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Special Article

Systematic review and meta-analysis of energy and macronutrient intakes during pregnancy in developed countries

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Research reporting diet during pregnancy in nationally representative samples is limited. This review summarizes the dietary intakes of pregnant women in developed countries and compares them with national recommendations. A systematic search without date limits was conducted. All studies reporting the macronutrient intakes of pregnant women were considered, irrespective of design. Two authors independently identified the studies to be included and assessed the methodological quality. Nutritional adequacy was summarized, with confounding factors considered. Meta-analysis data are reported for developed countries collectively, by geographical region, and by dietary methodology. Energy and macronutrient intakes of pregnant women do not match national recommendations. Energy and fiber intakes were consistently below recommendations, while total fat and saturated fat intakes were generally above recommendations and carbohydrate and polyunsaturated fat intakes were below to borderline low compared with recommendations. A mismatch between dietary practices and macronutrient recommendations in pregnant women is widespread and not well quantified. The implications of these practices are unknown until further research compares maternal diet with short-term and long-term maternal and offspring health outcomes.

INTRODUCTION

The influence of nutrition during pregnancy on subsequent maternal and offspring health has aroused research interest since Barker et al.[1] reported on the inverse relationship between birthweight and lifetime risk of coronary heart disease. A recent review has summarized the evidence that maternal nutrition affects fetal growth and birth outcomes.[2] Both undernutrition and overnutrition during pregnancy may predispose offspring to metabolic complications and obesity in adult life.[3,4] The challenge is to identify the ideal nutrient composition of diet during pregnancy to promote optimal short- and long-term health outcomes in mothers and their offspring.

It has been suggested that the maternal macronutrient profile can influence fetal development during different periods of pregnancy.[5,6] However, complex relationships exist between maternal macronutrient intake, energy expenditure, gestational weight gain, and fetal growth. Therefore, the hypothesis that increased dietary intake will increase maternal weight, leading to increased fetal growth and improved fetal survival, is no longer satisfactory.[7]

The effects of varying maternal macronutrient intake on fetal growth and pregnancy outcomes have been

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studied in both animal and human models. Animal experiments reveal that maternal total energy intake restriction or protein restriction can retard fetal growth and lead to increased blood pressure, altered glucose, and insulin homeostasis.[8,9] Satisfactory total fat intake, but with an increased proportion of saturated fat, has been shown to significantly decrease offspring birthweight compared with higher-percentage unsaturated fatty acid intakes in rats.[10] Animal studies have further demonstrated that maternal undernutrition as well as overnutrition can adversely influence adult health outcomes, irrespective of birthweight.[8,9]

Several cohort studies from developed countries suggest that macronutrient composition during human pregnancy can influence birth size and adult health. Higher percentages of energy from protein during early pregnancy have been positively associated with birthweight and placental weight,[11] while the percentage of energy derived from carbohydrate in early and late pregnancy has been negatively associated with the ponderal index of the neonate.[11] High carbohydrate intakes during early pregnancy have also been negatively associated with the above outcomes.[12] In Motherwell, Scotland, however, during 1952 and 1976, pregnant women who were encouraged to consume a high-protein, low-carbohydrate diet (0.45 kg/day red meat) reported infants of lower (0.51 standard deviations) birthweight; moreover, as adults, these offspring had higher blood pressure compared with the adult offspring of other women who were pregnant during the same years in Scotland.[13] The relationship between reduced birthweight and elevated adult blood pressure is now clearly established.[14] Evidently, studies in humans have not demonstrated a clear link between energy or protein intakes and pregnancy outcomes, leading to questions surrounding the methodological design and appropriateness of the chosen outcome measures.[15]

Unlike animal studies, human studies are frequently confounded by many environmental and social factors, which may explain the small variations in birthweight reported with nutritional modifications in both observational and interventional studies.[5] Due to the multifaceted nature of conducting dietary assessment in human populations, any effects are also likely to have been under- or overestimated as a result of measurement error. In addition, advancements in agricultural practice in the last 50 years have changed dietary patterns and, consequently, nutrient intakes throughout the world.[16] In industrialized countries, per capita food consumption has increased by approximately 1,675 kJ (400 kcal) per person per day.[16] It is likely that changes in food consumption patterns are also occurring during pregnancy, yet any effect on nutrient intakes or maternal and offspring health outcomes are unclear. A better understanding of diet during pregnancy is needed to establish whether contemporary dietary intakes during pregnancy are low in particular nutrients and to strategically identify other nutrients of critical importance.[6]

To determine the optimal macronutrient composition range for pregnancy, there must be a thorough understanding of the dietary intakes of pregnant women to date. However, research reporting dietary intakes during pregnancy in large, nationally representative samples is limited.[17–19] For these reasons as well as the increasing prevalence of prepregnancy obesity,[20] excessive gestational weight gain,[21–23] and many chronic diseases related to obesity,[24] a closer examination of the energy and macronutrient intakes of pregnant women from developed countries is warranted.

This systematic review aims to summarize the literature reporting the dietary intakes of pregnant women in developed countries in order to: 1) provide a description of the energy and macronutrient intakes in developed countries collectively and by geographical region, and 2) appraise the nutritional adequacy of intakes compared with current dietary recommendations. Meta-analyses are conducted to produce single-point estimates of macronutrient intake in an attempt to control between-study variation, to address the multicultural nature of populations, and to increase the generalizability of findings.

METHODS

The review protocol was developed using the Meta-analysis of Observational Studies in Epidemiology guidelines for meta-analyses and systematic reviews of observational studies.[25]

Eligibility criteria

Table 1 highlights the inclusion/exclusion criteria for the selection of studies. Developed countries were defined as countries that satisfied the Organisation for Economic Co-operation and Development criteria for high-income membership.[26] The outcomes measured were daily energy and macronutrient (protein, fat, and carbohydrate) intakes during pregnancy. Alcohol has been excluded from this review because it is not recommended during pregnancy and, on that basis, many studies do not report its consumption, although it has also been reviewed elsewhere.[27] Nutrient values, including supplements, were excluded. Supplement intake was treated as not included if no details about it were provided. Given the breadth of this topic, this review includes studies of any design that reported nutrient intakes during pregnancy, but it limits the focus to publications that reported

Table 1 **Inclusion and exclusion criteria for the selection of studies.**

Inclusion criteria	Exclusion criteria
Studies on dietary intake (macro- and micronutrient) in pregnant women of any age, without date limits	Studies published in languages other than English
Studies conducted in countries meeting the OECD criteria for high-income membership[a]	Studies in animals
Any study design[b]	Health conditions that may influence dietary intake (i.e., gestational diabetes, celiac disease)[c]
Studies reporting data in a format that enabled the daily mean or median nutrient intake for the population to be extracted	Studies in which dietary data include supplements
	Studies in duplicate populations
	Lack of a random sample

[a] Countries included Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, and United States.
[b] In randomized controlled trials, only the nutrient values from the control group or from all participants at baseline were extracted.
[c] When health status was not specified, it was assumed the sample was broadly representative of the population group.
Abbreviations: OECD, Organisation for Economic Co-operation and Development.

macronutrient intake separately from the contribution of nutrient supplements. While vitamin and mineral supplements may be taken during pregnancy, the focus of this review is to examine the nutrient contribution from food alone during pregnancy.

Search strategy

A systematic search for publications was conducted in August 2011, using the electronic databases MEDLINE, PreMedline, EMBASE, The Cochrane Library, and CINAHL, without date limits. To identify the population of pregnant women, the following keywords were searched (with special features in parentheses): pregnancy (exp/), pregnant women (exp/), mother (exp/), and trimester (exp/). To identify the outcome of nutrient intake, the following keywords were searched (with special features used in parentheses): dietary intake (dietary adj3 intake), food intake (food adj1 intake), food group (food adj1 group), diet variety (diet* adj3 variet*), diet quality (diet* adj3 quality), diet score (diet* adj1 score$), food adequacy (food adj3 adequacy), food habits (exp/), and food preferences (exp/). Limits included English language, humans, and the specific countries within the Organisation for Economic Co-operation and Development. Keywords were searched as free text in the title, abstract, and subject heading. Study population and outcome records were combined using the Boolean operator "AND". Additional publications were identified from references published in original papers.

Selection process

All records identified were first assessed for eligibility based on the information contained in the title, abstract, and description/MeSH heading by two independent reviewers (MB and AH), after which the inclusion/exclusion criteria were applied (Table 1). When multiple publications were available from the same data set, the data sets were either combined, if possible, or the publication that reported that largest number of nutrient variables was selected. The full text of all studies that appeared to meet the eligibility screening were retrieved and subjected to a second assessment for relevance by the same two reviewers (Table 1). Any difference in assessments that arose between reviewers was discussed in the first instance or resolved by a third independent reviewer (CC).

These studies were then assessed for methodological quality by two independent reviewers (MB and CC/LMW) in a two-step process using standardized critical appraisal instruments. In step 1, the quality of the dietary assessment tool used to measure dietary intake within the study was appraised. Dietary assessment tools included food frequency questionnaire (FFQ), estimated diet records, weighed food records (WFRs), 24-hour food recalls, and diet history. If an FFQ was used, the full text of any related validation study was retrieved and the EURopean micronutrient RECommendations Aligned Network of Excellence (EURRECA) scoring system was applied.[28] Scores greater than 3.5 were coded "good," scores between 2.5 and 3.5 were coded "acceptable," and scores less than 2.5 were coded "poor."[28] If the FFQ was not validated, it was coded "poor." If estimated diet records, WFRs, or 24-hour food recalls were used, studies containing two or more days of dietary data were coded "good"; otherwise, all were coded "poor." Diet histories conducted by a dietitian/nutritionist were coded "good"; otherwise, they were coded "poor". In step 2, all "good" and "acceptable" studies were subject to a full assessment of methodological quality using the Quality Criteria Checklist in the American Dietetic Association Evidence Analysis Manual.[29] The Quality Criteria Checklist included four relevance questions that addressed applicability to practice and ten validity questions that addressed scientific reliability, including confounding, study quality, and heterogeneity. The Quality Criteria Checklist enabled a systematic, objective rating (positive, negative, or neutral) to be given to each study and was used to confirm agreement among independent reviewers. "Positive" studies were of the highest quality, with most answers to the validity questions being positive, followed by "neutral" studies. "Negative" studies were of the lowest quality, with most of the answers to the validity questions being negative. Therefore, the "negative" studies were excluded from the review. Once again, any difference in assessments was resolved, if necessary, by a third independent reviewer (AH).

Data extraction

Nutrient data were extracted for all studies included in the review. Demographic and methodological data were extracted for the following confounding factors: stage of gestation, age, ethnicity, socioeconomic status (SES), smoking status, year of sample recruitment, and dietary assessment tool. Three studies reported data from the Osaka Maternal and Child Health Study.[30–32] Data were combined to provide a larger data set of nutrient variables; the data set is referred to as an individual study in analyses. Due to the large number of studies included, original authors were contacted only to confirm the year the study sample was recruited. If original authors could not be contacted, 3 years prior to the publication date was used as the estimated year of recruitment (8 studies).[33–40]

Comparison with international dietary guidelines

Nutritional adequacy was appraised by comparing the dietary intakes of pregnant women with the national dietary guidelines in each respective country or geographical region. Current macronutrient guidelines in the United States of America (USA)/Canada, Australia/New Zealand (NZ), Europe/United Kingdom (UK), and Japan are the Institute of Medicine's dietary reference intakes (DRIs) for macronutrients and energy,[41] the National Health and Medical Research Council of Australia nutrient reference values,[42] the World Health Organization/Food and Agriculture Organization of the United Nations (WHO/FAO) population nutrient intake goals for preventing diet-related chronic diseases,[43] and the Ministry of Health, Labour, and Welfare dietary reference intakes for Japanese,[44] respectively. Each dietary guideline contains population nutrient intake goals that are expressed as a percentage of total energy intake and referred to as either an adequate macronutrient distribution range (AMDR)[41,42] or a dietary goal.[43,44] AMDRs and dietary goals are associated with reduced risk of chronic disease while ensuring adequate intakes of essential nutrients.[41] If dietary intake exceeds the AMDR or the dietary goal, there may be an increased risk of chronic diseases and/or inadequate intake of essential nutrients.[41]

Statistical analysis

The main outcome measures were daily energy and macronutrient intakes for pregnant women in the studies included. Nutrient data were meta-analyzed for all high-income countries collectively and per geographical region (USA/Canada, UK, Europe, Australia/NZ, and Japan). To address possible heterogeneity, analyses were also stratified by trimester, SES, and dietary methodology. Studies that reported dietary intake separately by trimester were included in a subgroup analysis to identify reported dietary changes across each trimester and any differences historically over time.

Due to included studies reporting the central tendency of data as either mean or median values, linear regression models were performed to assess the trend in mean and median values for each nutrient. If no significant differences were observed between these trends for a particular nutrient, data were combined to represent an average nutrient value. This allowed analysis of the maximum amount of data from the studies included, while considering the reliability of results.

Comparisons of means were performed using analysis of variance (ANOVA) and two-sample t-tests. Fixed-effect regression models, weighted by sample size, were used to investigate nutrient intakes throughout pregnancy. Fixed-effect models were adjusted for time, country, and methodological quality, and – where appropriate – sensitivity analyses were conducted to further examine any effect of methodological quality. Simple linear regression models were performed to investigate any changes in nutrient intake over time. Statistical analyses were performed using the statistical software package Intercooled Stata, version 11 (Stata, College Station, Texas, USA). P values <0.05 were considered statistically significant due to the small number of studies in each model.

RESULTS

Description of studies

The study flow is summarized in Figure 1. Data were extracted from 90 studies ($n = 126{,}242$),[17–19,30,38,39,45–105] with 23 studies containing multiple dietary intake assessment points during pregnancy ($n = 4{,}985$).[11,12,33–37,40,106–120] The countries represented by geographical region are the USA (26 studies, $n = 12{,}765$)/Canada (5 studies, $n = 143$), UK (19 studies, $n = 15{,}653$), Europe (27 studies,

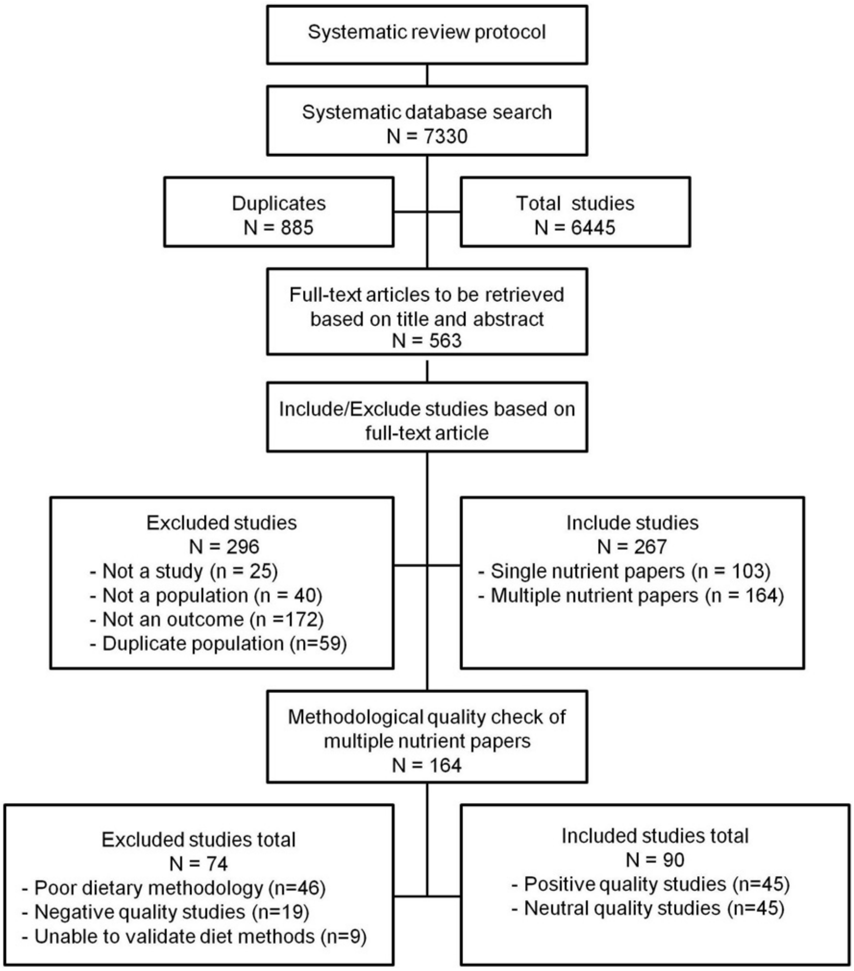


Figure 1 **Flow chart for the present systematic review.**

$n = 93{,}395$), Australia (5 studies, $n = 2{,}557$)/NZ (2 studies, $n = 291$), and Japan (6 studies, $n = 1{,}438$).

The methodological quality and study characteristics of the studies included are shown in the Supporting Information for this article available online (Table S1). Four population-based samples were identified for Denmark in 1999,[19] the UK in 1992,[17] and Norway in 1995 and 2003.[18,58] Twenty-six studies reported macronutrient data during the first trimester, followed by 43 in the second trimester and 51 in the third trimester. Twenty studies reported intakes as a single value to represent women across all trimesters. The mean ± standard deviation gestation reported was 25.0 ± 9.9 weeks.

The total number of participants ranged from 8[49,114] to 54,344[19] pregnant women. Women tended to be in their late twenties (27.6 ± 4.0 years) and more likely of medium to high SES. Research in low-SES pregnant populations has mainly been conducted in the USA (7 studies)[35,38,87,92,97,98,101]; only two additional studies, conducted in Finland and the UK, segregated dietary information by SES.[53,55] Thirty-eight studies did not report SES or smoking status information (Table S1 in Supporting Information).

FFQs were the most frequently used dietary assessment methodology (34 studies), particularly when the sample size was greater than 500 participants. Estimated diet records (26 studies), WFRs (14 studies), diet history questionnaires (8 studies), and 24-hour diet recalls (8 studies) were commonly used in smaller samples (Table S1 in Supporting Information). Fifty-five studies were excluded from the review based on poor dietary methodology or inability to validate the dietary data collection method used (Figure 1).

Energy

In all developed countries collectively, the mean reported energy intake during pregnancy was 8,969 ± 1,034 kJ/day (2,144 ± 247 kcal/day). Daily energy intakes in the third trimester (9,261 ± 1,231 kJ/day) were significantly higher than in the first trimester (8,491 ± 873 kJ/day, $P = 0.019$) (Figure 2).

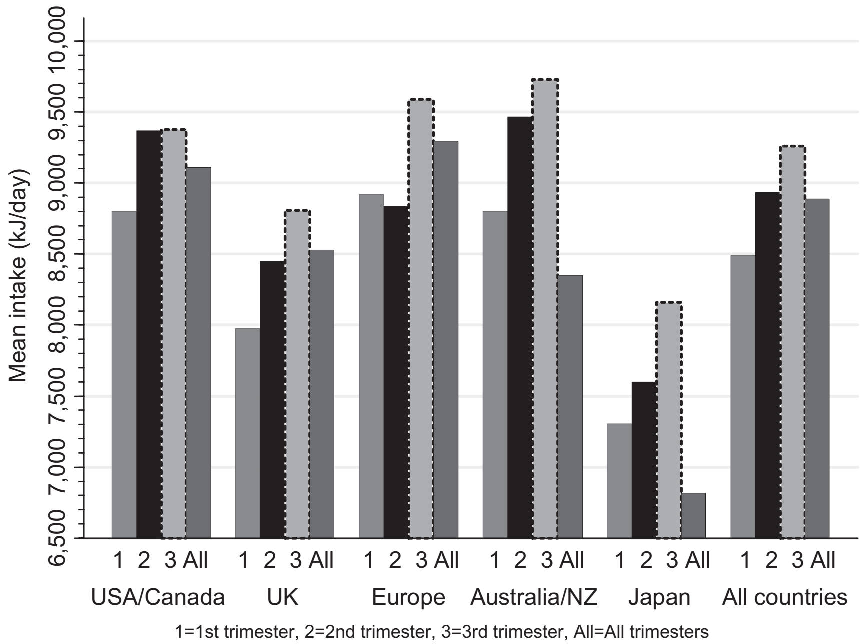


Figure 2 **Daily energy intake during pregnancy, by trimester, in each geographical region, as reported by studies included in the review.** "All" values refer to data that represent all trimesters within the one dietary value.

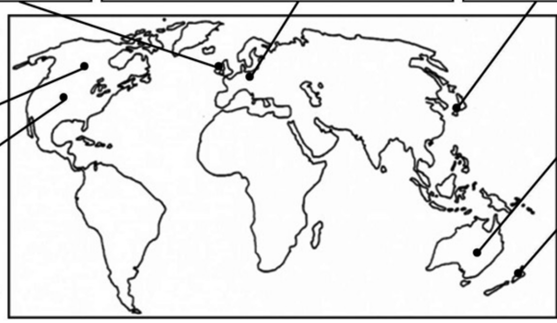
Figure 3 highlights the mean energy intakes reported during pregnancy by geographical region. Mean energy intakes differed by geographical region, with the USA/Canada (9,214 ± 722 kJ/day), Europe (9,197 ± 1,149 kJ/day), and Australia/NZ (9,261 ± 1,101 kJ/day) reporting similar mean intakes, while Japan reported the lowest energy intake (7,707 ± 892 kJ/day). The UK reported a significantly lower mean energy intake (8,495 ± 880 kJ/day) compared with the USA/Canada ($P = 0.024$) and Europe ($P = 0.029$). Pregnant women reported a mean of approximately 7,710 kJ (1,842 kcal) to 9,260 kJ (2,213 kcal) per day across the whole of pregnancy, with a wide range of values reported in each trimester (Figure 2). There was a 577 kJ (138 kcal) to 929 kJ (222 kcal) difference between daily energy intakes in the first and third trimesters among developed countries (Figure 2).

United Kingdom		
Nutrient	*Daily intake*	*Studies*
Energy	8495±880kJ	19
Protein	73±7g	18
Total fat	85±8g	17
Saturated fat	31±2g	5
Polyunsaturated fat	13±1g	3
Monounsaturated fat	25±1g	3
Carbohydrate	254±28g	15
Fibre	17±3g	12

Europe		
Nutrient	*Daily intake*	*Studies*
Energy	9197±1149kJ	27
Protein	85±12g	25
Total fat	88±17g	27
Saturated fat	34±11g	20
Polyunsaturated fat	12±4g	20
Monounsaturated fat	31±7g	18
Carbohydrate	268±42g	25
Fibre	19±5g	13

Japan		
Nutrient	*Daily intake*	*Studies*
Energy	7707±892kJ	6
Protein	67±14g	6
Total fat	62±9g	6
Saturated fat	18±2g	2
Polyunsaturated fat	13g	1
Monounsaturated fat	21±2g	2
Carbohydrate	250±11g	3
Fibre	15±6g	3

United States/Canada		
Nutrient	*Daily intake*	*Studies*
Energy	9214±722kJ	31
Protein	87±11g	29
Total fat	85±12g	23
Saturated fat	29±4g	12
Polyunsaturated fat	17±4g	7
Monounsaturated fat	31±5g	6
Carbohydrate	285±31g	21
Fibre	19±4g	10



Australia/New Zealand		
Nutrient	*Daily intake*	*Studies*
Energy	9261±1101kJ	7
Protein	87±12g	7
Total fat	88±11g	7
Saturated fat	41±6g	2
Polyunsaturated fat	11±1g	2
Monounsaturated fat	26g	1
Carbohydrate	271±42g	5
Fibre	22±1g	3

Figure 3 **Pooled energy and macronutrient intakes during pregnancy, as reported by geographical region.** Data collected from 1961 to 2009 and reported as mean ± standard deviation.

Inherent biases from differing dietary methodologies were also apparent, with lower mean energy intakes reported by WFRs (8,420 ± 808 kJ/day) compared with FFQs (9,319 ± 1,213 kJ/day, $P = 0.001$), diet history (9,168 ± 1,317 kJ/day, $P = 0.029$), 24-hour recalls (9,136 ± 503 kJ/day, $P = 0.024$), and estimated diet records (8,931 ± 827 kJ/day, $P = 0.013$). Differences in energy intake by dietary assessment tool in each geographical region are presented in Figure S1 of the Supporting Information.

Mean energy intakes differed by SES, with reported energy intakes increasing as SES decreased (high SES: 8,574 ± 603 kJ/day; medium SES: 9,374 ± 1,455 kJ/day; low SES: 9,616 ± 1,362 kJ/day; high versus low, $P = 0.009$). A similar relationship was seen in the difference in intakes by trimester, with the difference between the first and third trimesters (high SES: 563 kJ/day; medium SES: 1,908 kJ/day; low SES: 2,421 kJ/day).

Estimated energy requirements for pregnancy differ by geographical region (Table 2).[41,42,44,121] The USA/Canada was the only region that reported mean energy intakes in the first trimester that were similar to the intakes of nonpregnant women, using the 1999–2000 National Health and Examination Survey as the comparator.[122] However, this was followed by an increase in the second trimester of approximately 50% of energy recommendations, with no further increase reported during the third trimester. The UK and Australia/NZ both reported higher energy intakes in each trimester compared with the intakes of nonpregnant women in the 2002–2001 National Diet and Nutrition Survey[123] and the 1995 National Nutrition Survey,[124] respectively. However, the reported energy increments in the second and third trimesters were closely matched to national recommendations in both regions. Japan reported an increase in mean energy intake in the first trimester (35 kcal/day) similar to first trimester recommendations, using the 2007 National Health and Nutrition Survey Japan as the comparator.[125] However, this was followed by an increase in the second and third trimesters of approximately 33% and 40% of energy recommendations, respectively. The European region reported a mean energy increase of approximately 345 kJ (80 kcal) in the first trimester, using countries in the European Nutrition and Health Report 2004 as the comparator,[126] with no increase in mean energy intake reported in the second trimester and an increase in the third trimester that was less than 50% of the energy recommendations.

Protein

In all high-income countries collectively, the reported protein intake was 82.1 ± 12.5 g/day. There was a 5.9 g/day difference between the mean protein intakes in the

Table 2 **Daily dietary reference values for energy and macronutrient intake during pregnancy, according to geographical region. Unless otherwise specified, nutrient values are expressed as a percentage of total energy intake.**

Nutrients	United States/ Canada[41]	United Kingdom[43]	Europe[43]	Australia/ New Zealand[42]	Japan[44]
Energy[a]					
1st trimester	–	–	–	–	+50 kcal/day
2nd trimester	+340 kcal/day	+360 kcal/day	+360 kcal/day	+335 kcal/day	+250 kcal/day
3rd trimester	+450 kcal/day	+475 kcal/day	+475 kcal/day	+455 kcal/day	+500 kcal/day
Protein	10–35% E	10–35% E	10–35% E	15–25% E	<20% E
Total fat	20–35% E	15–30% E	15–30% E	20–35% E	20–30% E
Saturated fat	Minimize	≤10% E	<10% E	≤10% E	4.5–7.0% E
Polyunsaturated fat					
N-6 fatty acids	5–10% E (13 g/day [AI])	2% E	2% E	10 g/day (AI)	≤10% E (9 g/day [AI])
N-3 fatty acids	0.6–1.2% E (1.4 g/day [AI])	0.5% E	0.5% E	115 mg/day (AI)	2.1 g/day (AI)
Monounsaturated fat	–	–	–	–	–
Carbohydrate	45–65% E	55–75% E	55–75% E	45–65% E	50–70% E
Fiber	28 g/day (AI)	>25 g/day (AI)	>25 g/day (AI)	28 g/day (AI)	21 g/day (AI)

[a] Energy values expressed as the additional estimated energy requirement.
Abbreviations: AI, adequate intake; E, energy.

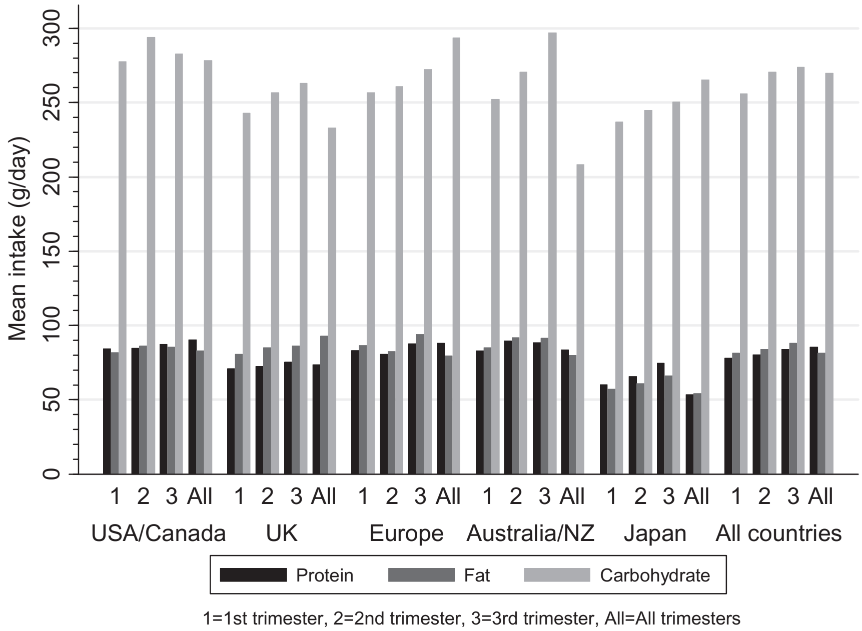


Figure 4 **Daily macronutrient intake during pregnancy, by trimester, in each geographical region, as reported by studies included in the review.** "All" values refer to data that represent all trimesters within the one dietary value.

first (78.1 ± 9.6 g/day) and third (84.0 ± 13.0 g/day) trimesters (Figure 4).

Mean protein intakes differed by geographical region, with the USA/Canada (87.0 ± 10.9 g/day), Europe (84.6 ± 11.7 g/day), and Australia/NZ (86.9 ± 11.8 g/day) reporting similar mean intakes, while Japan reported the lowest protein intake (67.5 ± 13.5 g/day) (Figure 3). Once again, the UK reported a significantly lower mean intake (73.4 ± 7.6 g/day) compared with most other developed countries (USA/Canada $P < 0.001$; Europe $P = 0.002$; Australia/NZ $P = 0.023$; Japan $P > 0.05$) (Figure 3). Japan reported the largest difference between daily protein intakes (14.4 g/day) in the first and third trimesters compared with other developed countries (USA/Canada 2.3 g/day, UK 4.4 g/day, Europe 4.9 g/day, Australia/NZ 5.3 g/day) (Figure 4).

Lower mean protein intakes were reported by WFRs (74.5 ± 8.5 g/day) compared with 24-hour recalls (93.3 ± 18.4 g/day, $P < 0.001$), FFQs (85.9 ± 14.4 g/day, $P < 0.001$), diet history (83.7 ± 13.7 g/day, $P = 0.013$), and estimated diet records (81.3 ± 8.2 g/day, $P = 0.002$) (Figure S2, Supporting Information).

Mean protein intakes during pregnancy did not differ by SES. Although, the difference between protein intakes in the first and third trimesters was greatest in low-SES pregnant women (high SES: 5.7 g/day; medium SES: 9.8 g/day; low SES: 22.3 g/day).

Protein intake recommendations differed by geographical region (Table 2). Pregnant women in developed countries reported consuming between 14.7% and 16.1% of total energy from protein, which is an adequate amount based on current recommendations. The percentage of energy provided by protein was similar across each trimester in all regions, with a 1.5% maximum difference reported between the first and third trimesters.

Total fat

In all high-income countries collectively, the reported fat intake was 84.7 ± 14.6 g/day. There was a 10.1 g/day difference between the mean fat intake in the first (78.1 ± 9.6 g/day) and third (88.2 ± 16.5 g/day) trimesters (Figure 4).

Mean fat intakes differed by geographical region, with Europe (87.9 ± 17.1 g/day) and Australia/NZ (88.2 ± 10.4 g/day) reporting the highest intakes, closely followed by the UK (85.2 ± 7.8 g/day) and the USA/Canada (84.6 ± 12.3 g/day). Japan reported the lowest mean fat intake (61.9 ± 8.9 g/day) (Figure 3). The difference between daily fat intakes in the first and third trimesters was 3.8 g/day in the USA/Canada, 5.8 g/day in the UK, 6.5 g/day in Australia/NZ, 8.3 g/day in Europe, and 8.8 g/day in Japan (Figure 4).

No significant differences were found in fat intake when different dietary data collection methodologies were used (FFQs 85.9 ± 15.2 g/day; WFRs 84.8 ± 16.7 g/day; estimated diet records 84.4 ± 13.7 g/day; diet history 83.7 ± 15.9 g/day; 24-hour recalls 82.0 ± 10.2 g/day) (Figure S2, Supporting Information).

Mean fat intakes were not significantly different by SES. However, the differences in fat intakes between the first and third trimesters were greatest in low-SES pregnant women (high SES: 0.4 g/day; medium SES: 18.4 g/day; low SES: 34.5 g/day).

Total fat intake recommendations were similar in each geographical region (Table 2). Western regions reported total fat intakes above recommendations, at 35% to 37.1% of total energy, while the reported total fat intake in Japan was 29.7% of total energy. The percentage of energy provided by total fat intake was similar across each trimester.

Saturated fat

Saturated fat intake for all developed countries collectively was 32.2 ± 9.1 g/day during pregnancy. The reported saturated fat intake in the first, second, and third trimesters was 30.5 ± 7.4 g/day, 31.0 ± 6.1 g/day, and 36.1 ± 11.8 g/day, respectively. Mean saturated fat intakes differed by geographical region, with the USA/Canada (28.9 ± 4.4 g/day), Europe (33.8 ± 10.6 g/day), and the UK (31.4 ± 2.0 g/day) reporting similar mean intakes, while Japan reported the lowest intake (17.8 ± 1.6 g/day) (Figure 3). Australia/NZ reported the highest mean saturated fat intake (41.3 ± 6.0 g/day) compared with all other developed regions except Europe (USA/Canada $P = 0.004$, $n = 12$; UK $P = 0.015$, $n = 5$; Japan $P = 0.033$, $n = 2$). Higher mean saturated fat intakes were reported with WFRs (44.3 ± 0.6 g/day) than with diet history (28.6 ± 8.8 g/day, $P = 0.012$) or 24-hour recall (27.7 ± 2.5 g/day, $P < .001$) assessment methods (estimated diet records 32.9 ± 11.7 g/day; FFQs 32.4 ± 17.2 g/day).

Saturated fat intake recommendations are similar in each geographical region (Table 2). All regions reported saturated fat intakes above recommended levels (USA/Canada 11.6% E, Europe 13.5% E, UK 13.7% E, Australia/NZ 16.5% E, Japan 8.5% E). The percentage of energy provided by saturated fat was similar across each trimester.

Polyunsaturated and monounsaturated fatty acids

Polyunsaturated fatty acid (PUFA) intake during pregnancy was 12.9 ± 4.1 g/day. The reported PUFA intake in the first, second, and third trimesters was 11.4 ± 4.0 g/day, 13.7 ± 5.1 g/day, and 12.7 ± 3.7 g/day, respectively. Mean PUFA intakes differed by geographical region. In the USA/Canada, reported intakes were significantly higher than those in Europe (16.7 ± 3.8 g/day versus 12.1 ± 4.1 g/day, $P = 0.004$) or Australia/NZ (11.2 ± 1.0 g/day, $P = 0.016$), but they were similar to those in the UK (12.8 ± 0.7 g/day, $P > 0.05$) and Japan (12.8 g/day, $P > 0.05$) (Figure 3). Mean PUFA intakes were lower when reported by diet history (8.9 ± 5.0 g/day) than by 24-hour recall (15.1 ± 2.9 g/day, $P = 0.041$), FFQ (14.9 ± 3.5 g/day, $P = 0.001$), or estimated diet records (13.2 ± 3.0 g/day, $P = 0.011$) assessment tools (WFRs 11.3 ± 1.2 g/day).

PUFA recommendations differ by geographical region (Table 2). Pregnant women in developed countries report consuming between 4.8% and 6.7% of total energy from PUFA, which is borderline low compared with current recommendations (USA/Canada 6.7%, Japan 6.1%, UK 5.6%, Europe 4.8%, and Australia/NZ 4.5%). The percentage of energy provided by PUFA was similar across each trimester.

Monounsaturated fatty acid (MUFA) intake during pregnancy was 29.8 ± 6.4 g/day for all developed countries. The reported MUFA intake in the first, second, and third trimesters was 28.7 ± 3.7 g/day, 29.9 ± 5.7 g/day, and 31.1 ± 7.6 g/day, respectively. Mean MUFA intakes differed by geographical region, with the USA/Canada (31.5 ± 5.4 g/day), Europe (30.6 ± 6.6 g/day), the UK (25.5 ± 1.2 g/day), and Australia/NZ (26.1 g/day) reporting similar mean intakes, while Japan reported a significantly lower intake (20.6 ± 2.2 g/day) compared with the other developed countries (Japan versus USA/Canada $P = 0.027$, Japan versus UK $P = 0.044$, Japan versus Europe $P = 0.045$) (Figure 3). No significant differences were found in MUFA intake when different dietary data collection methodologies were used (diet history 32.0 ± 5.7 g/day; FFQ 30.6 ± 7.4 g/day; 24-hour recalls 29.0 ± 1.7 g/day; estimated diet records 28.6 ± 6.0 g/day; no WFRs data).

The percentage of energy provided by MUFAs was similar across regions and trimesters (USA/Canada 12.7% E, Europe 12.3% E, UK 11.1% E, Australia/NZ 10.4% E, Japan 9.9% E). There are no specific dietary recommendations for MUFAs with which to compare reported intakes, and there is insufficient evidence by which to set an upper limit of intake.[41]

Carbohydrate

In all developed countries, the reported carbohydrate intake was 269.1 ± 37.0 g/day. There was a 17.8 g/day difference between the mean carbohydrate intakes in the first (256.0 ± 29.5 g/day) and third (273.8 ± 39.7 g/day) trimesters (Figure 4).

Mean carbohydrate intakes differed by geographical region, with the USA/Canada (285.1 ± 31.2 g/day) reporting the highest intake, followed by Australia/NZ (271.4 ± 40.6 g/day), Europe (267.6 ± 41.9 g/day), the UK (253.7 ± 27.8 g/day), and Japan (249.6 ± 10.4 g/day) (Figure 3). The difference between daily carbohydrate intakes in the first and third trimesters were 0.9 g/day in Japan, 5.2 g/day in the USA/Canada, 15.8 g/day in Europe, 20.1 g/day the UK, and 44.5 g/day in Australia/NZ (Figure 4).

Mean carbohydrate intakes reported by WFRs (246.0 ± 25.3 g/day) were lower than those reported by FFQ (288.1 ± 35.7 g/day, $P < 0.001$), diet history (284.7 ± 40.6 g/day, $P = 0.002$), and 24-hour recall (270.8 ± 17.7 g/day, $P = 0.032$) assessment tools (estimated diet records [260.9 ± 35.6 g/day, $P = 0.091$]) (Figure S2, Supporting Information). Mean carbohydrate intakes were not statistically different by SES, despite appearing to increase as SES decreased (high SES: 251.8 ± 40.2 g/day; medium SES: 276.6 ± 35.6 g/day; low SES: 283.7 ± 37.4 g/day).

Dietary recommendations for carbohydrate differ by geographical region (Table 2). Pregnant women in high-income Western countries are consuming between 46.6% and 49.6% of total energy from carbohydrate, compared with 51.8% in Japan. Carbohydrate intake is borderline low in Australia/NZ and the USA/Canada and Japan and is below current recommendations in the UK and Europe. The percentage of energy provided by carbohydrate was similar across each trimester.

Fiber

Fiber intake during pregnancy was 18.7 ± 4.4 g/day for all developed countries. The reported fiber intake in the first, second, and third trimesters was 18.2 ± 3.4 g/day, 19.5 ± 4.1 g/day, and 18.3 ± 5.4 g/day, respectively. Mean fiber intakes by geographical region were as follows: Australia/NZ 21.9 ± 1.1 g/day, followed by Europe 19.4 ± 5.3 g/day, the USA/Canada 18.8 ± 3.6 g/day, the UK 17.4 ± 3.3 g/day, and Japan 15.1 ± 6.2 g/day (Figure 3). Significant differences in fiber intake were found between Australia/NZ and Japan ($P = 0.045$) and Australia/NZ and the UK ($P = 0.008$). No significant differences were found in fiber intake by pregnancy trimester, SES, or dietary assessment method.

Dietary fiber recommendations are presented in Table 2. All regions reported fiber intakes below recommendations. Pregnant women reported consuming a mean of between 15.1 g and 21.9 g of fiber per day. Australia/NZ reported the highest mean fiber intake (21.9 g/day), while Japan reported the lowest intake (15.1 g/day). Only four studies reported a fiber intake greater than 25 g/day, and all studies except one were conducted in Europe.[18,19,53,59]

Sugars

Included studies reported sugar intake as either "sugars" (9 studies) or "added sugar" (9 studies). In developed countries, collectively, sugar intake and added sugar intake during pregnancy were 100.9 ± 40.1 g/day and 50.3 ± 9.2 g/day, respectively. There were insufficient data to perform reliable meta-analyses by pregnancy trimester, geographical region, SES, or dietary assessment method.

Changes in nutrient intakes throughout pregnancy and over time

In all studies from developed countries where dietary intake was assessed at multiple time points during pregnancy, the nutrients that increased across each pregnancy trimester after adjusting for year, country, and methodological quality, were energy (141 kJ/day/trimester, $P = 0.016$, 23 studies, 61 observations, $n = 4{,}386$), protein (1.2 g/day/trimester, $P = 0.045$, 23 studies, 61 observations, $n = 4{,}386$), and saturated fat (0.9 g/day/trimester, $P = 0.002$, 11 studies, 28 observations, $n = 2{,}886$). No nutrients decreased across each pregnancy trimester.

Historical changes in nutrient intakes over time are not reported due to the highly reduced validity of findings caused by the lack of representative data points.

DISCUSSION

This review found that, generally, dietary intakes of pregnant women from developed countries do not align with country-specific energy and macronutrient recommendations. Energy and fiber intakes were consistently lower than the recommendations, while total fat and saturated fat intakes were generally above the recommendations. Carbohydrate and PUFA intakes were either lower or borderline low compared with recommendations. Due to limited experimental data, many nutrient targets for pregnancy have been set on the basis of theoretical calculations to establish what is believed to optimize the health and well-being of pregnant women and their offspring. Therefore, until epidemiological studies demonstrate consistent associations between exposure and health or disease outcomes, the implications of such dietary intake for mother and offspring will be unknown.

A large number of published studies have reported the dietary intakes of nonrepresentative groups of pregnant women from developed countries. These highlight the large discrepancies in the quality of the dietary assessment tools used, and many studies do not report sufficient details of the method, demographic data, and/or information on confounders that can influence dietary intake assessment and reporting in order to enable readers to more accurately interpret the data. Interestingly, sugar or added sugars intakes were less commonly reported within the studies included. This was despite the availability of evidence showing a direct positive relationship between 1) maternal blood glucose levels during pregnancy and fetal growth and birthweight,[127] and 2) the consumption of sugar-sweetened beverages and overweight and obesity.[128]

The dietary intake results summarized in this review are similar to those reported for representative, nonpregnant populations.[41,69,122,124,126,129] Energy requirements during pregnancy are influenced by many factors, including prepregnancy weight or body mass index, maternal age, stage of gestation, basal metabolic rate, and physical activity levels. Current knowledge indicates that if maternal weight gain and fetal growth are adequate, then maternal energy intake is adequately meeting individual requirements, despite the large individual variation in reported energy intake.[130,131] Therefore, it is possible that energy homeostasis during pregnancy is achieved by a voluntary reduction in physical activity[132] or that overconsumption during preconception may mean there is a higher baseline intake such that women eating to appetite do not need to increase intake to the level of current recommendations, which presume women to be in the healthy weight range. In addition, variability in basal metabolic rate during pregnancy may contribute to energy homeostasis, as the effect of pregnancy can be individualized with cumulative reductions in basal metabolic rate, which has been reported in some populations.[130,133] The increasing prevalence of overweight/obesity[20] and excessive gestational weight gain during pregnancy in developed regions[21–23] suggests it is likely that women are not in energy deficit during pregnancy, despite not reporting an increased energy intake that is in line with recommendations. This may be particularly evident in the USA/Canada, Europe, and Japan, where reported mean energy intakes in both the second and third trimesters were less than 50% of the recommended energy requirement for pregnancy. Future research will need to evaluate these confounding factors and report physical activity data alongside dietary intake data to shed light on this situation to ultimately determine whether the current energy increment recommendations for pregnancy require revision.

There is a wide range of possible proportions of the major macronutrients that constitute a healthy dietary intake profile, as evidenced by the differing range of national recommendations for a healthy population.[41–44] Consumption of macronutrients outside these ranges may increase the risk of diet-related disease. However, research examining this in pregnant populations is limited.[42] In the studies conducted to date, it is often unclear which macronutrient drives a benefit or adverse effect. The recommended percentage energy distributions of macronutrients during pregnancy are similar to those for healthy women, with the assumption that dietary energy intake is sufficient to maintain current body weight.[134] However, pregnancy is a unique biological state that is influenced by many factors, including prepregnancy weight, ethnicity, gestational stage, parity, and health status. Consequently, sufficient intake may not directly reflect maternal body weight.[5] Therefore, pregnant women ultimately need specifically tailored dietary recommendations that have been derived on the basis of findings from high-quality studies, as opposed to research conducted in the nonpregnant state.

At present there is insufficient research data to determine whether current dietary practices have any detrimental effects on mother or offspring. The results in this review indicate that many women from developed countries consume diets low in fiber and high in both total and saturated fat during pregnancy, not unlike the dietary patterns reported by nonpregnant women.[122–125] It is well known that poor macronutrient quality can lead to undesirable health outcomes such as constipation[135] and excess weight gain[136] and can adversely influence glucose and cardiovascular risk markers in nonpregnant populations.[137] Therefore, unhealthful dietary practices may also unfavorably impact mother and offspring during pregnancy and future life. To improve the dietary quality of pregnant women, health professionals may consider a preventative approach by targeting nonpregnant women of reproductive age to encourage healthy eating behaviors that will likely extend into future pregnancies. To optimize health during pregnancy, and until further evidence is available, health practitioners should only provide generalized nutrition education in line with national dietary guidelines, without specific recommendations on macronutrient distribution.

To understand the implications of current dietary practices and dietary recommendations, future research needs to examine the relative risks of varying dietary intake patterns in representative populations of pregnant women for a range of short- and long-term health outcomes, including neonatal weights, perinatal mortality, hypertension, obesity, and life expectancy. Ideally, lifetime cohorts or time series studies, repeated at regular time points (e.g., 5-year intervals) with dietary intakes reported during and post pregnancy, in conjunction with an assessment of maternal and infant health outcomes are required. This will determine whether maternal intake patterns during pregnancy are changing over time and whether there is any impact on health outcomes. Without this, diet and outcome data will rapidly become outdated. There is a need for additional studies reporting dietary intake in the first trimester, as evidence suggests the first trimester may be the most significant for developmental programming[138]; moreover, current intake data have been reported predominantly in the second and third trimesters. Due to the uniqueness of each trimester, studies that report single, summarized dietary data across the entire pregnancy are less useful. Therefore, it is recommended that future studies collect gestational information and segregate dietary information by trimester. Large gaps in the research were also identified in low-SES populations as well as in adolescent and older populations of pregnant women. It is further recommended that authors report demographic and social data on confounding factors that may influence dietary intake during pregnancy, such as ethnicity, SES, antenatal smoking, and parity, to enable accurate interpretation of results.

Differences in energy and macronutrient intakes were found within the same geographical region when different dietary assessment tools were used. When assessing dietary intake, the methodology chosen is important because the use of tools that are validated in the population under study will increase the validity and reliability of the dietary data. WFRs that comprise 4 or more days of dietary data and include one weekend day are recommended for small-to-medium sample sizes. Although WFRs have been reported to be the gold standard method for assessing actual dietary intake,[139] they are not always practical for the population due to the burden placed on the subjects; hence, estimated diet records using standard household measures should be considered. The FFQ is a retrospective method designed to collect data on usual intakes over an extended period of time and have a low participant and analytic burden, while enabling efficient dietary intake assessment of large sample sizes.[139] When choosing an FFQ for use during pregnancy, it is important to use a tool validated in a similar population group and to collect dietary intake for the previous 1 to 3 months. This will maximize its accuracy by reducing the confounding factor of trimester.

The strengths of this review include the large, international scope and the comprehensive evaluation of the methodological quality of the studies included. The review is further strengthened by the development of and adherence to an evidence-based protocol. The systematic search without date limits identified a large body of literature that underwent strict critical appraisal of dietary assessment methods and study quality to ensure that only reliable dietary values were evaluated in the results. Validity was increased by excluding negative quality studies and by weighting statistical analyses by sample size to account for smaller, nonrepresentative samples at each time point. The inclusion of minority groups within each country in this meta-analysis has considered the multicultural nature of populations in developed countries.

One limitation is that demographic and social data were not published in many studies, and the lack of such data may confound data on dietary intake during pregnancy. This reduced the number of studies as well as the sample size of analyses involving SES and the capacity to examine the influence of other confounding factors on dietary intake during pregnancy. The limited number of studies that reported dietary data in nationally representative pregnant populations (4 studies) prevented an assessment of changes in dietary patterns over time. Data were not presented because the validity of these analyses was compromised due to the lack of multiple data points over time from the same representative sample. Furthermore, the meta-analysis of all data points did not provide an even spread of data for each geographical region. This, however, is an important finding of this review. There was inconsistency among many European countries and UK trading partners in their definitions of fiber and methods of analysis. For comparison, a fiber value of 18.0 g based on the Englyst method is similar to a fiber value of 24.0 g using the method of the Association of Official Agricultural Chemists International (AOAC). The majority of studies included in this review did not report the fiber analysis method used, so caution is required when interpreting these values. Lastly, observational studies are largely susceptible to the effects of chance, bias, and confounding, while dietary methodology attracts the potential for response bias and measurement error. These effects were minimized by the rigorous critical appraisal of dietary assessment methodology and study quality conducted independently by two reviewers.

CONCLUSION

Diet in pregnancy has commonly been reported in nonrepresentative pregnant populations from developed countries. However, large discrepancies in dietary data collection methods were present and many studies failed to report sufficient data on demographic and social factors that often confound dietary values. Results indicate that energy and macronutrient recommendations do not match with reported intakes of pregnant women. Energy and fiber intakes were consistently lower than recommendations, total fat and saturated fat intakes were generally above recommendations, and carbohydrate and PUFA intakes were either lower or borderline low compared to recommendations. The implications of current dietary practices and dietary recommendations are currently unknown until further research compares maternal diet to short-term and long-term health outcomes.

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SUPPORTING INFORMATION

The following supporting information is available for this article online:

Table S1 **Characteristics of the studies included in the review.**
Figure S1 **Daily energy intake during pregnancy in each geographical region, as reported by dietary methodology.** Data collected from 1961 to 2009.
Figure S2 **Daily macronutrient intake during pregnancy in each geographical region, as reported by dietary methodology.** Data collected from 1961 to 2009.

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