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Effects of maternal diets on preterm birth and low birth weight: a systematic review

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Abstract

Current evidence indicates that maternal diets before and during pregnancy could influence rates of preterm birth, low birth weight (LBW) and small for gestational age (SGA) births. However, findings have been inconsistent. This review summarised evidence concerning the effects of maternal diets before and during pregnancy on preterm birth, LBW and SGA. Systematic electronic database searches were carried out using PubMed, Embase, Scopus and Cochrane library using the preferred reporting items for systematic reviews and meta-analyses guidelines. The review included forty eligible articles, comprising mostly of prospective cohort studies, with five randomised controlled trials. The dietary patterns during pregnancy associated with a lower risk of preterm birth were commonly characterised by high consumption of vegetables, fruits, whole grains, fish and dairy products. Those associated with a lower risk of SGA also had similar characteristics, including high consumption of vegetables, fruits, legumes, seafood/fish and milk products. Results from a limited number of studies suggested there was a beneficial effect on the risk of preterm birth of pre-pregnancy diet quality characterised by a high intake of fruits and proteins and less intake of added sugars, saturated fats and fast foods. The evidence was mixed for the relationship between maternal dietary patterns during pregnancy and LBW. These findings indicate that better maternal diet quality during pregnancy, characterised by a high intake of vegetables, fruits, whole grains, dairy products and protein diets, may have a synergistic effect on reducing the risk of preterm birth and SGA.

Key words: Maternal diets: Dietary patterns: Pre-pregnancy: Pregnancy: Preterm birth: Low birth weight: Small for gestational age

Globally, over fifteen million infants are born preterm every year. Preterm birth (live birth < 37 weeks of gestation) and small for gestational age (SGA), which are linked with low birth weight (LBW) (live birth weight < 2500 g), are also significant causes of neonatal morbidity and mortality[1,2]. Over 80 % of the world's 2·5 million infants who die each year are of LBW, and the majority of these have been reported from low- and middle-income countries[3]. Preterm birth has been found to be associated with the diminishing child motor development and academic performance[4] and neurodevelopmental impairment[5]. It also has long-term effects on the risk of cardiovascular, pulmonary and metabolic diseases[6–8]. Moreover, a number of studies have documented that LBW is associated with obesity, diabetes, hypertension and kidney diseases later in life[9–12].

Maternal nutrition has a significant role in ensuring successful birth outcomes[13]. Many studies have examined the association of maternal intake of single or a few nutrients, and/or foods, with adverse birth outcomes. In recent decades, there has been a growing interest in using a dietary pattern approach to assess overall dietary intakes because people do not habitually consume isolated single nutrients or single foods. It is also difficult to examine the separate effects of some nutrients due to the high level of inter-correlation among nutrients, for example, Mg and K. Analyses of single nutrient might potentially be confounded by the effect of dietary patterns since nutrients are commonly associated with certain dietary patterns. Therefore, the synergistic or antagonistic effects of overall dietary patterns could be significantly large enough to be measurable[14–16].

A few prospective cohort studies have shown a beneficial effect of dietary patterns such as 'prudent diets', 'Mediterranean diets' and 'Dietary Approaches to Stop Hypertension (DASH)' during pregnancy, on lowering the risk of preterm birth[17–20]. These dietary patterns were mostly characterised by high consumption of vegetables, fruits and whole grains. Some prospective studies have shown a detrimental effect of 'Western diets' on increasing the risk of preterm birth, LBW and SGA[21–23]. This dietary pattern is commonly

Abbreviations: DASH, Dietary Approaches to Stop Hypertension; LBW, low birth weight; RCT, randomised controlled trial; SGA, small for gestational age; VFR, vegetable–fruits–rice.

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characterised by processed meat, potatoes, sweetened snacks and saturated fats, which contain pro-inflammatory nutrients, which act as a stressor on the hypothalamic-pituitary-adrenal system and subsequently increase the risk of adverse birth outcomes[24,25].

Current prospective studies show an association between maternal dietary patterns during pregnancy and adverse birth outcomes; however, the findings remain inconsistent. In 2016, a traditional review was published by Chen *et al.*[26] and a systematic review by Kjollesdal *et al.*[27]. These reviews focused specifically on the association between dietary patterns during pregnancy and birth weight or pregnancy outcomes, including gestational diabetes mellitus and hypertension disorder in pregnancy. They also used a single database, PubMed to search potential articles and considered publications up to 2015. A large number of studies have been published since Chen *et al.*[26]. To our knowledge, there has been no current review conducted on the effects of maternal diets before and during pregnancy on preterm birth, LBW and SGA. The present study aimed to systematically review current evidence on the relationships between maternal diets, including single or selective food items and overall diets before and during pregnancy, and preterm birth, LBW and SGA.

Methods

Searching strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guideline was followed to develop the systematic review[28] and registered at PROSPERO 2018 CRD42018098714. A systematic search of PubMed, Embase, Scopus and the Cochrane library was carried out using keywords and subject search terms, including Mesh (PubMed) and Emtree (Embase). Additional relevant articles were also identified by Snowballing[29] and Pearl growing methods[30]. Publications from February 2002 to August 2018 were included, and the search was limited to studies published in the English language. The following search terms were used in different combinations of keywords, subject and Boolean searching: Maternal AND diet* OR food* OR nutrient* OR 'dietary pattern' OR 'meal pattern' OR 'dietary habit' OR 'dietary intake' OR 'dietary consumption' OR 'eating consumption' OR 'eating pattern' OR 'eating behaviour' OR 'eating habit' OR 'food consumption' OR 'food intake' OR 'food habit' OR 'nutritional consumption' OR 'nutritional habit' OR 'nutritional pattern' AND 'preterm birth' OR 'premature birth' OR 'preterm delivery' OR 'premature delivery' OR 'preterm labour' OR 'premature labour' OR 'birth outcome' OR 'Low Birth Weight' OR 'Infant, Small for Gestational Age' OR 'Infant, Very Low Birth Weight' OR 'Infant, Extremely Low Birth Weight' OR 'birth weight'.

Study selection

Any studies that observed maternal diets before and during pregnancy as the exposure variable and used preterm birth, LBW and SGA as outcome variables were included. Both observational (cross-sectional, case–control, cohort studies) and interventional studies (randomised controlled trials (RCT) and non-RCT) were included. Appropriateness of the statistical analyses was assessed, and studies with a high risk of bias, review articles and commentaries were excluded. Animal studies, conference papers and studies without full text were also excluded. Moreover, studies that focused on nutrients, sugar-sweetened or artificially sweetened beverages, alcohol intake, caffeine consumption and nutritional supplements alone or not in combination with dietary intake were excluded. Furthermore, studies that examined fish consumption contaminated with harmful substances (acrylamide, mercury and dioxin) or evaluated a biomarker of nutritional intake were excluded.

Dietary patterns are defined as the quantities, proportions, variety or combinations of different foods and beverages in diets, and the frequency with which they are habitually consumed[31].

Selective diets are the intake of specific foods (not overall diets), created based on previous knowledge without using statistical or extraction method.

Data extraction

Data extraction and quality assessment were conducted by two independent reviewers (D. G. G. and M. W.). The following information was extracted in the observational studies: author, year, study area, study design, sample size, population characteristics, dietary assessments (method, period, course, extraction method and food groups), outcomes assessments (outcomes and percentage of cases), main findings and potential confounders (Table 1). If the studies identified were intervention studies, the following data were added: dietary assessments (follow-up period, control and interventional diets, intervention and control food groups and nutritional supplementation) and outcomes assessments (outcomes, percentage of cases in intervention and control groups) (Table 2).

Quality assessment

The Newcastle–Ottawa Scale for observational studies[64] and the Cochrane handbook for interventional studies[65] were used to assess the risk of bias for the eligible studies. Selection, comparability and outcome assessment were rated separately for observational studies, and the rating scores ranged from 0 (highest degree of bias) to 9 (lowest degree of bias) (online Supplementary Tables S3–S5). The risk of bias during selection, performance, detection, attrition, reporting and other potential sources was assessed for interventional studies, and the quality assessments were recorded as high risk of bias (X), low risk of bias (√) or unclear (?) (online Supplementary Table S1).

Data synthesis and analysis

Narrative analysis and qualitative summarisations were conducted to synthesise the included articles. We did not undertake meta-analysis due to wide diversity of maternal dietary intake. There were large variations in the methods, periods, extraction methods and food items across the studies and also for cut-offs for outcomes.

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Table 1. Characteristics of observational studies with maternal diets and adverse birth outcomes (preterm birth, low birth weight (LBW) and small for gestational age (SGA))

Methods				Dietary assessments					Outcome assessments		
										Cases	
References	Study area	Study design	Study sample	Method	Period	Course	Extraction method	Food group	Outcomes	*n*	%
Bouwland *et al.* [32]	Netherlands	Prospective cohort	847	293 items of FFQ	Peri-conception, 3 months before 10–13 weeks of gestation	Dietary patterns	PCA	Energy-rich Mediterranean Western	SGA		4·50
Brantsaeter *et al.*[33]	Norway	Prospective cohort	62 099	255 items of FFQ	Gestational week 17–22	Specific diets	Selective diets (seafood)	Seafood with *n*-3 fatty acid supplements	LBW	437	0·7
Chatzi *et al.*[19]	Spain and Greece	Prospective cohort	2461 (Spain) and 889 (Greek)	100 (INMA) and 250 (RHEA) items of FFQ	First trimester of pregnancy (INMA) and mid-pregnancy (RHEA)	Dietary patterns	Mediterranean diets score	Mediterranean diets	SGA		8·9 (INMA) and 10·3 (RHEA)
Chia *et al.*[34]	Singapore	Prospective cohort	923	Sixty-eight items of FFQ	26–28 weeks of gestation	Dietary patterns	PCA	VFR SFN PCP	Preterm SGA	70 124	7·6 13·4
Emond *et al.*[35]	USA	Prospective cohort	862	Sixty-one items of FFQ	24–28 weeks of gestation	Dietary patterns	AHEI	Eleven dietary components	LBW SGA	29 40	3·4 4·6
Englund-Ogge *et al.*[17]	Norway	Prospective cohort	66 000	255 items of FFQ	Gestational weeks 17–22	Dietary patterns	PCA	Prudent Traditional Western	Preterm	3505	5·3
Englund-Ogge *et al.*[36]	Norway	Prospective cohort	65 487	255 items of FFQ	Gestational weeks 17–22	Dietary patterns	PCA	GI and GL	Preterm	3505	5·3
Grieger *et al.*[37]	Australia	Cross-sectional, retrospective	309	100 items of FFQ	Preconception, 12 months before pregnancy	Dietary patterns	PCA	High-protein/fruit High-fat/sugar Vegetarian type	Preterm LBW SGA	32 15 42	10 5 14
Hajianfar *et al.*[22]	Iran	Prospective cohort	812	117 items of FFQ	First trimester	Dietary patterns	PCA	Western Traditional	LBW	Not reported	
Halldorsson *et al.*[38]	Denmark	Prospective cohort	44 824	360 items of FFQ	Gestational weeks 25	Specific diets	Selective diets	Total fish Fatty fish Lean fish	SGA	Not reported	
Haugen *et al.*[39]	Norway	Prospective cohort	40 817	255 items of FFQ	Gestational weeks 17–22	Dietary patterns	Mediterranean diets index	Mediterranean diets	Preterm	1184	4·5
Heppe *et al.*[40]	Netherlands	Prospective cohort	3405	293 items of FFQ	First trimester of pregnancy	Specific diets	Selective diets	Milk product	Preterm SGA		4·7 5·0
Heppe *et al.*[41]	Netherlands	Prospective cohort	3380	293 items of FFQ	First trimester of pregnancy	Specific diets	Selective diets	Fish intake	Preterm LBW SGA		4·7 4·1 6·1
Hillesund *et al.*[42]	Norway	Prospective cohort	72 072	255 items of FFQ	Gestational weeks 17–22	Dietary patterns	NND score	NND	Preterm	2129	3·0
Knudsen *et al.*[23]	Denmark	Prospective cohort	44 612	360 items of FFQ	Gestational weeks 25	Dietary patterns	PCA	Western health Conscious Intermediate	SGA		7·99
Knudsen *et al.*[43]	Denmark	Prospective cohort	47 003	360 items of FFQ	Gestational weeks 25	Dietary patterns	GL and GI	GI and GL diets	SGA	Not reported	
Lu *et al.*[44]	China	Prospective cohort	6954	Sixty-four items of FFQ	Not reported	Dietary patterns	Cluster analysis	Cereals, eggs, cantonese soups, fruits, nuts, Cantonese desserts, meats, vegetables and varied	SGA	102	6·2
Lu *et al.*[45]	China	Prospective cohort	7352	Sixty-four items of FFQ	24–28 weeks of gestation	Dietary patterns	Cluster analysis	Milk, cereals, eggs, cantonese soups, fruits, nuts, meats, varied vegetables	Preterm	351	4·8

Table 1. (*Continued*)

Methods				Dietary assessments					Outcome assessments		
										Cases	
References	Study area	Study design	Study sample	Method	Period	Course	Extraction method	Food group	Outcomes	*n*	%
Martin *et al.*[20]	USA	Prospective cohort	3143	109 items of FFQ	Gestational weeks 26–29	Dietary patterns	PCA DASH	Factor 1 Factor 2 Factor 3 Factor 4 DASH diets	Preterm	364	12
Mendez *et al.*[46]	Spain	Prospective cohort	657	101 items of FFQ	First trimester of pregnancy	Specific diets	Selective diets (seafood)	All seafood, crustaceans, shellfish, canned tuna, fatty and lean fish	SGA	46	7·8
Mikkelsen *et al.*[18]	Denmark	Prospective cohort	35 530	360 items of FFQ	Gestational weeks 25	Dietary patterns	Mediterranean diets score	Mediterranean diets	Preterm	1543	14·01
Mitchell *et al.*[47]	New Zealand	Case–control	1714 Case = 844; control = 870	Seventy-one items of FFQ	At delivery (at time of conception and last months of pregnancy)	Dietary patterns	Not used	Fruit, vegetables, carbohydrate-rich food, meat snacks, fish and dairy products	SGA	844	49·2
Myhre *et al.*[48]	Norway	Prospective cohort	18 888	255 items of FFQ	Gestational weeks 17–22	Specific diets	Selective diets (probiotics lactobacilli)	Probiotic milk or yogurt	Preterm	951	5
Myhre *et al.*[49]	Norway	Prospective cohort	18 888	255 items of FFQ	Gestational weeks 17–22	Specific diets	Selective diets (antimicrobial foods)	Allium and dried fruits	Preterm	950	5
Muthayya *et al.*[50]	India	Prospective cohort	676	FFQ	3 months of each trimester	Specific diets	Selective diets	Fish and *n*-3 PUFA intakes	LBW	140	20·7
Okubo *et al.*[51]	Japan	Prospective cohort	803	150 items of DHQ	24–28 weeks of gestation	Dietary patterns	Cluster analysis	‘Meat and eggs’, ‘wheat products’ and ‘rice, fish and vegetables’	SGA	Not reported	
Olmedo *et al.*[52]	Spain	Prospective cohort	973	118 items of FFQ	Gestational weeks 20–22	Specific diet	Selective diet	Dairy products	SGA	127	13
Olsen *et al.*[53]	Denmark	Prospective cohort	8729	FFQ	Gestational weeks of 16 and 30	Specific diets	Selective diets	Low seafood consumption	Preterm LBW SGA	299 232 572	3·4 2·7 3·4
Olsen *et al.*[54]	Denmark	Prospective cohort	50 117	360 items of FFQ	Gestational weeks 25	Specific diet	Selective diet	Milk consumption	SGA	4711	9·4
Poon *et al.*[55]	USA	Prospective cohort	893	DHQ	28 and 36 weeks of gestation	Dietary patterns	AHEI-P Mediterranean diets GI and GL	HEI diets Mediterranean diets GI and GL diets	SGA	71	7·9
Rasmussen *et al.*[21]	Denmark	Prospective cohort	59 949	360 items of FFQ	Gestational weeks 25	Dietary patterns	PCA	Vegetables/prudent, alcohol, Western, Nordic, seafood, candy rice/pasta/poultry	Preterm	2682	4·5
Ricci *et al.*[56]	Italy	Case–control	2521 Case = 555 Control = 1966	Fifteen items of FFQ	After delivery	Specific diets	Not used	Not grouped	SGA	555	22
Saunders *et al.*[57]	France	Prospective cohort	728	214 items of FFQ	During pregnancy	Dietary patterns	Mediterranean diets score	Mediterranean diets	Preterm	107	14·7
Thompson *et al.*[58]	New Zealand	Case–control	1714 Case = 844 Control = 870	Seventy-one items of FFQ	After delivery (1st and last months of pregnancy)	Dietary Patterns	PCA	Traditional Junk Fusion	SGA	844	49·2

PCA, principal component analysis; INMA, Infancia y Medio Ambiente; VFR, fruits–vegetables–rice; SFN, seafood and noodle; PCP, pasta–cheese–processed meat; AHEI, Alternative Healthy Eating Index; GI, glycaemic index; GL, glycaemic load; NND, new Nordic diets; DASH, Dietary Approaches to Stop Hypertension; DHQ, Diet History Questionnaire; HEI, healthy eating index.

Table 2. Characteristics of interventional studies with maternal diets and adverse birth outcomes (preterm birth, low birth weight (LBW) and small for gestational age (SGA))

Methods			Dietary assessments					Outcome assessments				
									Cases in intervention group		Cases in control group	
References	Study area	Study design and sample	Follow-up period	Control diets	Intervention diets	Intervention food groups	Control food groups	Outcome	*n*	%	*n*	%
Hillesund *et al.*[59]	Norway	RCT (*n* 606) Intervention = 303 Control = 303	From preconception to birth	Usual diets	Ten healthy dietary score	High intake of fruits, vegetables, plenty of water; low intake of added sugar, salt, sweet snacks and fast foods	Usual diets	Preterm	Overall cases (5·8 %)			
Huybregts *et al.*[60]	Burkina-Faso	RCT (*n* 1296) Intervention = 655 Control = 641	Not specified	MMN without FFS	FFS with MMN	Peanut butter, soya flour, vegetable oil, sugar and MMN cocktail	MMN cocktail	Preterm LBW SGA	92 67 167	16 13·5 32·2	79 67 177	13·9 12·5 35·8
Janmohamed *et al.*[61]	Cambodia	RCT (*n* 547) Intervention = 333 Control = 214	From first trimester to birth	Normal diets	CSB	A maize and soyabean flour fortified with vitamin and mineral	Normal diets	Preterm LBW SGA	6 18 44	2·1 6·2 15·4	14 21 29	7·1 10·7 14·8
Khoury *et al.*[62]	Norway	RCT (*n* 290) Intervention = 141 Control = 149	From gestational week 17 to 20 to birth	Usual diets	CLD	Fish, low-fat meats and dairy products, oils, whole grains, fruits, vegetables and legumes	Usual diets	Preterm	1	0·7	11	7·4
Moses *et al.*[85]	Australia	Non-RCT (*n* 70) Intervention = 35 Control = 35	From gestational week 17 to 20 to birth	HGI	LGI	Pasta and brand-name breads and breakfast cereals with a high fibre content	High-fibre and low-sugar content diets	SGA		9·40		6·70
Potdar *et al.*[63]	India	RCT (*n* 6513) Intervention = 3205 Control = 3308	From preconception to birth	Control snack	Treatment snacks	Fresh and dried green leafy vegetables, milk and dried fruit	Potato, tapioca and onion	Preterm LBW SGA		13 34 67		12 39 69

RCT, randomised controlled trial; MMN, multi micronutrients; FFS, fortified food supplements; CSB, maize–soya blend diets; CLD, cholesterol-lowering diets; HGI, high glycaemic index; LGI, low glycaemic index.

Results

A total of 23 363 records were identified by the electronic database searches (PubMed, Embase and Scopus). After removing duplicates, 10 429 records were screened by title reading and 183 records were screened by abstract reading. Of these, seventy-eight studies met the criteria for full document review. A further nineteen potentially eligible articles were found by manual search (snowballing and pearl growing) and from the Cochrane library. Following a thorough review of the articles based on the inclusion and exclusion criterion, forty eligible articles were included overall in the systematic review (Fig. 1).

Study characteristics

The thirty-four observational studies were mostly prospective cohort studies (thirty), three studies were case–control and one study was retrospective cross-sectional. Also, of six interventional studies, five were RCT and one was not. The majority of observational studies were from the Norway (Norwegian Mother and child cohort study (MoBa)) and Denmark (Danish national birth cohort). The study samples ranged from 309 to 72 072 in prospective cohort studies with the largest samples derived from the MoBa study. The sample sizes in case–control and RCT studies ranged from 1714 to 2521 and 290 to 1296, respectively. One non-RCT study was conducted on small samples (thirty-five intervention, thirty-five control group) (Tables 1 and 2).

Almost all observational studies used validated FFQ to assess maternal dietary intake. Two studies used a diet history questionnaire, and one study used an automated self-administered 24 h recall tool (ASA24). The FFQ ranged from fifteen food items in Italy to 360 items in Denmark (Table 1).

Three methods were widely used to evaluate the relationships between maternal dietary patterns and adverse birth outcomes: Factor analysis, cluster analysis and different dietary indices, such as the healthy eating index, Mediterranean diet, DASH, new Nordic diets and glycaemic index. The majority of studies (nine) used maternal dietary patterns derived from principal component analysis to examine the risk of adverse birth outcomes (Tables 1 and 2).

The majority of studies (40 %) assessed maternal dietary intake at the second trimester. Neonatal data were collected after delivery, from medical records and hospital registries. The

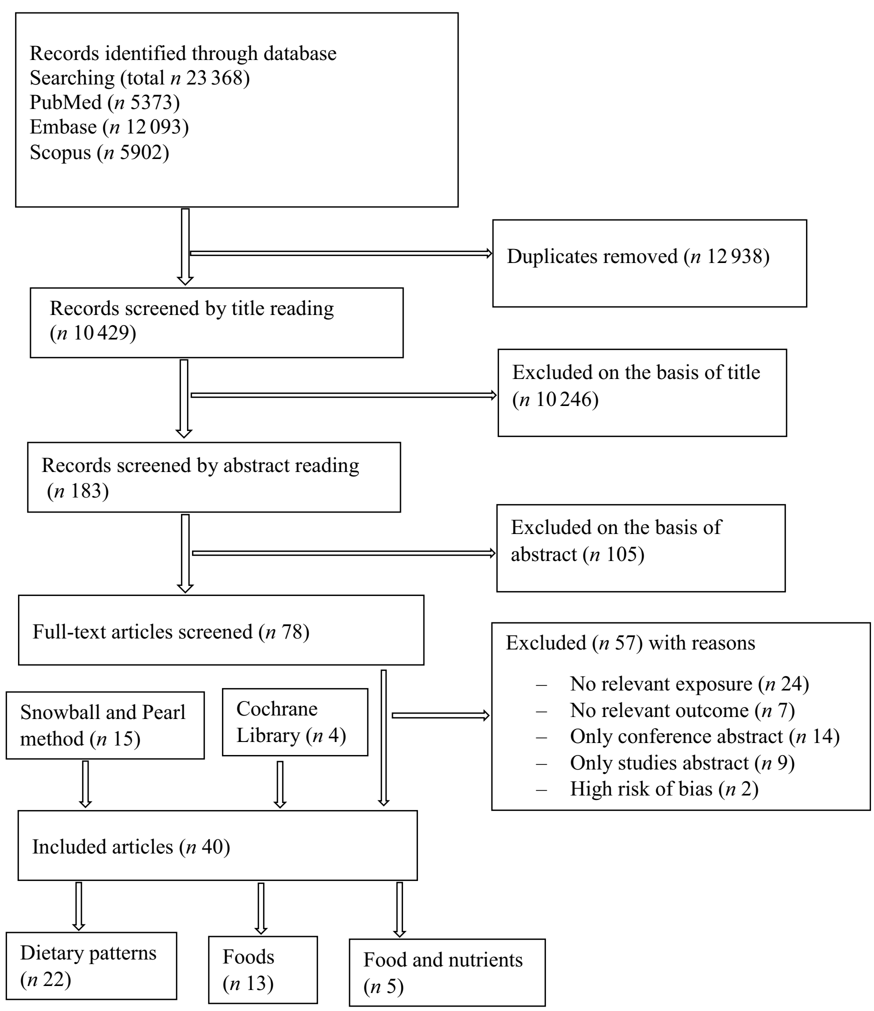

Fig. 1. Flow diagram showing the number of articles sourced at each stage of the systematic review.

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percentage of preterm births ranged from 3·0 to 14·7 %, the percentage of LBW from 0·7 to 20·7 % and of SGA from 3·4 to 49·2 % (Tables 1 and 2).

The majority of included studies did not control for possible covariates, such as pregnancy complications (gestational diabetes mellitus and hypertension disorder in pregnancy), nutritional supplementations (Fe, Zn and folic acid) and caffeinated beverages (coffee, tea and cola). Over one-quarter of studies used self-administered postal questionnaires to collect maternal dietary intake, which might have selection bias (online Supplementary Table S2).

The quality assessment scores ranged from 3 to 8 for prospective cohort studies, 7 to 8 for case–control studies and 3 to 6 for cross-sectional studies. However, one prospective cohort[66] and one cross-sectional study[67] were excluded due to having a high risk of bias. The major concerns of included articles were selection bias (did not ascertain exposure) and comparability (did not control for any additional pertinent factors) (online Supplementary Tables S3–S5). The common concern for intervention studies was performance bias (the study participants and investigators were not blinded for the intervention allocation) (online Supplementary Table S1).

In the present review, the definition of SGA varied from birth weight < 2·5th percentile[23] to < 5th percentile[32,40,41] to <10th percentile of gestational age[34,35,38]. The majority of studies (seventeen articles) defined SGA as birth weight below the 10th percentile for the gestational age. However, three articles defined SGA as <5th percentile for the gestational age – these studies showed no association between SGA and maternal diet[32,40,41].

There is well established evidence that preterm birth is the primary cause of LBW. Only one study excluded extremely preterm (<28 weeks) and post-term (>42 weeks) birth in the final analysis between maternal diet and LBW[33]. For the analyses of associations between maternal diet and SGA, five studies[44,47,55,56,58] excluded only preterm birth and two studies[46,51] excluded both pre- and post-term birth from the final samples.

Maternal diets during pregnancy and preterm birth

Sixteen eligible articles reported on the association between maternal dietary patterns during pregnancy and preterm birth – from these articles, seven studies have shown beneficial effects of maternal diet on the risk of having preterm infants (Table 3). Greater adherence to maternal diet quality, including prudent, traditional, DASH, and vegetable–fruits–rice (VFR) diets were associated with lowering the risk of preterm birth[17,20,34]. A large prospective cohort study conducted in Norway, MoBa observed that prudent diets (characterised by high intake of vegetables, fruits, whole grains, cereals, oils, water as a beverage and fibre-rich bread) and traditional diets (high intake of potatoes and fish) lowered the risk of preterm birth[17]. Martin *et al.* also reported that the DASH dietary pattern (high intakes of fruits, vegetables, nuts and legumes, low-fat dairy products and whole grains; low intake of Na, red and processed meats and sweetened beverages) was significantly associated with a lower risk of preterm birth[20]. Furthermore, Chia *et al.* found that those with high adherence to a VFR pattern had a lower risk of preterm birth[34].

In contrast, Rasmussen *et al.* and Martin *et al.* reported that Western diets characterised by high intake of salty and sweet snacks, processed meat, white bread and desserts, and a dietary pattern characterised by collard greens, coleslaw or cabbage, maize bread, red and processed meats, whole milk and vitamin C-rich drinks increased the risk of preterm birth[20,21]. Two prospective cohort studies documented that high glycaemic index diets, characterised by high intake of carbohydrates, added sugar and dietary fibre[36], and Western diets (high intake of salty and sweet snacks, white bread, desserts and processed meat products) had no significant association with risk of preterm birth[17].

Inconsistent findings were found in association between Mediterranean diets and preterm birth (Table 3). Mikkelsen *et al.* observed that Mediterranean diets (characterised by high intake of olive or rapeseed oil, intake of fish ≥2/week, >5/d fruits and vegetables, meat twice a week and two cups of coffee per d) were associated with lowering risk of early preterm birth[18]. Saunder *et al.* reported that there was no association between adherence to Mediterranean diets (characterised by intake of vegetables, legumes, fruits and nuts, cereals, fish, meat and poultry, dairy products, alcohol and fat) and the risk of preterm birth[57]. Moreover, in a study conducted in Norway, maternal adherence to the Mediterranean diet was not associated with preterm birth risk[39].

Limited evidence was found on the relationship between maternal milk consumption and preterm birth (Table 4). A prospective cohort study conducted in Norway showed that high consumption of milk-based probiotic products was significantly associated with reduced risk of spontaneous preterm birth[48]. However, Heppe *et al.* reported that there was no association between milk consumption and the risk of preterm birth[40].

We found two prospective cohort studies with discrepant findings on the association between maternal fish consumption and preterm birth (Table 5). A study conducted in Denmark showed that low seafood consumption was a strong risk factor for preterm birth[53]. However, in the Netherlands, there were inconsistent findings observed in associations between consumption of total fish or different types of fish and preterm birth[41].

Maternal diets during pregnancy and low birth weight

We found four eligible studies reporting on the association between LBW and maternal dietary patterns during pregnancy. The findings were mixed (Table 6). Hajianfar *et al.* showed a positive association between high intake of the Western dietary pattern and risk of having a LBW infant[22]. Emond *et al.* found no significant association between maternal diet quality and LBW. Maternal exposures to high-quality diets (characterised by high intake of fruits, vegetables, legumes, whole grains, nuts, moderate alcohol consumption, long-chain *n*-3 fatty acids and polyunsaturated fats, and low intake of sugar-sweetened beverages and fruit juice, red and processed meats, *trans*-fatty

Table 3. Associations between maternal dietary patterns and preterm birth

References	Dietary patterns	Association	Findings	95 % CI	Food items
Chia *et al.*[34]	VFR	↓	AOR 0·67	0·50, 0·91	Vegetables, fruit, rice
	SFN	↔			Seafood and noodles
	PCP	↔			Pasta, cheese, processed meat
Englund-Ogge *et al.*[17]	Prudent	↓	HR 0·88	0·80, 0·97	Prudent: vegetables, fruits, oils, whole grains, cereals and fibre-rich bread
	Traditional	↓	HR 0·91	0·83, 0·99	Traditional: potatoes and fish
	Western	↔			Western: salty and sweet snacks, white bread, desserts and processed meat
Englund-Ogge *et al.*[36]	GI and GL	↔			High intake of carbohydrates, added sugar, and fibre
Grieger *et al.*[37]	High protein/fruit	↓	AOR 0·31	0·13, 0·72	High protein/fruit: fish, meat, chicken, fruit, whole grains
	High fat/sugar	↑	AOR 1·54	1·10, 2·15	High fat/sugar/takeaway: takeaway, potato chips and refined grains
	Vegetarian type	↔			Vegetarian type: vegetables, legumes and whole grains
Haugen *et al.*[39]	Mediterranean diets	↔			Intake of fish ≥ 2 times/week, fruit and vegetables ≥ 5 times/d, use of olive/rapeseed oil, red meat intake < 2 times/week and < 2 cups of coffee/d
Hillesund *et al.*[42]	NND	↔			Intake of Nordic fruits, root vegetables, cabbages, potatoes, oatmeal porridge, whole grains, wild fish, game, berries, milk and water
Hillesund *et al.*[59]	Healthy dietary score	↓	AOR 0·81	0·68, 0·97	High intake of fruits, vegetables, plenty of water and low intake of added sugar, salt, sweets and snacks, and fast foods
Huybregts *et al.*[60]	FFS with MMN	↔			Peanut butter, soya flour, vegetable oil, sugar and MMN cocktail
Janmohamed *et al.*[61]	CSB	↓	AOR 0·33	0·12, 0·89	Maize and soyabean flour that is fortified with a vitamin and mineral
Khoury *et al.*[62]	CLD	↓	RR 0·10	0·01, 0·77	Intake of fish, low-fat meats and dairy products, oils, whole grains, fruits, vegetables and legumes
Lu *et al.*[45]	Milk pattern	↑	AOR 1·59	1·11, 2·29	Fresh milk, pasteurised milk, milk powder, and formula
Martin *et al.*[20]	Factor 1	↔	AOR 1·55	1·07, 2·24	Factor 1: fruits, vegetables, low-fat dairy products, high-fibre and fortified cereals and wheat bread
	Factor 2	↔	AOR 0·59	0·40, 0·85	Factor 2: beans, maize, French fries, hamburgers or cheeseburgers, white potatoes and ice cream
	Factor 3	↑			Factor 3: collard greens, coleslaw or cabbage, red and processed meats, maize bread or hushpuppies, whole milk and vitamin C drinks
	Factor 4	↔			Factor 4: shellfish, pizza, salty snacks and refined grains
	DASH diets	↓			DASH diets: high intakes of fruits, vegetables, nuts and legumes, low-fat dairy products and whole grains; low intake of Na, red and processed meats, and sweetened beverages
Mikkelsen *et al.*[18]	Mediterranean diets	↓	AOR 0·28	0·11, 0·76	Consumptions of fish twice a week or more, used olive or rapeseed oil, consumed five + fruits and vegetables/d, ate meat (other than poultry and fish) at most twice per week, and drank at most two cups of coffee per d
Myhre *et al.*[49]	Alliums	↓	AOR 0·97	0·78, 1·20	Alliums (garlic, onion, leek and spring onion)
	Dried fruits	↓	AOR 0·82	0·72, 0·94	Dried fruits (raisins, apricots, prunes, figs and dates)
Potdar *et al.*[63]	Treatment snack	↔			Fresh and dried green leafy vegetables, milk and dried fruit
Rasmussen *et al.*[21]	Vegetables/prudent	↔	AOR 1·30	1·13, 1·49	Vegetables/prudent: cabbage, onion, mushroom, maize, salad, tomato and legumes
	Western	↑			Western: potatoes, French fries, white bread, beef, veal, pork, and mixed meat, meat cold and dressing sauce
	Nordic	↔			Nordic: dark bread, Nordic fruits and cheese
	Seafood	↔			The seafood component mainly associated with the food item partition fish
	Sweets	↔			
	Rice/pasta/poultry	↔			
Saunders *et al.*[57]	Mediterranean diets	↔			Intake of vegetables, legumes, fruits and nuts, cereals, fish, meat and poultry, dairy products, alcohol and fat

VFR, vegetables–fruits–rice; AOR, adjusted OR; SFN, seafood and noodle; PCP, pasta–cheese-processed meat; HR, hazard ratio; GI, glycaemic index; GL, glycaemic load; NND, new Nordic diets; FFS, fortified food supplements; MMN, multi micronutrients; CSB, maize–soya blend diets; CLD, cholesterol-lowering diets; RR, risk ratio; DASH, Dietary Approaches to Stop Hypertension.
↓, Negative association; ↔, null association; ↑, positive association.

Table 4. Associations between maternal milk consumption and adverse birth outcomes (preterm birth, low birth weight (LBW) and small for gestational age (SGA))

References	Exposures	Outcomes	Association	Adjusted OR	95 % CI	Exposure measures
Heppe *et al.*[40]	Milk product	Preterm	↔			Yogurt, yogurt drinks, cheese, butter, quark, pudding, ice cream (dairy cream based) and cream/ creamers. Categorised by 0–1, 1–2, 2–3, and 3 glasses/d
Myhre *et al.*[48]	Probiotic milk or yogurt	Preterm	↓	0·86	0·74, 0·99	High intake of probiotic food item: Biola milk (Tine, Oslo, Norway), Biola yogurt (Tine) or probiotic milk (Probiotic food item B: Cultural milk (Tine))
Heppe *et al.*[40]	Milk product	SGA	↔			Yogurt, yogurt drinks, cheese, butter, quark, pudding, ice cream (dairy cream based) and cream/ creamers. Categorised by 0–1, 1–2, 2–3, and 3 glasses/d
Olmedo *et al.*[52]	Dairy products	SGA	↓	0·89	0·83, 0·96	High intake of yogurt, cheese, ice cream and custard
Olsen *et al.*[54]	Milk product	SGA	↓	0·51	0·39, 0·65	Milk consumption (200 ml/d) and yogurt (150 ml/d) aggregated into glasses/d in eight categories; intake of cheese and ice cream was excluded

Table 5. Associations between maternal fish intake and adverse birth outcomes (preterm birth, low birth weight (LBW) and small for gestational age (SGA))

References	Exposures	Outcomes	Associations	Adjusted OR	95 % CI	Food items
Brantsaeter *et al.*[33]	Seafood	Preterm	↓	0·56	0·35, 0·88	High intake of lean fish, fatty fish, shellfish, fish liver and *n*-3 fatty acid supplements
Heppe *et al.*[41]	Fish intake	Preterm	↔			High intake of total fish, lean fish, fatty fish, shell fish, processed fish, roe fish derived from liver
Olsen *et al.*[53]	Low fish intake	Preterm	↑	3·60	1·15, 11·20	Low fish intake in a hot meal, bread with fish, green salad or pasta salad with fish, and fish oil as a supplement as including roe, prawn, crab and mussels
Heppe *et al.*[41]	Fish intake	LBW	↔			High intake of total fish, lean fish, fatty fish, shell fish, processed fish, roe fish derived from liver
Muthayya *et al.*[50]	Low fish intake	LBW	↑	2·49	1·16, 5·36	Low fish intake with cod liver and *n*-3 PUFA supplement
Olsen *et al.*[53]	Low fish intake	LBW	↑	3·57	1·14, 11·14	Low fish intake in a hot meal, bread with fish, green salad or pasta salad with fish, and fish oil as a supplement as including roe, prawn, crab, and mussels
Halldorsson *et al.*[38]	Fatty fish	SGA	↑	1·24	1·03, 1·49	Fatty fish: salmon, mackerel, trout, herring and Greenland halibut. Lean fish: while cod, pollack, plaice, flounder and garfish. Total fish: intake of both type of fish
	Lean fish	SGA	↔			
	Total fish	SGA	↔			
Heppe *et al.*[41]	Fish intake	SGA	↔			High intake of total fish, lean fish, fatty fish, shell fish, processed fish, roe fish derived from liver
Mendez *et al.*[46]	Crustaceans tuna	SGA	↑	3·05	1·34, 6·99	All seafood, crustaceans, shellfish, canned tuna, fatty and lean fish
	Canned tuna	SGA	↑	2·49	1·04, 5·97	
Mitchell *et al.*[47]	Low fish intake	SGA	↑	1·69	1·07, 2·69	Low intake of any type of fish
Olsen *et al.*[53]	Low fish intake	SGA	↔			Low fish intake in a hot meal, bread with fish, green salad or pasta salad with fish, and fish oil as a supplement as including roe, prawn, crab and mussels
Ricci *et al.*[56]	Fish intake	SGA	↓	0·8	0·6, 1·0	High intake of any type of fish

acids and Na) had no association with LBW[35]. In addition, two RCT conducted in Cambodia and Burkina Faso examined the effect of providing maize–soya blended and fortified food supplements during pregnancy and reported no significant effects on LBW[60,61]. These RCT studies might not be comparable with the above observational studies since the effects of dietary interventions may influence diet only, and last for a limited time, so this result should be interpreted with caution.

Three prospective cohort studies reported on the association between maternal fish consumption and LBW (Table 5). Olsen *et al.* reported that low fish intake was a strong risk factor for LBW[53]. Muthaya *et al.* documented that pregnant women who did not eat fish during the third trimester had a significantly higher risk of having LBW infants[50]. Brantsaeter *et al.* also reported that women with seafood consumption >60 g/d had a lower risk of having LBW infants[33].

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Table 6. Associations between maternal dietary patterns and low birth weight

References	Dietary patterns	Associations	Food items
Emond *et al.*[35]	AHEI	↔	High intake of fruits, vegetables, legumes, whole grains, nuts, and moderate alcohol consumption, long-chain *n*-3 FA from foods and supplements, and polyunsaturated fats
Grieger *et al.*[37]	High protein/fruit	↔	High protein/fruit: fish, meat, chicken, fruit and whole grains
	High fat/sugar		High fat/sugar/takeaway: takeaway foods, potato chips and refined grains
	Vegetarian type		Vegetarian type: vegetables, legumes and whole grains
Hajianfar *et al.*[22]	Western	↑	'Western': high intake of processed meats, fruit, fruit juice, sweets, sugar, saturated fat, sweat fruit, potato, legumes, coffee, eggs, pizza, high-fat dairy products, whole grains and soft drinks
	Traditional	↔	'Traditional': high intake of refined grains, coloured vegetables, olive, sugar, salt, spices, unsaturated fat, garlic, onion and tea
	Healthy	↔	'Healthy': high of green vegetables, leafy vegetables, coloured vegetables, fruit, low-fat dairy products, poultry, bulky vegetables and red meat
Huybregts *et al.*[60]	FFS with MMN	↔	Peanut butter, soya flour, vegetable oil, sugar and MMN cocktail
Janmohamed *et al.*[61]	CSB	↔	Maize and soyabean flour that is fortified with a vitamin and mineral
Potdar *et al.*[63]	Treatment snack	↔	Fresh and dried green leafy vegetables, milk and dried fruit

AHEI, Alternative Healthy Eating Index; FA, fatty acids; FFS, fortified food supplements; MMN, multi micronutrients; CSB, maize–soya blend diets.

Maternal diets during pregnancy and small for gestational age

Ten studies used a dietary pattern approach to evaluate maternal dietary intakes. Of these, 'alternative healthy eating index', 'Mediterranean diets', 'health-conscious', 'traditional' and 'varied' patterns were significantly associated with reducing the risk of giving birth to SGA infants (Table 7). Emond *et al.* found that healthy diets characterised by high intake of fruits, vegetables, legumes, whole grains, nuts, and moderate alcohol consumption, intake of long-chain *n*-3 fatty acids from foods and supplements, and of polyunsaturated fats, and low intake of sugar-sweetened beverages and fruit juice, red and processed meats, *trans*-fatty acids and Na, decreased rates of SGA[35]. In a prospective cohort study conducted in the Infancia y Medio Ambiente cohort in Spain, Chatzi *et al.* showed that high adherence to 'Mediterranean diets' characterised by vegetables, fruits, legumes and nuts, cereals, seafood and milk products had a lower risk of delivering SGA[19]. In addition, a Danish national birth cohort study has also found that the 'health-conscious' diets characterised by a high intake of vegetables, fruits, fish and poultry led to a significantly lower risk of having SGA infants[23]. In a case–control study from New Zealand, Thompson *et al.* found that the traditional dietary pattern characterised by apples/pears, citrus fruit, kiwifruit/feijoas, bananas, green vegetables, root vegetables, peas/maize, dairy food/yogurt and water was significantly associated with a lower risk of having a SGA infant[58]. In a large prospective cohort study conducted in China, Lu *et al.* reported that maternal consumption of a 'varied or mixed' dietary pattern, with high intakes of 'noodles, bread, root vegetables, mushrooms, melon vegetables, sea vegetables, bean vegetables, poultry, seafood, animal organ meat, bean products, yogurt, sweet beverages, puffed food, confectionery and snacks', was associated with a lower risk of having an SGA infant.

However, a 'Western diet' (characterised by high-fat dairy products, red and processed meat) was positively associated with the risk of SGA infants[44]. In addition, in Japan, Okubo *et al.* found that consumption of a 'wheat products' pattern (characterised by a high intake of bread, fruit and vegetable juice, confectionery and soft drinks) was associated with increased risk of having a SGA infant[51].

In contrast, Knudsen *et al.* reported that adherence to the glycaemic index diet was not significantly associated with the risk of delivering SGA infants[43]. Studies conducted in Singapore and the USA by Chia *et al.* and Poon *et al.* also documented no dietary patterns (VFR, seafood and noodle, pasta, cheese, processed meat, healthy eating index, Mediterranean diets) as significantly associated with the risk of having a SGA infant[34,55].

Six studies reported results of fish consumption in relation to SGA deliveries, but the findings were inconsistent (Table 5). Halldorsson *et al.* found that high intake of fatty fish (salmon, mackerel, trout, herring and Greenland halibut) increased the risk of having a SGA infant[38]. In another prospective cohort study conducted in Spain, Mendez *et al.* reported that maternal intake of crustaceans and canned tuna (more than once/week) was associated with an increased risk of SGA[46]. Contrary to this, Olson *et al.* and Heppe *et al.* found no association between maternal fish consumption and SGA infants[41,53]. In a case–control study conducted in New Zealand, people with a low intake of fish had an increased risk of having SGA infants[47]. In another case–control study, Ricci *et al.* also reported that fish consumption was inversely associated with the risk of SGA[56].

Two prospective cohort studies reported the beneficial effects of milk intake on having SGA infants, while one prospective cohort study reported no association (Table 4). In Denmark, maternal milk consumption during pregnancy was inversely associated with the risk of having SGA infants[54]. In addition, Olmedo *et al.* found that high maternal dairy consumption was significantly associated with reduced risk of SGA[52]. However, Heppe *et al.* reported that there was no significant association between milk consumption and the risk of delivering a SGA baby[40].

Table 7. Associations between maternal dietary patterns and small for gestational age

References	Dietary pattern	Association	Findings	95 % CI	Food items
Bouwland *et al.*(32)	Energy-rich diets	↔			High intakes of bread, margarine, nuts and snacks/sweets
Chia *et al.*(34)	VFR	↔			Vegetables, fruit, and white rice
	SFN				Seafood and noodles
	PCP				Pasta, cheese, and processed meat
Chatzi *et al.*(19)	Mediterranean diets	↓	RR 0·5	0·3, 0·9	High intake of vegetables, fruits, legumes and nuts, cereals, seafood and milk products
Emond *et al.*(35)	AHEI	↓	AOR 0·35	0·11, 1·08	High intake of fruits, vegetables, legumes, whole grains, nuts, moderate alcohol consumption, long-chain *n*-3 fatty acids from foods and supplements, and polyunsaturated fats. Low intake of sugar sweetened beverages and fruit juice, red and processed meats, *trans*-fatty acids and Na
Grieger *et al.*(37)	High protein/fruit	↔			High protein/fruit: fish, meat, chicken, fruit and whole grains
	High fat/sugar				High fat/sugar/takeaway: takeaway foods, potato chips and refined grains
	Vegetarian type				Vegetarian type: vegetables, legumes and whole grains
Knudsen *et al.*(23)	Health conscious	↓	AOR 0·74	0·64, 0·86	Health conscious: vegetables, fruits, fish and poultry
	Western	↑			Western diet: high-fat dairy products, red and processed meat
	Intermediate	↔			Intermediate diets: pregnant women who had eaten both food groups
Knudsen *et al.*(43)	GI and GL diets	↔			High intake of carbohydrate-rich foods, such as potatoes, rice and white bread, while dairy products, legumes and nuts
Okubo *et al.*(51)	Wheat products, meat	↑	AOR 5·2	1·1, 24·4	Wheat products: high intake of bread, fruit and vegetable juice, confectionery and soft drinks
	and eggs rice, and	↔			
	fish and vegetables	↔			
Lu *et al.*(44)	Varied or mixed	↓	AOR 0·77	0·57, 1·04	High intake of noodles, bread, root vegetables, mushrooms, melon vegetables, sea vegetables, bean vegetables, poultry, seafood, animal organ meat, bean products, yogurt, sweet beverages, puffed food and confectionery
Poon *et al.*(55)	HEI diets	↔			HEI: high intake of vegetables, whole fruit, whole grains, nuts and legumes, *n*-3 fats, folate, Ca and Fe
	Mediterranean diets	↔			MD: vegetables, legumes, fruits, nuts, whole grains, fish, while less intake of red and processed meats
	GI and GL diets	↔			GI: high intake of carbohydrates, added sugar and fibre
Thompson *et al.*(58)	Traditional	↓	AOR 0·86	0·75, 0·99	Traditional diets: apples/pears, citrus fruit, kiwifruit/feijoas, bananas, green vegetables, root vegetables, peas/maize, dairy food/yogurt and water
	Junk	↔			Junk diets: ice cream, sweet biscuits, scones, cakes, sweetened cereal, crisps, pies, lollies, chocolate bars, ice blocks and Milo (chocolate energy drink)
	Fusion	↔			Fusion: fruits, fried rice/noodles, boiled rice/pasta, fish/shellfish, milk and negative loading for tea/coffee, sherry/wine and hard cheeses

VFR, vegetables–fruits–rice; SFN, seafood and noodle; PCP, pasta–cheese–processed meat; RR, risk ratio; AHEI, Alternative Healthy Eating Index; AOR, adjusted OR; GI, glycaemic index; GL, glycaemic load.

Maternal diets before pregnancy and adverse birth outcomes

We found only four eligible studies that examined the relationship between preconception dietary patterns and adverse birth outcomes (preterm birth, LBW and SGA)[32,37,63]. Grieger *et al.* observed the association between pre-pregnancy dietary patterns in the 12 months before conception and preterm birth among Australian women. Those with a higher intake of protein/fruit had a lower risk of preterm birth, whereas the risk of preterm birth was higher in women with a high intake of fat/sugar/takeaways[37]. Recently, Hillesund *et al.* also showed an inverse association between a high healthy dietary score (characterised by high intake of fruits, vegetables, plenty of water, and low intake of added sugar, salt, sweet snacks and fast foods) and risk of having a preterm infant[59].

In a prospective cohort study conducted on 847 Dutch mothers, Bowland *et al.* reported no significant association between pre-pregnancy dietary patterns in the 3 months before 10–13 weeks of gestation and risk of having SGA infants[32]. One RCT study conducted in India examined the effect of providing treatment snacks (fresh and dried green leafy vegetables, milk and dried fruit) and control snacks (low-micronutrient vegetables such as potato, tapioca and onion) from preconception to giving birth. They reported that there was no significant effect of the treatment snack on adverse birth outcomes[63].

Discussion

The present study has reviewed forty articles comprising mostly of prospective cohort studies with few RCT, which focused on the association between maternal diets and adverse birth outcomes. The review suggests that better maternal diet quality during pregnancy, including 'prudent', 'traditional', 'DASH' and 'VFR', may reduce the risk of preterm birth[17,20,34]. It has been

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challenging to summarise robust evidence from the findings because of the variation in quantity and quality of maternal dietary intake and of the assessment techniques used. Dietary patterns were also named differently across the studies. However, the dietary patterns did share somewhat similar characteristics among the studies. For example, the 'prudent', 'DASH' and 'VFR' patterns all included similar food items, such as a high intake of fruits and vegetables. Only traditional diets did not include fruits and vegetables. Whole grains were also listed in the 'prudent' and 'DASH' diets. Fish and dairy products were included in Mediterranean diet, DASH and traditional diets. Therefore, a high adherence to dietary patterns characterised by fruits, vegetables, whole grains, fish and dairy products might have a protective synergetic effect on preterm birth. These diets are rich in anti-inflammatory nutrients or antioxidants, which might reduce both local and systemic inflammation. The dietary patterns characterised by collard greens, coleslaw or cabbage, red and processed meats and 'Western' diets commonly characterised by higher intakes of processed meat were associated with a higher risk of having preterm infants[20,21]. These diets contain pro-inflammatory nutrients, which act as a stressor on the hypothalamic-pituitary-adrenal system, and might also curb the transfer of nutrients through the placenta[24,25].

The findings regarding adherence to a 'Mediterranean diet' during pregnancy and preterm birth have been inconsistent. A prospective cohort study by Mikkelsen *et al.* showed that higher adherence was associated with decreased risk of preterm birth[18]. However, studies conducted in Norway[57] and France[39] reported no association between Mediterranean diet and preterm birth. Khoury *et al.* also showed the beneficial effects of cholesterol-lowering diets in reducing the risk of preterm birth[62]. The discrepancy of these findings might be due to the variation of dietary assessments and sample size across the studies. There are challenges to establishing a specific definition of 'Mediterranean diet' due to socio-cultural and geographic differences, and therefore, the studies used different measurement techniques to assess 'Mediterranean diet' intake. The sample sizes also varied from 728[57] to 40 817[39] in the prospective studies, while the RCT study included only 290 study participants[62]. The studies also used a variety of names for the 'Mediterranean diet', such as 'Mediterranean-type diet', 'Mediterranean diet adherence', 'Mediterranean diet index' and 'cholesterol-lowering diet'. However, the food items were commonly characterised by a high intake of fish, dairy products, oils, whole grains, fruits, vegetables and legumes.

Maternal dietary patterns, including higher adherence to 'alternative healthy eating index', 'Mediterranean diet', 'health-conscious', 'traditional' and 'varied' diets, were inversely associated with the risk of having SGA infants[19,23,35,44,58]. These findings were contradicted by a study conducted in the USA by Poon *et al.* which did not observe a significant association between dietary patterns ('healthy eating index' and 'Mediterranean diet') and SGA[55]. 'Western diets' and consumption of wheat products were significantly associated with an increased risk of SGA infants[23,51]. One possible explanation for this disagreement is that maternal dietary intake was only measured once during the third trimester in the infant feeding practices study II cohort[55], while dietary intake in both the Infancia y Medio Ambiente[19] and NHBCS[35] cohorts was measured in the first trimester and mid-pregnancy period, respectively. The dietary patterns inversely associated with the risk of SGA were termed differently, but were characterised by somewhat similar food items, such as high intake of vegetables, fruits, legumes, seafood/fish and milk, across the studies. Such diets are rich in antioxidants, fibre and unsaturated fats, which reduce both systemic and local inflammation[68–70].

Inconsistent findings have been observed in association between maternal fish consumption and preterm birth with reports of either positive[53] or null association[41]. The discrepancy of these findings might be due to the variety of measurement techniques used to assess fish intake and sample size. The nineteen large population-based European birth cohort studies showed that moderate fish intake during pregnancy had a beneficial effect on lowering the risk of preterm birth[71].

The association between maternal fish consumption and SGA infants has also been discrepant, with reports of either positive[38,46] or negative[47,56] or null associations[41,53]. This might be due to fish intake being assessed differently across the studies. Halldorsson *et al.* excluded women who were receiving fish oil supplements[38], while Olsen *et al.* quantified long-chain *n*-3 fatty acids[53]. There was large variability in the sample sizes, from 657[46] to 44 824[38].

Based on the findings from all prospective cohort studies, fish consumption has been inversely associated with the risk of having LBW infants[33,53,50], except in one study, which reported a null association[41], and which could be due to difference in quantity and quality of maternal fish intake[41]. The findings might also be influenced by the intake of nutritional supplements, such as *n*-3 PUFA[50] or *n*-3 fatty acid[33]. The inverse association between fish intake and LBW might be due to fish being a major source of essential nutrients, such as Se, iodine, *n*-3 PUFA and protein, which are considered to have beneficial effects on reducing adverse birth outcomes[72–74].

The discrepant findings between milk intake and preterm birth might be due to the use of different outcome assessments and sample sizes[40,48]. For example, Myhre *et al.* assessed only spontaneous preterm birth (between 22 and 37 weeks of gestation)[48], while Heppe *et al.* included both spontaneous and induced preterm birth (live birth < 37 weeks of gestation)[40]. Maternal milk consumption that contains probiotics might decrease spontaneous preterm birth, particularly if caused by the premature rupture of membrane, possibly through an effect of probiotics on vaginal tract infections and lowering overall inflammatory response[75]. In addition, many studies showed that bacterial vaginosis was positively associated with preterm birth, which might be one explanation for the association between milk intake and reduced risk of spontaneous preterm birth[76,77].

Beneficial effects of milk intake on reducing having an SGA infant are evident in two prospective studies[52,54], which is also confirmed by this review. However, one prospective cohort study did not show a significant association[40]. This discrepancy might be due to maternal milk intake being measured differently across the studies. The gestational period in which maternal milk intake was assessed differed among studies, from being assessed at first trimester[40], mid-pregnancy[54] and between 20 and

22 weeks of gestation[52]. The findings were scarce, but suggestive of a negative association between milk consumption and SGA. However, it should be noted that excessive maternal milk intake (>2 glasses/d) was positively associated with increased risk of having large for gestational age infants[54]. In addition, some studies showed positive associations between maternal milk intake and birth weight used as a continuous variable[40,54,78].

To date, studies on preconception dietary patterns and adverse birth outcomes are scarce and the findings are mixed. Only two studies (one cross-sectional and one RCT) showed an association between preconception dietary patterns and preterm birth[37,59], while one prospective cohort[32] and one RCT[63] study reported no association. These studies were conducted using different dietary patterns, study designs and sample sizes. In addition, the period of preconception diet was assessed differently among these studies. For example, Grieger *et al.* observed the association between pre-pregnancy dietary patterns in the 12 months before conception and adverse birth outcomes[37], while Bouland *et al.* evaluated diet in the 3 months before 10–13 weeks of gestation. Timing and duration of exposure (preconception diet) and its effects on maternal and fetal outcomes can be considered as a critical period, a sensitive period and cumulative effects, respectively. The period around conception (8–12 weeks before conception) is a critical period for gamete maturation and early fetal and placental development[79]. For example, folic acid supplementations during peri-conception could decrease the risk of neural tube defects[80,81] as well as LBW and SGA[82,83]. Adolescence might be a sensitive period for poor lifestyle behaviours, such as harmful dietary intake, smoking and alcohol intake. Such pre-pregnancy risk factors could also have a cumulative effect on lifelong adulthood health as well as for future generations. For example, prevention of obesity in women of reproductive age has a crucial impact on pregnancy and birth outcomes[84].

The present review is limited by the wide diversity of maternal dietary intake measures, including the quality and quantity of foods. The review also included mostly prospective cohort studies, and so it is not possible to draw definite causal inferences. The findings are based on studies in mostly high-income countries, which limit the ability to generalise the evidence to a wide range of populations around the globe. Furthermore, for the studies of the relationship between maternal diets and SGA, results may have been influenced by variations in the prevalence of SGA infants and the use of different cut-offs for SGA across the studies. The operational definitions of SGA were different from birth weight <2·5th percentile[23] to <5th percentile[40,41] to <10th percentile of gestational age[34,35,38]. Because of these limitations, we have used a narrative approach for this systematic review rather than a meta-analysis.

In conclusion, we found several prospective cohort studies that examined the relationship between maternal dietary patterns during pregnancy, preterm birth and SGA. Despite some disagreements and variation of dietary patterns across the studies, some common characteristics were found in the relationships between maternal dietary patterns and the risk of preterm birth and SGA. Better maternal diet quality during pregnancy, characterised by a high intake of vegetables, fruits, whole grains, fish and dairy products, may have a beneficial effect on lowering the risk of preterm birth. Furthermore, maternal dietary patterns during pregnancy characterised by a high intake of vegetables, fruits, legumes, fish and milk products may reduce the risk of having SGA infants. No consistent associations were observed between maternal dietary patterns during pregnancy and LBW. Evidence on associations between pre-pregnancy diets and adverse birth outcomes is limited and inconsistent. Therefore, well-powered population-based prospective studies are needed to establish the association between pre-pregnancy diets and adverse birth outcomes. More specific definitions and homogenous measurements for dietary patterns are also needed for potential meta-analysis, to estimate a combined effect size.

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Supplementary material

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