Carbohydrate</td>
<td>24hR (T1, T2, and T3)</td>
<td>Measured GWG (T3 minus T2)</td>
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<td>Siega-Riz and Adair, 1993</td>
<td>Philippines</td>
<td>Longitudinal</td>
<td>715</td>
<td>Women from general population</td>
<td>Energy</td>
<td>24hR (NR)</td>
<td>Measured GWG (T3 minus prepregnancy weight)</td>
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<td>Smith, 1997</td>
<td>Nepal</td>
<td>Longitudinal</td>
<td>35</td>
<td>NR (18–43)</td>
<td>Energy</td>
<td>24hR (T2 and T3)</td>
<td>Measured GWG (covered period NR)</td>
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<td>Tontisirin et al., 1986</td>
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<td>Intervention</td>
<td>43</td>
<td>Healthy women</td>
<td>Energy supplementation</td>
<td>FR (T2 or T3), 24hR (T3)</td>
<td>Measured GWG (T3 minus T1 or T2)</td>
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<td>Wagner et al., 1975</td>
<td>Colombia</td>
<td>Longitudinal</td>
<td>145</td>
<td>Women with ≥50% of their children being undernourished</td>
<td>Energy, Protein</td>
<td>24hR (T1 or T2 and T3)</td>
<td>Measured GWG (T3 minus T2)</td>
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<td>Zulfiqar et al., 2011</td>
<td>Pakistan</td>
<td>Longitudinal</td>
<td>118</td>
<td>Healthy women with term childbirth</td>
<td>Energy, Protein Total fat Carbohydrate</td>
<td>24hR (T2 and T3)</td>
<td>Measured GWG (T3 minus T2)</td>
<td>5</td>
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1FFQ, food-frequency questionnaire; FR, food record; GWG, gestational weight gain; NR, not reported; SR, self-reported; T, trimester of pregnancy; 24hR, 24-h dietary recall.
2All values are means; ranges in parentheses (unless otherwise indicated).
3Adequacy of GWG was determined according to Institute of Medicine recommendations 1990 (81).
4Estimation of weight gained between 20 wk of pregnancy and enrollment and between the last measurement and delivery.
5Adequacy of GWG was categorized as low GWG (≤8 kg) and adequate GWG (>8 kg).
6Adequacy of GWG was determined according to Institute of Medicine recommendations 2009 (3).
7The low-energy diet contained 1200 kcal/d, and the control diet contained 30 kcal/kg ideal prepregnancy weight.
8Median (instead of mean).
9Additional information received from the author.
10Age was reported stratified by exposure (or by the outcome in case-control studies).
11Adequacy of GWG was determined according to Icelandic guidelines as follows: optimal GWG for normal weight between 12.1 and 18.0 kg and for overweight between 7.1 and 12.0 kg.
12Adequacy of GWG was categorized as follows: inadequate GWG (≤6.8 kg) and adequate GWG (>6.8 kg).
13Details on supplementation are provided in Supplemental Table 2.
14Adequacy of GWG was categorized as follows: recommended GWG (11.5–16 kg) and excessive GWG (>16 kg).
15Adequacy of GWG was categorized as follows: low GWG (<6 kg) and adequate GWG (>6 kg).
16Macronutrient intake from the home diet (not taking into account the supplementation).
17Authors assumed that the pregnancy duration was exactly 40 wk for all participants.
18Content of supplementation was as follows: supplement 1 contained 59 kcal/180 mL (from carbohydrates), and supplement 2 contained 163 kcal/180 mL (from protein, fats, and carbohydrates).
19Adequacy of GWG was categorized as follows: low GWG when GWG was ≤0.5 kg/mo.
20Adequacy of GWG was categorized as follows: adequate GWG when GWG was >1 kg/mo.
21Living location of the women (rural vs. urban).
22Dietary intake was not measured for each individual but in a subgroup of women, which was taken as representative for the whole population.
healthy women, 2 studies were restricted to women with gestational diabetes (31, 32), and one study exclusively included women with type 2 diabetes (33). The results of these studies have not been included in the figures. Twenty-nine studies did not report the health status of the participants. The absolute change of weight during pregnancy was reported in 42 studies, whereas 17 studies reported on the adequacy of GWG. Twenty-eight studies were performed in high-income countries (21), namely countries in Europe (25, 27, 28, 33–45), North America (46–55), and Oceania (32, 56). The other 28 studies were conducted in low- and middle-income countries in Central and South America (26, 29, 30, 57–60), Africa (61), Asia (31, 62–79), and Europe (80). Ten of 56 studies were intervention studies of which 2 studies were RCTs (32, 62). The remaining 46 studies were observational studies with a longitudinal design, except for one case-control study (30).

The quality score of the studies ranged from 2 to 10 (Table 2), and the median quality score was 5. Eleven of 56 studies received a quality score of ≥7 and, therefore, were considered as providing high-quality evidence. The majority of the studies did not receive any quality points for covariate adjustments because these studies did not adjust for relevant covariates, such as prepregnancy BMI or energy intake.

### High-income countries compared with low- and middle-income countries

Fifty percent of the included studies \((n = 28)\) were performed in high-income countries. The majority (82%) of supplementation studies were located in low- and middle-income countries. The quality of studies was comparable, with a median quality score of 4.5 for studies performed in high-income countries compared with a median score of 5 for studies conducted in low- and middle-income countries. We did not observe differences in reported associations between macronutrient intake and GWG in low- and middle-income countries or in high-income countries (Supplemental Tables 1–8).

### Maternal energy intake and GWG

Forty-two studies reported on the association of energy intake with GWG (Supplemental Table 1). Twenty-three studies (55%) were performed in high-income countries, and 9 studies (21%) were of high quality. Figure 2 gives an overview of studies that reported on the association of energy intake with GWG. Four studies were not included in Figure 2 because the studies were restricted to diseased populations \((n = 3)\) (31–33) or did not report a directionality of the association \((n = 1)\) (75). Results from high-quality studies \((n = 9)\) suggested that higher energy intake was associated with higher GWG (29, 37, 43, 52, 55, 61, 76), except in 2 studies that reported no consistent association (36, 66). Of the 33 low-quality studies, statistically significantly higher GWG was reported in 5 studies (26, 48, 63, 65, 67) and 3 studies reported this association in subgroups only (25, 41, 51) [e.g., in overweight women but not in normal-weight women (41) and in nonsmoking women, whereas no association was shown in the total population (51)]. No consistent association was shown in 20 low-quality studies (27, 28, 30, 34, 35, 38, 39, 46, 47, 49, 50, 53, 56–58, 69, 70, 77, 79, 80). One study showed that energy intake during the first trimester was positively correlated with GWG, whereas a change in energy intake between 3 and 8 mo of pregnancy was negatively correlated with GWG (25). Another study showed that energy intake in women who were living in urban areas, but not in rural areas, contributed statistically significantly to the explained variance of GWG although no directionality of this association was reported (75).

![FIGURE 2](harvest_plot.png)

**FIGURE 2** Harvest plot of the evidence of an association between energy intake and GWG \((n = 38\) observational studies). Each study that was not restricted to diseased women and reported a directionality of the association between energy intake and GWG was added to the x axis [consequently, the studies by Bompiani and Botta (33), Ho et al. (31), Rae et al. (32), and Saowakontha et al. (75) are not displayed]. The height of each bar represents the quality score, and the color shows whether studies were performed in high-income countries (dark gray) or in low- and middle-income countries (light gray). Magnitudes of the associations are quantified in Supplemental Table 1. *Higher GWG was shown in women with BMI \((\text{in kg/m}^2) ≥ 25\), but no association was shown in women with BMI <25. †A positive correlation was shown between energy intake during the first trimester and the change of intake during the first trimester with GWG, and a negative correlation was shown between the change in energy intake later in pregnancy with GWG. ‡No association was reported in the total population, and a higher GWG was reported in nonsmokers. GWG, gestational weight gain.
Three studies included only diseased women, namely women with diabetes (33) or gestational diabetes (31, 32). In the RCT by Rae et al. (32), obese women with gestational diabetes had comparable GWG regardless of their diet (a moderately energy-restricted diet compared with a control diet that was not energy restricted). Nonetheless, the actual energy intake between these groups was comparable. A second intervention study was performed in women with type 2 diabetes and showed that those who received a low-energy diet (1200 kcal/d) gained less weight during pregnancy than did those who received a control diet (30 kcal/d per kg ideal prepregnancy weight) (33). The third study that had an observational design was in women with gestational diabetes and showed no association between energy intake and GWG (31).

Higher energy intake may be associated with excessive GWG (n = 9) (30, 37, 41, 51, 52, 55, 58, 66, 80), although at some occasions only in subgroups. However, 8 studies did not find associations of energy intake with GWG adequacy (28, 34, 38, 53, 56–58, 69).

Maternal macronutrient supplementation and GWG

Eleven studies reported on GWG differences between participants with macronutrient supplementation and those who received either no supplementation or a macronutrient supplement that was low in energy (Supplemental Table 2, Figure 3). The macronutrient supplementation in the included studies consisted of different macronutrient compositions. Nine studies (82%) were performed in low- and middle-income countries (62, 64, 68, 70–74, 78), and only one study (62) was of high quality (9%). In this high-quality trial by Adair et al. (62), no difference in GWG was shown between women who received a macronutrient supplement that contained 400 kcal/d throughout pregnancy and women who received a supplement that contained <50 kcal/d with similar food intake besides the supplementation. The 10 studies of low quality reported either no consistent difference in GWG (n = 5) (45, 68, 70, 72, 74), higher GWG (n = 4) in the intervention group than in the control group (64, 71, 73, 78), or significant associations in subanalyses only (n = 1) (44). In this latter study by Viegas et al. (44), statistically significantly higher GWG was reported during second-trimester supplementation but not during third-trimester supplementation.

Maternal protein intake and GWG

Twenty-nine studies reported on the association between maternal protein intake and GWG (Supplemental Table 3), all of which had a longitudinal design, and 23 studies (79%) were of low quality. Figure 4 displays the 28 studies that reported a direction of the association. The 6 studies of high quality reported conflicting results (37, 40, 43, 55, 61, 66). Although higher protein intake was associated with lower GWG in 2 studies (43, 61), one study showed that protein intake was associated with lower GWG in normal-weight and overweight women only (40). In addition, one study reported that higher protein intake was associated with higher GWG (37), and one study showed no association between protein intake and GWG (55). In 15 low-quality studies, protein intake was not associated with GWG (26, 28, 30, 35, 41, 42, 49, 51, 54, 56, 60, 63, 65, 69, 79), whereas higher protein intake was associated with higher GWG in 4 studies (48, 53, 67, 80). In 4 low-quality studies, one of which is not included in Figure 4 (75), authors showed associations in subgroups only [e.g., older ages (46), urban-living women (75), or different associations during a specific trimester].
of pregnancy \((n = 2)\) \((25, 70)\). The effect of substituting fat or carbohydrate for protein was examined in 2 studies \((40, 61)\), and both studies reported that the substitution of both fat and carbohydrate for protein was associated with lower GWG. The source of protein (e.g., animal protein compared with vegetable protein) was also not consistently associated with GWG \((n = 2)\) \((40, 42)\) \((Supplemental Table 4)\).

Of the 11 studies that evaluated higher protein intake and the adequacy of GWG, 8 studies showed no association \((28, 30, 34, 35, 49, 51, 53, 56, 66, 69)\). Although Gaillard et al. \((37)\) and Popa et al. \((80)\) showed a higher prevalence of excessive GWG, Shin et al. \((53)\) reported a lower prevalence of inadequate GWG.

### Maternal fat intake and GWG

The association of total fat intake with GWG was assessed in 21 observational studies \((Supplemental Table 5)\) and is summarized in Figure 5 when the directionality of the association was reported \((n = 20)\). The 4 studies of high quality \((19\%)\) reported either no association \((n = 3)\) \((55, 61, 66)\) or that higher fat intake was associated with higher GWG \((n = 1)\) \((37)\). Of the low-quality studies \((n = 17)\), no association was reported in 12 studies \((28, 30, 34, 35, 49, 51, 53, 56, 60, 69, 70, 80)\), and in one study \((75)\), the direction of the association was not reported. In addition, 2 low-quality studies \((67, 79)\) reported that higher fat intake was associated with higher GWG, one study \((41)\) showed an association in overweight women but not in normal-weight women, and, in one study \((25)\), fat intake during the first trimester, but not in other periods, was associated with GWG.

The majority of studies \((n = 9)\) did not show an association between total fat intake and the prevalence of inadequate or excessive GWG \((28, 34, 51, 53, 55, 56, 66, 69, 80)\). A higher prevalence of excessive GWG was shown in the total population in one study \((37)\) and, in a second study, in overweight women only \((41)\).

In 9 studies \((30, 34, 42, 43, 49, 53, 55, 56, 59)\), an association was reported of specific fatty acids (e.g., SFAs, unsaturated fatty acids, and trans fatty acids) with GWG \((Supplemental Table 6)\). Of the 2 high-quality studies \((43, 55)\), one study reported an association of higher saturated fatty acid intake with marginally higher GWG \((43)\), whereas the second study showed no association \((55)\). In the 7 low-quality studies, no association was shown in 5 studies \((30, 34, 42, 49, 56)\), and in one study \((59)\), higher saturated fat intake was associated with higher GWG. No association was reported of trans-fat intake with GWG \((55)\) or for unsaturated fat \((30)\). One study \((55)\) reported that higher monounsaturated fat intake was associated with lower GWG, whereas 3 studies showed no association \((42, 49, 56)\). There was no evidence that polyunsaturated fat intake was associated with GWG \((n = 3)\) \((49, 55, 56)\). One study \((48)\) stratified fat intake on the basis of its source and showed that higher fat intake from animal sources was associated with higher GWG, whereas higher vegetable-based fat intake was not associated with higher GWG \((Supplemental Table 7)\).
Maternal carbohydrate intake and GWG

The association of carbohydrate intake with GWG was described in 18 observational studies (Supplemental Table 8), which reported inconsistent associations (Figure 6 shows the 17 studies that reported a directionality of the association). The 3 studies of high quality (17%) reported either that higher carbohydrate intake was associated with higher GWG (37) or reported no association (61, 66). In the fifteen low-quality studies, higher carbohydrate intake was either associated with higher GWG (n = 1) (79), with lower GWG (n = 1) (48), or was not associated with GWG (n = 10) (28, 30, 35, 49, 51, 53, 56, 60, 69, 80). Three low-quality studies reported associations in subgroups only [e.g., overweight women (41), urban-living women (75), or different correlations in specific trimesters of pregnancy (25)].

Of the 9 studies on GWG adequacy, carbohydrate intake was not associated with the prevalence of inadequate or excessive GWG in 7 studies (28, 51, 53, 56, 66, 69, 80). In addition, Gaillard et al. (37) reported a higher prevalence of excessive GWG, and Olafsdottir et al. (41) showed a lower prevalence of excessive GWG with higher intake of carbohydrate in overweight women.

DISCUSSION

This systematic review suggests that higher total energy intake during pregnancy is associated with higher GWG. More specifically, results on the effect of maternal fat intake were inconsistent, and the effect might be restricted to subgroups of women (e.g., overweight) or to specific types of fat (e.g., saturated fat). The effects of maternal protein and carbohydrate intakes on GWG remain unclear. No differences were shown between studies performed in high-income countries and studies performed in low- and middle-income countries.

Our results for energy intake are in line with a previous systematic review that was restricted to high-income countries (14). Although most observational studies showed that energy intake was associated with higher GWG, trials with macronutrient supplementation did not always report differences in GWG. The discrepancy between results from trials may be explained by differences in the energy content of supplements, the duration of the intervention, or the variation in macronutrient composition.

Fats, carbohydrates, and proteins are the 3 primary energy-providing nutrients. However, it is unclear whether different macronutrients have different effects on GWG and its specific components independent of their energy contents. Although we showed no association of protein intake with GWG, higher protein intake might decrease GWG as a result of higher energy expenditure because the thermogenesis of protein is higher than that of carbohydrate or fat (82, 83). Also, higher protein intake might increase satiety because it has been shown that protein, and specifically animal-based protein, provides a higher level of satiety than does carbohydrate or fat, which may affect overall energy intake (84, 85).

In our systematic review, we showed no consistent associations between total fat intake and GWG. A recent meta-analysis in non-pregnant adults reported weight reduction in participants who
consumed a diet that was low in fat compared with diets with normal fat contents (86). Fat is the macronutrient that is most efficiently stored in the body, although evidence has suggested differences in fat storage for different types of fats (87). For example, SFAs might be more likely to be stored in adipose tissue than are unsaturated fats (88). The results of 2 studies included in this systematic review (43, 59) implied that saturated fat intake may increase GWG, which is in line with nonpregnant populations (89, 90).

We showed no consistent association of carbohydrate intake with GWG. This finding may be explained by differences in the carbohydrate quality [e.g., differences in the glycemic index (GI)]. Consumption of high-GI foods could lead to decreased fat utilization and provide a lower satiety than does intake of low-GI foods (91, 92). Some studies described that higher GI-diets were associated with higher GWG (93, 94), but additional studies are needed to confirm this association.

The effect of the macronutrient content and composition of the diet could differ between malnourished populations and persons with an adequate nutrient status. For example, maternal protein-energy malnutrition is prevalent in many low- and middle-income countries (16). We observed similar associations between macronutrient intake and GWG in studies in low-, middle-income countries and those in high-income countries. However, we were unable to take into account the nutritional status at baseline because this information was often not reported. In addition, dietary behavior is shaped by regional, cultural, and economic influences (95), which could not be captured completely by our distinction between high-income countries and low- and middle-income countries.

A strength of this review was the inclusion of studies performed in low-, middle-, and high-income countries, which enhanced the external validity of the review. Another strength of this systematic review was the comprehensive systematic search strategy in 8 different databases as well as the reviewing process by 2 independent collaborators and the use of a comprehensive quality-scoring system.

A limitation of this review was the overall low quality of the studies and, in particular, the insufficient adjustment for confounding factors in many of the included studies. Many studies did not adjust for potential confounding factors such as prepregnancy BMI and physical activity levels. Therefore, residual confounding might still remain. Another limitation was the measurement of energy intake with the use of self-reporting methods such as food-frequency questionnaires (96). Energy intake can be either overestimated or underestimated (96), but the relation between macronutrient composition and GWG may also depend on total energy intake. To reduce the magnitude of this measurement error related to energy intake or to assess whether the relation between macronutrient intake and GWG is independent of energy intake, energy adjustment can be applied (97). However, only 13 of 31 observational studies that assessed the association of a macronutrient with GWG used a form of energy adjustment. In addition, changes in energy intake during pregnancy were not evaluated in relation to increased energy requirements or altered physical activity levels in pregnancy (12, 98).

Also, we were not able to study the associations of macronutrient intake with different components of GWG such as the

![FIGURE 6](image-url)
effect on maternal fat accretion, which is an important determinant of postpartum weight retention (99). In addition, many studies did not take into account pregnancy complications. Pre-eclampsia, e.g., often coexists with excess amounts of extracellular fluid (edema), which leads to high GWG. Also, we were not able to present results by maternal weight status because most studies did not report analyses stratified by BMI.

We were not able to perform a meta-analysis of the findings because of large heterogeneity in the studies (e.g., different assessment methods). Also, dietary assessments were conducted during different periods in pregnancy. However, other studies have shown that macronutrient intake (relative to total energy intake) remains relatively stable during pregnancy (100, 101). Hence, we believe that the different measurement periods during pregnancy may not have influenced the results to a great extent. The studies also applied different definitions for GWG, used various cutoffs for the adequacy of GWG, and used diverse measurement strategies for GWG.

Finally, only a few studies reported the association of macronutrients on GWG adjusted for each other or for other foods or nutrients. Because individuals consume combined macronutrients in food products and not individual macronutrients, the effects of the macronutrients may depend on the source and interaction with other foods or nutrients (102).

In conclusion, increased energy intake is associated with higher GWG, whereas the effect is not conclusive for specific macronutrients. Higher intake of fat, mainly saturated fat, might be associated with higher GWG, whereas the effects of protein intake and carbohydrate intake remain unclear. We did not observe different associations between macronutrient intake and GWG in low-, middle-, and high-income countries. However, the included studies had, on average, a low quality. Results from this systematic review implicate that higher-quality research is needed as is the studying of the effect of maternal diet as a whole including the macronutrient composition.

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