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Dietary assessment methods for micronutrient intake in pregnant women: a systematic review

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The EURopean micronutrient RECommendations Aligned (EURRECA) Network of Excellence needs clear guidelines for assessing the validity of reported micronutrient intakes among vulnerable population groups. A systematic literature search identified studies validating the methodology used for measuring usual dietary intake during pregnancy. The quality of each validation study selected was assessed using a EURRECA-developed scoring system. The validation studies were categorised according to whether the study used a reference method that reflected short-term intake (<7 d) long-term intake (≥ 7 d) or used biomarkers (BM). A correlation coefficient for each micronutrient was calculated from the mean of the correlation coefficients from each study weighted by the quality of the study. Seventeen papers were selected, which included the validation of fifteen FFQ, two dietary records (DR), one diet history and a Fe intake checklist. Estimates of twenty-six micronutrients by six FFQ were validated against 24-h recalls indicating good correlation for six micronutrients. Estimates of twenty-four micronutrients by two FFQ were validated against estimated DR and all had good or acceptable correlations. Estimates of fourteen micronutrients by three FFQ were validated against weighed DR indicating good correlations for five. Six FFQ were validated against BM, presenting good correlations only for folic acid. FFQ appear to be most reliable for measuring short-term intakes of vitamins E and B_6 and long-term intakes of thiamin. Apart from folic acid, BM do not add any more certainty in terms of intake method reliability. When frequency methods are used, the inclusion of dietary supplements improves their reliability for most micronutrients.

Pregnant women: Dietary assessment methods: Systematic review: Validation: Micronutrients

Pregnant women must consume enough calories and nutrients to provide sustenance for both themselves and the developing fetus(1). Moreover, adequate nutrition during pregnancy is important for the development of the placenta, for a healthy delivery and for future lactation. A key focus of attention in public health has been micronutrient deficiencies in pregnancy, because of the increased needs and greater vulnerability of pregnant women to the effects of micronutrient deficiency or imbalance(2). Deficiency of certain nutrients can lead to anaemia and neural tube defects(1). Dietary surveys of pregnant women in industrialised countries consistently demonstrate Fe intake well below current recommendations(3). As a consequence, Fe deficiency anaemia is common in pregnancy. Beneficial health effects of nutrient supplementation in a well-nourished pregnant population have only been documented for folate in the prevention of neural tube defects(4), and for Fe in the prevention of anaemia(5).

Epidemiological studies indicate that fetal nutrition may influence fetal growth, development and the risk of developing various diseases later in life(6). As such, it would also be necessary to monitor the diets of pregnant and lactating women to verify whether they are adequate in long-chain *n*-3 fatty acids, given the structural role played by DHA in the brain and retina, and the rapid brain development that takes place during the last trimester of pregnancy and infancy(7,8). There is a growing interest in the mother's diet during pregnancy, and it is becoming increasingly important to develop reliable methods for monitoring maternal consumption of foods and nutrients, including dietary supplements. The FFQ is a tool commonly used in large epidemiological studies in different contexts, groups and populations, owing to their low cost and ease of administration(9,10). In general, the studies have been conducted to evaluate intake of nutrients and foods from the

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Abbreviations: BM, biomarkers; DH, diet history; DR, dietary records; EDR, estimated dietary records; WDR, weighed dietary records.

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diet, leaving out information on the use of dietary supplements. Assessment of dietary supplement use in pregnant women is necessary, owing to the fact that both the use of dietary supplements and the consumption of fortified foods are on the rise.

Research conducted as part of the European Commission's EURopean micronutrient RECommendations Aligned (EURRECA) Network of Excellence has focused on extensive literature reviews addressing the validation of methods used to assess intake of micronutrients, *n*-3 fatty acids and of special population groups: pregnant women, infant, children, adolescents and elderly people(11). In the present review, the studies on dietary methods used to assess micronutrient intake during pregnancy are presented.

Material and methods

The research question applied to the systematic review was 'which dietary methods are reliable for the assessment of micronutrient intake during pregnancy?'. The main stages of the review are illustrated in Fig. 1. The review included English, Spanish, French, Italian, Portuguese and German articles, without limits on time frame or country. Stage 1 of the review involved searching for publications using electronic databases (MEDLINE and EMBASE). The MeSH terms used in the general search were: nutritional assessment, diet, nutritional status, dietary intake, food intake, validity, validation study, reproducibility, replication study, correlation coefficient and correlational study in the title and abstract. As a second specific search, the following words were included: pregnancy, pregnant women, 'dietary assessment', 'dietary intake', 'nutrition assessment', 'diet quality', reliability, reproducibility, validit* and correlate* as free text in the title and abstract. Additional publications were identified from references published in the original papers. At stage 2 of the review, the title and abstract were analysed by two independent reviewers and the exclusion criteria were applied (Table 1). At stage 3, studies that fulfilled the inclusion criteria were analysed for relevance to the research question.

The selected studies were then classified into three different types according to the reference method applied in the validation studies: (1) reference method assessing intake of <7 d (including 24-h dietary recall, estimated dietary records (EDR) and weighed dietary records (WDR)), classified as reflecting short-term intake; (2) reference method assessing intake of ≥ 7 d, reflecting more long-term intake; (3) reference method that employed the use of a biomarker (BM).

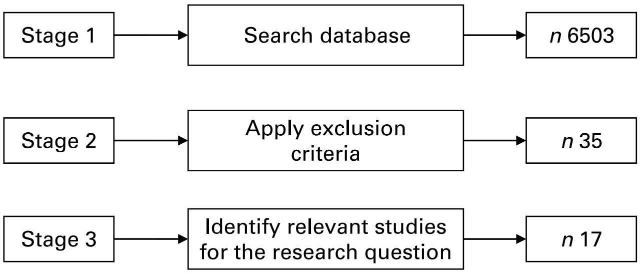

Fig. 1. Main stages of the systematic review process.

Table 1. Inclusion and exclusion criteria

Inclusion criteria
- A. Studies on micronutrient intake in pregnant women, including supplements
- B. Validation study in human subjects

Exclusion criteria
- A. Studies describing the content of foods in nutrients, additives or contaminants
- B. Studies exclusively focused on diseased or institutionalised persons
- C. Articles presenting reference values for food consumption, nutrient intake, biochemical markers and anthropometric measurements
- D. Articles establishing associations between food consumption, nutrient intake, biological variables, biochemical markers and anthropometric measurements
- E. Studies relating diseases to food consumption or nutrient intake
- F. Intervention studies and other therapeutic studies with nutrients or drugs related to the metabolism of these nutrients
- G. Calibration studies and those discussing statistical methods
- H. Studies evaluating the physiological effects of foods, nutrients and in relation to their genetic determinants
- I. Studies in animals
- J. Studies written in other languages than English, Spanish, French, Italian, Portuguese and German and those without abstract

Furthermore, the different studies included in the present review were scored according to a quality score system developed by EURRECA, which has been described in another article in this supplement(12). A total score was calculated according to the mean of the correlation coefficients weighted by the quality score of the validation study. It was considered a poor method for assessing specific nutrient intake when the mean weighted correlation was $<0{\cdot}30$. Methods whose mean weighted correlations were between 0·30 and 0·50 were regarded as acceptable for assessing nutrient intake. Good methods were those whose weighted correlation average was between 0·51 and 0·70, and finally, when the mean weighted correlation was $>0{\cdot}70$, the method was considered very good.

Results

A total of seventeen publications(2,13–28) were selected for inclusion, with information on each validation study summarised in Table 2. Six of the publications showed results from European countries (Norway, Denmark, United Kingdom and Finland), ten from American countries (United States of America, Mexico and Brazil) and one study was Australian. The number of participants varied from 16 to 710 in the selected studies.

In five of the studies presented(2,17,20,24,28), only one type of micronutrient was analysed, while in the rest of the publications included in the present review, correlations for a wide variety of micronutrients were observed, and a total of twenty-seven micronutrients were analysed. Tables 3–5 show information on the correlation between methods and other statistics in the validation studies in pregnant women for *n*-3 fatty acids, fifteen vitamins and eleven minerals, respectively. Table 6 presents the classification of the dietary methods utilised for studies in pregnant women according to the mean of the correlation coefficients for each micronutrient weighted by the quality of different validation studies included in the present review. Six studies validated FFQ

Table 2. Characteristics of included studies

Author/year of publication and country	Participants	Dietary method	Reference method	Nutrient	Conclusions
Brantsaeter *et al.* (2007)$^{(13)}$ Norway	119 healthy women at 18–27 weeks of gestation enrolled in the Norwegian Mother and Child Cohort Study (MoBa) (23–44 years). The exclusion criteria were: hyperesis and anorexia	FFQ (diet during the first 4 months of pregnancy)Self-reported 255 foods + thirteen dietary supplements. Nine frequency category The Norwegian food composition table was used	4-d weighed dietary records (three consecutive weekdays and one weekend day) Interval between methods: 24 d Biomarkers Erythrocyte sum *n*-3 Plasma retinol Plasma β-carotene Plasma 25(OH)D Plasma tocopherol Serum folate Erythrocyte folate Urine iodine excretion	Vitamins D, E, retinol, β-carotene, folate, *n*-3 fatty acids, iodine	The correlations between the two dietary methods (FFQ and WDR) were statistically significant for intake of all nutrients. The correlations between biomarker concentration/excretion and intake calculated with the FFQ were statistically significant for 25(OH)D, serum folate and urinary iodine
Mikkelsen *et al.* (2006)$^{(14)}$ Denmark	Eighty-eight participants in gestational week 32–38	FFQ Week 25 of pregnancy (covering the women's diet during the last 4 weeks) 360 food items Dietary supplement was coded according to brand name. The Danish food tables and individual portion size and recipes were used	7-d weighed dietary records. Interval between methods: 2–3 months Biomarkers Erythrocyte EPA Plasma retinol Erythrocyte folic acid	Folic acid, retinol, *n*-3 fatty acids	The FFQ gave reasonably valid estimates of protein, retinol and folic acid intakes, but seemed to overestimate intake of *n*-3 fatty acids
Mouratidou *et al.* (2006)$^{(15)}$ UK	123 participants at gestational week 14–18. Excluded cases with diabetes or celiac disease	The Sheffield FFQ included sixty-two quantitative and qualitative questions. Interviewer-administered Q-Builder based on the UK food tables was used	Two 24-h recalls. The first, after FFQ administration at the initial interview. The second, administered via telephone after 10–14 d	Retinol, carotene, vitamins C, D, E, B_6, B_{12}, thiamin, riboflavin, niacin, folate, pantothenic acid, biotin, Na, K, Ca, Mg, P, Fe, Cu, Zn, Mn, Se, iodine	The intakes of all examined nutrients, except for iodine, carotene, vitamins E, C, biotin and alcohol, were higher when determined by the FFQ than when determined by 24-h recall
Baer *et al.* (2005)$^{(16)}$ USA	Low-income American Indian and Caucasian women participating in North Dakota WIC. Phase 1: 279 women at 12 weeks of gestation Phase 2: 242 women at 28 weeks of gestation	The Harvard Service FFQ. Eighty-four foods HSFFQ1 at 12 weeks of gestation HSFFQ2 after week 12 HSFFQ3 at 28 weeks of gestation Minnesota Nutrient Database System software was used	Administered by telephone or in person. Six 24-h recalls. Three between HSFFQ1 and HSFFQ2. Three between HSFFQ2 and HSFFQ3. In general, two recalls were taken on weekdays and one recall on the weekend	Vitamins A, E, C, B_1, B_2, B_6, B_{12}, niacin, folate, Ca, Fe, Mg, P, Zn	The Harvard Service FFQ can provide reasonable assessment of relative nutritional intake among low-income American Indian and Caucasian women during pregnancy
Zhou *et al.* (2005)$^{(17)}$ Australia	Fifty-four women assessed at 36 weeks of gestation	Checklist included sixty-five food and drink items with reference serving size. Included vitamin and mineral supplements containing Fe. Interviewer-administered. Past 24-h intake	Diet history interviewer records typical food intake over 1 week including vitamin and mineral supplements	Fe	Simple Fe checklist was a useful tool in describing Fe intake in a population of pregnant women, but has limited ability to predict Fe status

Table 2. *Continued*

Author/year of publication and country	Participants	Dietary method	Reference method	Nutrient	Conclusions
Parra *et al.* (2002)(18) Mexico	Thirty-five healthy women during the last trimester of pregnancy (18–42 years)	FFQ, including 104 items Administered by trained interviewers. Ten frequency categories; past year intake. No available food composition table that included the contents of PUFA and/or their metabolic derivatives in Mexican foods. Software SNUT 3·0 was used	Biomarkers Erythrocyte cell membrane phospholipid levels	PUFA	FFQ provided estimates of average long-term intakes of PUFA and correlated reasonably well with erythrocyte cell membrane phospholipid status
Erkkola *et al.* (2001)(19) Finland	113 Finnish pregnant women	FFQ, 181 food items open-frequency categories in increasing order. Serving sizes based on commonly used portions in Finland and for some foods natural units were used. Dietary supplements were not included. FFQ assessed entire diet over a period of 1 month. Food composition data were analysed with a software program developed at the National Public Health Institute. Self-administered	Two 5-d estimated dietary records. The first recording was during 29–32 weeks of gestation, and the second during 33–36 weeks of gestation. The food record covered four weekdays and one weekend day. Photo book of 126 common food items and mixed dishes was used to facilitate portion size estimation	Vitamins A, D, E, B$_{12}$, B$_6$, C, retinol, β-carotene, thiamin, riboflavin, niacin, folate, biotin, pantothenic acid, Ca, Cu, Fe, Mg, Na, Zn, Mn, iodine, Se	The intake of foods and nutrients was higher when determined by FFQ than when assessed using food records
Rifas-Shiman *et al.* (2000)(20) USA	204 pregnant women	Modified version of the Willett Service FFQ. Self-administered, eight categories First trimester intake	Biomarkers Blood concentrations of fatty acids	Fatty acids	The SFFQ in the present study was appropriate for assessing intake of at least several important nutrients during early pregnancy
Rondó *et al.* (1999)(2) Brazil	710 pregnant women from Sao Paulo	An interviewer-administered FFQ was utilised, considering the high percentage of illiteracy. Included fifty-five foods. The portion sizes being assigned to each food item on the basis of a previous study in the same area. Three frequency categories (daily, weekly and monthly) Food composition table of McCance and Widdwson's	Biomarkers Plasma levels of vitamin A (12–72 h after delivery) No participant received vitamin A supplements during pregnancy	Vitamin A	FFQ did not provide very precise information on vitamin A, probably because of the day-to-day variation in vitamin A intake, and the insensitivity of plasma concentrations to vitamin A consumption
Wei *et al.* (1999)(21) USA	101 low-income pregnant women aged 14–43 years from Massachusetts	PFFQ. Past 4-week intake. Supplements not included. Nutrients were estimated using the Harvard nutrient database	24-h recalls Interviewer administered. Two-dimensional Food Portion Visual	Vitamins C, E, B$_1$, B$_2$, B$_6$, B$_{12}$, A, folate, retinol, carotene, Zn, Na, K, Ca, Fe, Mg, P	A FFQ for English-speaking, low-income pregnant women can provide a valid estimate of diet across a wide range of nutrients

Table 2. *Continued*

Author/year of publication and country	Participants	Dietary method	Reference method	Nutrient	Conclusions
Brown *et al.* (1996)[22] USA	Fifty-six healthy, pregnant, well-educated, white women	FFQ, reflect dietary intake over 1-month period. Supplements were not included. Minnesota Nutrition Data System	4-d weighed dietary records. The food record covered two weekdays and two weekend days	Vitamins C, D, A, folate, Ca, Fe, Zn, Na	Comparison with 4-d WDR indicated that the FFQ was appropriate for obtaining reliable estimates of changes in nutrient intake during pregnancy
Robinson *et al.* (1996)[23] UK	569 women at 15 weeks of gestation from Southampton. Women were excluded if they had a past history of diabetes or treatment for infertility	FFQ. 100 food items. Standard portion sizes were assigned. Each women reported daily food consumption over the 3-month period preceding the interview. Eight frequency categories. Included dietary supplements	4-d estimated dietary records. Women kept a prospective record of all food and drink consumed for a period of 4 d (including one weekend day). Used household measure (e.g. bowl, teaspoon, serving spoon)	Retinol, thiamin, riboflavin, niacin, pyridoxine, vitamins B_{12}, C, D, E, folate, Ca, Fe, Zn, Cu	The FFQ appeared to give meaningful estimates of nutrient intake in early pregnancy, which can be used to rank individuals
Olsen *et al.* (1995)[24] Denmark	135 pregnant women in the 30th week of gestation	Dietary self-administered questionnaire and interview Photographs modelling various portion sizes. Past 3 months of intake, corresponding roughly to the second trimester of pregnancy	Biomarkers Fatty acids measured in erythrocyte phospholipids	*n*-3 fatty acids	It was possible to detect a comparatively strong correlation between erythrocyte levels and questionnaire-assessed intake of *n*-3 fatty acids
Forsythe *et al.* (1994)[25] USA	Eighty pregnant and lactating women. Age 22–43 years Caribbean and African descendants	Modified Harvard FFQ for African and Caribbean foods. Eighty-two items. Self-administered	Three 24-h recalls. First in person, second and third by telephone	Vitamins A, B_{12}, folate, Na, Ca, Fe, Zn	The FFQ presented greater intakes for energy, carbohydrate and total fat
Greeley *et al.* (1992)[26] USA	Fifty healthy women at gestational weeks 16 and 21 (second trimester) and 30 and 35 (third trimester)	Optically scannable FFQ evaluating daily food consumption during a 2-month time period 116 item self-administered Harvard FFQ	Four 24-h recalls at 16, 21, 30 and 35 gestational weeks. Interviewer administered	Fe, Ca, vitamin C, folate	The mWFFQ was a useful tool for assessing nutrient intake in groups of pregnant women
Suitor *et al.* (1989)[27] USA	295 pregnant women	The Prenatal FFQ modified to evaluate daily food consumption during past 4-week period; no portion size; contained open-ended question on type of supplements used. Included 90 foods and a total of 111 items. Self-administered	Three 24-h diet recalls on randomly selected subset of ninety-five women Interviewer administered. Two-dimensional Food Portion Visual	Ca, Fe, Zn, vitamins A, B_6, C	A self-administered questionnaire can provide useful data about individual recent intake of selected nutrients in a majority of English-speaking, low-income pregnant women, but the overestimation of food use may occur for up to 20 % of this population
Anderson *et al.* (1988)[28] USA	Sixteen women at delivery	Diet history. Interviewer-administered. 48 h after delivery. Standard history-gathering technique and a cross-check food list. Included supplements	Biomarkers Maternal blood 25(OH)D	Vitamin D	A single diet history obtained at delivery does not provide information that will allow an accurate prediction of a mother's vitamin D status

25(OH)D, 25-hydroxyvitamin D; WDR, weighed dietary records; HSFFQ1, Harvard Service FFQ at 12 gestational week; HSFFQ2, HSFFQ after week 12; HSFFQ3, HSFFQ at 28 gestational week; PFFQ, pregnancy FFQ; SFFQ, semi-quantitative food frequency questionnaire; mWFFQ, modified Willett FFQ.

Table 3. Validation studies in pregnant women: *n*-3 fatty acids

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
Brantsaeter *et al.* (2007)(13) Norway (5)	FFQ *v.* WDR	Spearman CC 0·49**	Median dietary intake FFQ: 3·6 %
	FFQ *v.* BM	Spearman CC Erythrocyte sum *n*-3 0·18	WDR: 3·0 %
	WDR *v.* BM	Spearman CC Erythrocyte sum *n*-3 0·16	
Mikkelsen *et al.* (2006)(14) Denmark (4·5)	FFQ *v.* WDR	Spearman CC 0·28**	Mean estimated intake FFQ-25: 0·54 g/d
	FFQ *v.* BM	Spearman CC Erythrocyte EPA 0·37**	WDR: 0·43 g/d % classified into the same or adjacent quintile: 66 %
	WDR *v.* BM	Spearman CC Erythrocyte EPA 0·62***	
Parra *et al.* (2002) (18) Mexico (1·5)	FFQ *v.* BM	Spearman CC ALN in erythrocyte cell membranes 0·32* DHA in erythrocyte cell membranes 0·35* EPA in erythrocyte cell membranes 0·36*	Dietary fatty acid levels (mg/d) FFQ (means and standard deviations) ALN: 1·518 (SD 0·71); DHA: 0·140 (SD 0·11), EPA: 0·170 (SD 0·08) Erythrocyte cell membrane fatty acid (%/total) (means and standard deviations) ALN: 1·8512 (SD 1·068); DHA: 6·0592 (SD 0·852); EPA: 9·6901 (SD 2·299)
Rifas-Shiman *et al.* (2000)(20) USA (2·5)	FFQ *v.* BM	Spearman CC 0·98	Not specified
Olsen *et al.* (1995)(24) Denmark (2·5)	FFQ *v.* BM	Pearson CC ALN: 0·02 DHA: 0·28 EPA: 0·37	Not specified
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·25† Week 28 diet recalls HSFFQ3 0·26† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·33 (0·13, 0·50)‡ Week 28 diet recalls HSFFQ3 0·52 (−0·12, 0·86)‡	Mean of week 12 recalls (SD): 0·05 g (0·10) Mean of HSFFQ2 (SD): 0·04 g (0·05) Mean of week 28 recalls (SD): 0·04 g (0·10) Mean of HSFFQ3 (SD): 0·04 g (0·05)
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·30 Energy adjusted 0·34 Attenuation and energy adjusted 0·39	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 62
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·11	Mean estimated intake FFQ: 223·8 mg 24HR: 152·6 mg % classified into the same quintile: 61 %

WDR, weighed dietary records; CC, correlation coefficient; BM, biomarker; 24HR, 24-h recall; ALN, α-linolenic acid; HSFFQ2, Harvard Service FFQ after week 12; HSFFQ3, Harvard Service FFQ at 28 gestational week.

Significance: *$P<0·05$; **$P<0·01$; ***$P<0·001$.

† Adjusted for total energy intake.

‡ Adjusted for total energy intake and corrected for random within-person variation.

against 24-h recall(15,16,21,25–27) analysing a total of twenty-six micronutrients. These assessment methods showed poor correlation for twelve micronutrients and acceptable correlation for eight other micronutrients, while six micronutrients showed a good correlation and therefore a good classification. Two different FFQ were validated against EDR(19,23). In these studies applying FFQ *v.* EDR, twenty-four micronutrients were analysed in which acceptable correlations were observed in twelve micronutrients, whereas another twelve micronutrients presented a good classification. Micronutrients with correlations $<0·3$ (poor) were not observed in any study. Additionally, three FFQ were validated against WDR, and a total of fourteen micronutrients were analysed(13,14,22). These assessment methods showed poor correlations only for Na and acceptable correlations for eight micronutrients, while five micronutrients showed a good correlation and therefore a good classification. It should be noted that micronutrients with correlations $>0·7$ (very good) were not observed in any study. Comparison of different dietary assessment methods in pregnant women by vitamins and minerals is presented in Fig. 2. This figure shows that EDR used as the reference method for evaluating FFQ present better correlations for several micronutrients than other methods in these population groups.

Table 4. Validation studies in pregnant women: vitamins

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
Vitamin A			
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·33† Week 28 diet recalls HSFFQ3 0·25† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·56 (0·39, 0·69)‡ Week 28 diet recalls HSFFQ3 0·35 (0·19, 0·50)‡	Mean of week 12 recalls (SD): 2912·7 µg (7274) Mean of HSFFQ2 (SD): 3180·6 µg (5001) Mean of week 28 recalls (SD): 3577·8 µg (9178) Mean of HSFFQ3 (SD): 3282·9 µg (4962)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·38 Energy adjusted 0·07 Deattenuated (95 % CI): 0·12 (−0·25, 0·46)	Mean estimated intake (SD) 24HR: 1891·56 (1712·52) µg PFFQ: 3739·11 (2600·52) µg
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 1692 µg retinol (1142) 24HR: 1413 µg retinol (1088)
Suitor *et al.* (1989)(27) USA (4·5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·12 Adjusted (95 % CI): 0·15 (−0·14, 0·42)	Mean (SD) Diet recalls: 1966·5 (1638·3) µg PFFQ: 3618·6 (2592) µg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·44 Energy adjusted 0·30 Attenuation and energy adjusted 0·37	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 70
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·46 Deattenuated density 0·70 Observed 0·28 Observed density§ 0·41	Mean (SD) IU 4-d WDR: 3637·5 (3560·7) FFQ: 3657·9 (2218·8)
Rondó *et al.* (1999)(2) Brazil (3)	FFQ *v.* BM	Spearman CC 0·11	Mean level of vitamin A in plasma was 1·71 µmol/l (SD = 0·59); Mean value for the FFQ score was 484·31 (SD = 117·88)
Retinol			
Brantsaeter *et al.* (2007)(13) Norway (5)	FFQ *v.* WDR	Spearman CC 0·32**	Median dietary intake
	FFQ *v.* BM	Spearman CC Plasma retinol‖ 0·12	FFQ: 950 µg/d
	WDR *v.* BM	Spearman CC Plasma retinol‖ 0·08	WDR: 820 µg/d
Mikkelsen *et al.* (2006)(14) Denmark (4·5)	FFQ *v.* WDR	Spearman CC Diet 0·27** Supplement 0·53*** Total intake 0·37**	Mean estimated intake Diet: FFQ-25: 708 µg/d; WDR: 642 µg/d; % classified into the same or adjacent quintile: 56 % Supplements: FFQ-25: 551 µg/d; WDR: 498 µg/d Total intake: FFQ-25: 1258 µg/d; WDR: 1143 µg/d; % classified into the same or adjacent quintile: 65 %
	FFQ *v.* BM	Spearman CC Plasma retinol −0·03	
	WDR *v.* BM	Spearman CC Plasma retinol −0·008	
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·09	Mean estimated intake FFQ: 369·2 µg 24HR: 276·8 µg % classified into the same quintile: 55·3 %
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·41 Energy adjusted 0·19 Deattenuated (95 % CI) 0·31 (0·03, 0·54)	Mean estimated intake (SD) 24HR: 735·72 (584·25) µg PFFQ: 1512·18 (1265·28) µg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·64 Energy adjusted 0·68 Attenuation and energy adjusted 0·71	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 68
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·34 Energy adjusted 0·41 Food only + supplement Crude 0·40 Energy adjusted 0·46	Median (25th and 75th centiles) µg FFQ: 898 (688, 1147) EDR: 678 (486, 900)

Table 4. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
β-Carotene			
Brantsaeter *et al.* (2007)[13] Norway (5)	FFQ *v.* WDR	Spearman CC 0·34**	Median dietary intakes FFQ: 2010 μg/d WDR: 1700 μg/d
	FFQ *v.* BM	Spearman CC Plasma‖ 0·16	
	WDR *v.* BM	Spearman CC Plasma β-carotene‖ 0·32**	
Mouratidou *et al.* (2006)[15] UK (4)	FFQ *v.* 24HR	Pearson CC 0·26**	Mean estimated intake FFQ: 1228 μg 24HR: 1287·6 μg % classified into the same quintile: 52·8 %
Wei *et al.* (1999)[21] USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·28 Energy adjusted 0·08 Deattenuated (95 % CI) 0·15 (−0·27, 0·52)	Mean estimated intake (SD) 24HR: 1155·81 (1502·94) μg PFFQ: 2226·93 (1858·62) μg
Erkkola *et al.* (2001)[19] Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·41 Energy adjusted 0·44 Attenuation and energy adjusted 0·53	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 77
Vitamin D			
Brantsaeter *et al.* (2007)[13] Norway (5)	FFQ *v.* WDR	Spearman CC 0·61**	Median dietary intake FFQ: 8·8 μg/d WDR: 7·8 μg/d
	FFQ *v.* BM	Spearman CC Plasma 25(OH)D‖ 0·45**	
	WDR *v.* BM	Spearman CC Plasma 25(OH)D‖ 0·51**	
Anderson *et al.* (1988)[28] USA (2)	DH *v.* BM	Pearson CC 0·072	Mean (SD) DH: 20·45 (7·425) μg ergocalciferol/d BM: 14 (8) ng/ml
Mouratidou *et al.* (2006)[15] UK (4)	FFQ *v.* 24HR	Pearson CC 0·20*	Mean estimated intake FFQ: 2·7 μg 24HR: 1·6 μg % classified into the same quintile: 61 %
Erkkola *et al.* (2001)[19] Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·32 Energy adjusted 0·39 Attenuation and energy adjusted 0·44	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 63
Robinson *et al.* (1996)[23] UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·32 Energy adjusted 0·37 Food only + supplement Crude 0·36 Energy adjusted 0·41	Median (25th and 75th centiles) μg FFQ: 2·8 (2·1, 3·6) EDR: 2·0 (1·3, 2·8)
Brown *et al.* (1996)[22] USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·59 Deattenuated density 0·49 Observed 0·45 Observed density§ 0·34	Mean (SD) μg ergocalciferol 4-d WDR: 9·3 (3·375) FFQ: 9·475 (3·95)
Vitamin E			
Brantsaeter *et al.* (2007)[13] Norway (5)	FFQ *v.* WDR	Spearman CC 0·45**	Median dietary intake FFQ: 18·3 mg/d WDR: 18·3 mg/d
	FFQ *v.* BM	Spearman CC Plasma tocopherol‖¶ 0·10	
	WDR *v.* BM	Spearman CC Plasma tocopherol‖¶ 0·12	
Mouratidou *et al.* (2006)[15] UK (4)	FFQ *v.* 24HR	Pearson CC 0·20*	Mean estimated intake FFQ: 4·3 mg 24HR: 5 mg % classified into the same quintile: 61 %
Baer *et al.* (2005)[16] USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·37† Week 28 diet recalls HSFFQ3 0·34† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·52 (0·38, 0·64)‡	Mean of week 12 recalls (SD): 17 mg (9) Mean of HSFFQ2 (SD): 13 mg (5) Mean of week 28 recalls (SD): 16 mg (7) Mean of HSFFQ3 (SD): 13 mg (4)

Table 4. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
		Week 28 diet recalls HSFFQ3 0·44 (0·28, 0·58)‡	
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·46 Energy adjusted 0·39 Deattenuated (95 % CI) 0·80 (−0·45, 0·99)	Mean estimated intake (SD) 24HR: 10·2 (11·5) mg PFFQ: 11·6 (13·4) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·19 Energy adjusted 0·19 Attenuation and energy adjusted 0·22	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 65
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·30 Energy adjusted 0·41 Food only + supplement Crude 0·36 Energy adjusted 0·46	Median (25th and 75th centiles) mg FFQ: 6·3 (5·0, 7·8) EDR: 4·8 (3·3, 6·4)
Thiamin			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·22*	Mean estimated intake FFQ: 1·5 mg 24HR: 1·2 mg % classified into the same quintile: 57·7 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·41† Week 28 diet recalls HSFFQ3 0·38† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·50 (0·37, 0·61)‡ Week 28 diet recalls HSFFQ3 0·52 (0·37, 0·65)‡	Mean of week 12 recalls (SD): 3 mg (2) Mean of HSFFQ2 (SD): 3 mg (1) Mean of week 28 recalls (SD): 3 mg (1) Mean of HSFFQ3 (SD): 3 mg (1)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·46 Energy adjusted 0·44 Deattenuated (95 % CI) 0·76 (0·08, 0·96)	Mean estimated intake (SD) 24HR: 2·0 (1·0) mg PFFQ: 2·3 (1·1) mg
Erkkola *et al.* (2001(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·49 Energy adjusted 0·70 Attenuation and energy adjusted 0·74	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 70
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·35 Energy adjusted 0·50 Food only + supplement Crude 0·40 Energy adjusted 0·56	Median (25th and 75th centiles) mg FFQ: 1·9 (1·5, 2·2) EDR: 1·4 (1·1, 1·7)
Riboflavin			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·33**	Mean estimated intake FFQ: 1·3 mg 24HR: 1·1 mg % classified into the same quintile: 61·8 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·51† Week 28 diet recalls HSFFQ3 0·44† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·61 (0·49, 0·71)‡ Week 28 diet recalls HSFFQ3 0·56 (0·42, 0·68)‡	Mean of week 12 recalls (SD): 4 mg (2) Mean of HSFFQ2 (SD): 4 mg (1) Mean of week 28 recalls (SD): 4 mg (1) Mean of HSFFQ3 (SD): 4 mg (1)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·49 Energy adjusted 0·38 Deattenuated (95 % CI) 0·60 (0·20, 0·83)	Mean estimated intake (SD) 24HR: 2·7 (1·3) mg PFFQ: 3·2 (1·5) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·23 Energy adjusted 0·50 Attenuation and energy adjusted 0·57	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 81
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·44 Energy adjusted 0·55	Median (25th and 75th centiles) mg FFQ: 2·2 (1·8, 2·7) EDR: 1·6 (1·2, 2·1)

Table 4. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
		Food only + supplement Crude 0·48 Energy adjusted 0·58	
Niacin			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC Niacin 0·20* Potential niacin −0·16	Mean estimated intake Niacin: FFQ: 18·5 mg; 24HR: 13·3 mg; % classified into the same quintile: 49·6 % Potential niacin: FFQ: 14·3 mg; 24HR: 11·2 mg; % classified into the same quintile: 58·5 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·37† Week 28 diet recalls HSFFQ3 0·32† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·50 (0·35, 0·62)‡ Week 28 diet recalls HSFFQ3 0·45 (0·39, 0·58)‡	Mean of week 12 recalls (SD): 36 mg (11) Mean of HSFFQ2 (SD): 33 mg (12) Mean of week 28 recalls (SD): 36 mg (11) Mean of HSFFQ3 (SD): 34 mg (10)
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·33 Energy adjusted 0·55 Attenuation and energy adjusted 0·60	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 64
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·31 Energy adjusted 0·42 Food only + supplement Crude 0·36 Energy adjusted 0·47	Median (25th and 75th centiles) mg FFQ: 20·8 (16·7, 25·4) EDR: 16·7 (13·0, 20·3)
Vitamin B$_6$			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·27**	Mean estimated intake FFQ: 2 mg 24HR: 1·4 mg % classified into the same quintile: 62·6 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·43† Week 28 diet recalls HSFFQ3 0·41† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·53 (0·40, 0·64)‡ Week 28 diet recalls HSFFQ3 0·52 (0·37, 0·64)‡	Mean of week 12 recalls (SD): 4 mg (2) Mean of HSFFQ2 (SD): 4 mg (1) Mean of week 28 recalls (SD): 4 mg (1) Mean of HSFFQ3 (SD): 4 mg (1)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·46 Energy adjusted 0·35 Deattenuated (95 % CI) 0·62 (0·25, 0·83)	Mean estimated intake (SD) 24HR: 2·0 (1·1) mg PFFQ: 2·8 (1·4) mg
Suitor *et al.* (1989)(27) USA (4·5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·42 Adjusted (95 % CI) 0·50 (0·24, 0·70)	Mean (SD) Diet recalls: 2·06 (1·16) mg PFFQ: 2·46 (1·49) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·33 Energy adjusted 0·61 Attenuation and energy adjusted 0·66	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 74
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·34 Energy adjusted 0·46 Food only + supplement Crude 0·40 Energy adjusted 0·50	Median (25th and 75th centiles) mg FFQ: 2·2 (1·8, 2·7) EDR: 1·7 (1·3, 2·1)
Vitamin B$_{12}$			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·09	Mean estimated intake FFQ: 3·5 μg 24HR: 2·4 μg % classified into the same quintile: 56·9 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls	Mean of week 12 recalls (SD): 8 mcg (4) Mean of HSFFQ2 (SD): 8 mcg (4)

Table 4. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
		HSFFQ2 0·40† Week 28 diet recalls HSFFQ3 0·31† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·53 (0·37, 0·67)‡ Week 28 diet recalls HSFFQ3 0·46 (0·30, 0·60)‡	Mean of week 28 recalls (SD): 9 mcg (4) Mean of HSFFQ3 (SD): 9 mcg (4)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·35 Energy adjusted 0·03 Deattenuated (95 % CI) 0·07 (−0·42, 0·53)	Mean estimated intake (SD) 24HR: 7·5 (6·2) mcg PFFQ: 12·1 (12·4) mcg
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 4·7 μg (2·6) 24HR: 2·8 μg (2)
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·23 Energy adjusted 0·33 Attenuation and energy adjusted 0·38	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 72
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·42 Energy adjusted 0·42 Food only + supplement Crude 0·43 Energy adjusted 0·44	Median (25th and 75th centiles) μg FFQ: 5·5 (4·1, 7·3) EDR: 3·8 (2·6, 4·9)
Folate			
Brantsaeter *et al.* (2007)(13) Norway (5)	FFQ *v.* WDR	Spearman CC 0·32**	Median dietary intakes FFQ: 290 μg/d WDR: 200 μg/d
	FFQ *v.* BM	Spearman CC serum folate‖ 0·26** erythrocyte folate 0·11	
	WDR *v.* BM	Spearman CC serum folate‖ 0·57** erythrocyte folate 0·30**	
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·29**	Mean estimated intake FFQ: 229·2 μg 24HR: 179·7 μg % classified into the same quintile: 59·3 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·45† Week 28 diet recalls HSFFQ3 0·45† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·57 (0·44, 0·67)‡ Week 28 diet recalls HSFFQ3 0·55 (0·40, 0·66)‡	Mean of week 12 recalls (SD): 840 mcg (358) Mean of HSFFQ2 (SD): 929 mcg (350) Mean of week 28 recalls (SD): 888 mcg (372) Mean of HSFFQ3 (SD): 936 mcg (302)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·61 Energy adjusted 0·46 Deattenuated (95 % CI) 0·86 (−0·16, 0·99)	Mean estimated intake (SD) 24HR: 317·8 (219·9) mcg PFFQ: 461·9 (296·2) mcg
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 248·6 μg (109·3) 24HR: 207·5 μg (128·6)
Greeley *et al.* (1992)(26) USA (3·5)	FFQ *v.* 24HR	Pearson CC Second trimester 0·39 Third trimester 0·48	Second trimester Mean 24-h recall: 224 mcg/d Mean mWFFQ: 341 mcg/d Third trimester Mean 24-h recall: 245 mcg/d Mean mWFFQ: 343 mcg/d
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·32 Energy adjusted 0·39 Attenuation and energy adjusted 0·48	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 69
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only	Median (25th and 75th centiles) μg FFQ: 304 (247, 373) EDR: 205 (156, 266)

Table 4. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
		Crude 0·37 Energy adjusted 0·52 Food only + supplement Crude 0·41 Energy adjusted 0·55	
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·56 Deattenuated density 0·78 Observed 0·38 Observed density§ 0·46	Mean (SD) mg 4-d WDR: 363 (180) FFQ: 350 (249)
Folic acid			
Mikkelsen *et al.* (2006)(14) Denmark (4·5)	FFQ *v.* WDR	Spearman CC Diet 0·35** Supplement 0·56*** Total intake 0·53***	Mean estimated intake Diet: FFQ-25: 334 μg/d; WDR: 361 μg/d; % classified into the same or adjacent quintile: 74 % Supplements: FFQ-25: 241 μg/d; WDR: 242 μg/d Total intake: FFQ-25: 816 μg/d; WDR: 840 μg/d; % classified into the same or adjacent quintile: 77 %
	FFQ *v.* BM	Spearman CC Erythrocyte folic acid 0·55***	
	WDR *v.* BM	Spearman CC Erythrocyte folic acid 0·52***	
Pantothenic acid			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·24**	Mean estimated intake FFQ: 3·5 mg 24HR: 3 mg % classified into the same quintile: 61 %
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·47 Energy adjusted 0·57 Attenuation and energy adjusted 0·60	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 74
Biotin			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·09	Mean estimated intake FFQ: 18·2 μg 24HR: 18·7 μg % classified into the same quintile: 59·3 %
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·37 Energy adjusted 0·46 Attenuation and energy adjusted 0·50	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 72
Vitamin C			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·42**	Mean estimated intake FFQ: 73·9 mg 24HR: 74·6 mg % classified into the same quintile: 62·6 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·49† Week 28 diet recalls HSFFQ3 0·31† Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·64 (0·49, 0·75)‡ Week 28 diet recalls HSFFQ3 0·40 (0·24, 0·54)‡	Mean of week 12 recalls (SD): 192 mg (94) Mean of HSFFQ2 (SD): 227 mg (109) Mean of week 28 recalls (SD): 189 mg (84) Mean of HSFFQ3 (SD): 220 mg (88)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·41 Energy adjusted 0·36 Deattenuated (95 % CI) 0·54 (0·26, 0·73)	Mean estimated intake (SD) 24HR: 138·6 (122·9) mg PFFQ: 244·9 (162·3) mg
Greeley *et al.* (1992)(26) USA (3·5)	FFQ *v.* 24HR	Pearson CC Second trimester 0·48 Third trimester 0·52	Second trimester Mean 24-h recall: 113 mg/d Mean mWFFQ: 169 mg/d Third trimester Mean 24-h recall: 118 mg/d Mean mWFFQ: 170 mg/d

Table 4. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
Suitor *et al.* (1989)(27) USA (4·5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·56 Adjusted (95 % CI) 0·67 (0·43, 0·82)	Mean (SD) Diet recalls: 134 (109) mg PFFQ: 183 (147) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10d EDR	Pearson CC Unadjusted 0·47 Energy adjusted 0·61 Attenuation and energy adjusted 0·65	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 74
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·38 Energy adjusted 0·44 Food only + supplement Crude 0·38 Energy adjusted 0·44	Median (25th and 75th centiles) mg FFQ: 122 (84, 169) EDR: 65 (37, 103)
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·57 Deattenuated density 0·73 Observed 0·39 Observed density§ 0·45	Mean (SD) mg 4-d WDR: 135 (78) FFQ: 155 (87)

24HR, 24-h recall; CC, correlation coefficient; HSFFQ2, Harvard Service FFQ after week 12; HSFFQ3, Harvard Service FFQ at 28 gestational week; EDR, estimated dietary records; WDR, weighed dietary records; BM, biomarker; 25(OH)D, 25-hydroxyvitamin D; PFFQ, pregnancy FFQ; mWFFQ, modified Willett FFQ.
Significance: * $P<0.05$; ** $P<0.01$; *** $P<0.001$.
† Adjusted for total energy intake.
‡ Adjusted for total energy intake and corrected for random within-person variation.
§ Density refers to nutrients per 4184 kJ (1000 kcal).
|| Supplement and non-supplement users.
¶ Sum of plasma α-and γ-tocopherols.

Moreover, these studies were classified according to which reference method was used and categorised into short-term intake, long-term intake or BM. Ten studies were classified into group 1 with a reference method that reflected short-term intake, in which six applied 24-h recalls(15,16,21,25–27), two used WDR(13,22), one applied EDR(23) and one utilised a diet history (DH)(17). Likewise, two other studies were classified into group 2 where the reference method reflected long-term intake (one WDR(14) and one EDR(19)). Finally, in group 3, where dietary methods were validated against BM, seven studies were found(2,13,14,18,20,24,28). Some articles presented validations of more than one instrument(13,14).

The FFQ was the main dietary method, which had been validated in fifteen studies. Accordingly, Fig. 3 shows only validation of FFQ studies that assessed *n*-3 fatty acids and micronutrient intake in pregnant women using a short-term(13,15,16,21–23,25–27) or a long-term(14,19) dietary assessment instrument or BM as a reference method(2,13,14,18,20,24). In regards to the reference method that reflected short-term intake, very good correlations were observed for vitamins E and B_6. However, when the reference method used reflected long-term intake, very good correlations were observed only for thiamin. Additionally, BM used as reference methods presented good correlations for folic acid. FFQ validation studies that assessed micronutrient intake in pregnant women, including(13,23,27) or not including(15,16,21,22,25,26) dietary supplements, using short-term dietary instruments as the reference method are presented in Fig. 4. When the reference method used reflected short-term intake and the FFQ that were being validated included dietary supplements, poor correlation was observed only for vitamin A.

Validated dietary methods

Of the seventeen articles included in the present review, fifteen different FFQ had been validated(2,13–16,18–27). Some articles presented validation of more than one instrument, of which two studies also validated WDR(13,14). A dietary history has been validated in one study(28), and a Fe checklist had been validated in another for assessing dietary Fe intake of pregnant women(17). Six studies collected information on dietary supplements. All FFQ were designed to capture usual diet; however, the time period covered ranged from habitual diet in the last month (five studies), the last 2 months (one study), the last 3 months (two studies), the last 4 months (one study) or the last 12 months (one study). This information was not specified in five studies. One study developed an Fe checklist for assessing dietary Fe intake of pregnant women, whereas the remaining studies included a wide range of items (55–360 food items) in the questionnaire. The frequency categories reported ranged from three to ten. Six studies developed self-administered FFQ to assess dietary intake during pregnancy and in another five studies, the FFQ were completed by an interviewer.

Reference methods used

Ten studies were classified into group 1 with a reference method that reflected short-term intake, in which six applied 24-h recalls(15,16,21,25–27), two used WDR(13,22), one applied EDR(23) and another a DH(17). Likewise, another two studies were classified into group 2 where the reference method reflected long-term intake (one WDR(14) and one EDR(19)).

Table 5. Validation studies in pregnant women: minerals

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
Na			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·07	Mean estimated intake FFQ: 2417 mg 24HR: 2311 mg % classified into the same quintile: 58·5 %
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·37 Energy adjusted 0·09 Deattenuated (95 % CI) 0·35 (−0·09, 0·68)	Mean estimated intake (SD) 24HR: 3704·9 (1466·9) mg PFFQ: 3357·5 (1402·1) mg
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 808·2 mg (1369) 24HR: 2320 mg (1495)
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·35 Energy adjusted 0·54 Attenuation and energy adjusted 0·59	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 65
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·21 Deattenuated density 0·17 Observed 0·15 Observed density† 0·09	Mean (SD) mg 4-d WDR: 3694 (755) FFQ: 2106 (678)
K			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·15	Mean estimated intake FFQ: 2532 mg 24HR: 2179 mg % classified into the same quintile: 58·5 %
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·58 Energy adjusted 0·27 Deattenuated (95 % CI) 0·38 (0·13, 0·59)	Mean estimated intake (SD) 24HR: 3191·9 (1404·2) mg PFFQ: 4124·6 (2004·8) mg
Ca			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·12	Mean estimated intake FFQ: 715·2 mg 24HR: 654·1 mg % classified into the same quintile: 59·3 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·52‡ Week 28 diet recalls HSFFQ3 0·39‡ Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·67 (0·53, 0·77)§ Week 28 diet recalls HSFFQ3 0·48 (0·33, 0·60)§	Mean of week 12 recalls (SD): 1320 (560) Mean of HSFFQ2 (SD): 1387 (566) Mean of week 28 recalls (SD): 1364 (639) Mean of HSFFQ3 (SD): 1464 (502)
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 1008 mg (543·6) 24HR: 770·6 mg (410·4)
Greeley *et al.* (1992)(26) USA (3·5)	FFQ *v.* 24HR	Pearson CC Second trimester 0·19 Third trimester 0·48	Second trimester Mean 24-h recall: 1140 mg/d Mean mWFFQ: 1419 mg/d Third trimester Mean 24-h recall: 1366 mg/d Mean mWFFQ: 1479 mg/d
Suitor *et al.* (1989)(27) USA (4·5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·60 Adjusted (95 % CI) 0·71 (0·48, 0·84)	Mean (SD) Diet recalls: 1195 (495) mg PFFQ: 1393 (716) mg
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·57 Energy adjusted 0·39 Deattenuated (95 % CI) 0·55 (0·26, 0·75)	Mean estimated intake (SD) 24HR: 1268·0 (643·1) mg PFFQ: 1559·0 (810·8) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·36 Energy adjusted 0·49 Attenuation and energy adjusted 0·58	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 75

Table 5. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·41 Energy adjusted 0·51 Food only + supplement Crude 0·41 Energy adjusted 0·50	Median (25th and 75th centiles) mg FFQ: 1197 (946, 1498) EDR: 884 (659, 1132)
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·49 Deattenuated density 0·57 Observed 0·34 Observed density† 0·38	Mean (SD) mg 4-d WDR: 1349 (414) FFQ: 1363 (431)
Mg			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·37**	Mean estimated intake FFQ: 235·2 mg 24HR: 188·4 mg % classified into the same quintile: 63·4 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·35‡ Week 28 diet recalls HSFFQ3 0·39‡ Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·45 (0·30, 0·58)§ Week 28 diet recalls HSFFQ3 0·50 (0·35, 0·62)§	Mean of week 12 recalls (SD): 290 mg (117) Mean of HSFFQ2 (SD): 257 mg (101) Mean of week 28 recalls (SD): 291 mg (105) Mean of HSFFQ3 (SD): 271 mg (98)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·60 Energy adjusted 0·33 Deattenuated (95 % CI) 0·46 (0·20, 0·66)	Mean estimated intake (SD) 24HR: 304·9 (125·6) mg PFFQ: 354·1 (153·6) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·21 Energy adjusted 0·39 Attenuation and energy adjusted 0·44	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 76
P			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·18**	Mean estimated intake FFQ: 1153 mg 24HR: 916·2 mg % classified into the same quintile: 58·5 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·45‡ Week 28 diet recalls HSFFQ3 0·36‡ Deattenuated Pearson CC (95 % CI) Week 12 diet recalls HSFFQ2 0·63 (0·45, 0·75)§ Week 28 diet recalls HSFFQ3 0·46 (0·30, 0·59)§	Mean of week 12 recalls (SD): 1473 mg (521) Mean of HSFFQ2 (SD): 1485 mg (572) Mean of week 28 recalls (SD): 1475 mg (517) Mean of HSFFQ3 (SD): 1565 mg (537)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·56 Energy adjusted 0·43 Deattenuated (95 % CI) 0·57 (0·28, 0·77)	Mean estimated intake (SD) 24HR: 1646·2 (665·2) mg PFFQ: 1946·7 (816·1) mg
Fe			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·32**	Mean estimated intake FFQ: 11·2 mg 24HR: 8 mg % classified into the same quintile: 61 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·42‡ Week 28 diet recalls HSFFQ3 0·44‡ Deattenuated Pearson CC (95 % CI) Week 12 diet recalls	Mean of week 12 recalls (SD): 55 mg ((27) Mean of HSFFQ2 (SD): 58 mg (23) Mean of week 28 recalls (SD): 61 mg (30) Mean of HSFFQ3 (SD):

Table 5. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
		HSFFQ2 0·51 (0·38, 0·62)§ Week 28 diet recalls HSFFQ3 0·51 (0·38, 0·63)§	59 mg (21)
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·37 Energy adjusted 0·36 Deattenuated (95 % CI) 0·68 (−0·03, 0·93)	Mean estimated intake (SD) 24HR: 16·9 (11·0) mg PFFQ: 17·1 (9·4) mg
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 24·2 mg (12·1) 24HR: 15 mg (9·5)
Greeley *et al.* (1992)(26) USA (3·5)	FFQ *v.* 24HR	Pearson CC Second trimester 0·22 Third trimester 0·56	Second trimester Mean 24-h recall: 13 mg/d Mean mWFFQ: 16 mg/d Third trimester Mean 24-h recall: 13 mg/d Mean mWFFQ: 17 mg/d
Suitor *et al.* (1989)(27) USA (4·5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·43 Adjusted (95 % CI) 0·55 (0·26, 0·76)	Mean (SD) Diet recalls: 16·5 (9·2) mg PFFQ: 18·0 (12·5) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·30 Energy adjusted 0·56 Attenuation and energy adjusted 0·60	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 65
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·27 Energy adjusted 0·39 Food only + supplement Crude 0·36 Energy adjusted 0·50	Median (25th and 75th centiles) mg FFQ: 15·0 (12·2, 18·6) EDR: 10·1 (7·9, 12·4)
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·67 Deattenuated density 0·70 Observed 0·36 Observed density† 0·35	Mean (SD) mg 4-d WDR: 17·9 (6·7) FFQ: 15·3 (9·6)
Zhou *et al.* (2005)(17) Australia (4·5)	Checklist *v.* DH	Food only: 0·69 (*P*< 0·001) Food + dietary supplements: 0·99 (*P*< 0·001)	Mean (SD) mg/d Food only: Checklist: 16 (7); DH: 16 (5) Food + dietary supplements: Checklist: 46 (59); DH: 47 (58)
Cu			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·008	Mean estimated intake FFQ: 1·1 mg 24HR: 0·9 mg % classified into the same quintile: 58·5 %
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·31 Energy adjusted 0·28 Attenuation and energy adjusted 0·32	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 71
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·26 Energy adjusted 0·35 Food only + supplement Crude 0·27 Energy adjusted 0·36	Median (25th and 75th centiles) mg FFQ: 1·3 (1·1, 1·6) EDR: 1·0 (0·8, 1·2)
Zn			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·19*	Mean estimated intake FFQ: 7·8 mg 24HR: 6·2 mg % classified into the same quintile: 55·3 %
Baer *et al.* (2005)(16) USA (7)	FFQ *v.* 24HR	Pearson CC Week 12 diet recalls HSFFQ2 0·43‡ Week 28 diet recalls HSFFQ3 0·48‡ Deattenuated Pearson CC (95 % CI) Week 12 diet recalls	Men of week 12 recalls (SD): 28 mg (11) Mean of HSFFQ2 (SD): 30 mg (11) Men of week 28 recalls (SD): 30 mg (13) Mean of HSFFQ3 (SD): 31 mg (10)

Table 5. *Continued*

Author/year of publication/ country/(quality index)	Methods	Correlation between methods	Other statistics
		HSFFQ2 0·53 (0·40, 0·64)§ Week 28 diet recalls HSFFQ3 0·60 (0·46, 0·72)§	
Wei *et al.* (1999)(21) USA (5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·50 Energy adjusted 0·45 Deattenuated (95 % CI) 0·90 (−0·91, 1·00)	Mean estimated intake (SD) 24HR: 13·1 mg (7·5) PFFQ: 15·2 mag (8·3)
Forsythe *et al.* (1994)(25) USA (2)	FFQ *v.* 24HR	Not specified	Mean (SD) FFQ: 10·5 mg (3·9) 24HR: 8·3 mg (4·1)
Suitor *et al.* (1989)(27) USA (4·5)	FFQ *v.* 24HR	Pearson CC Unadjusted 0·46 Adjusted (95 % CI) 0·56 (0·30, 0·74)	Mean (SD) Diet recalls: 12·0 (4·6) mg PFFQ: 13·1 (6·7) mg
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·44 Energy adjusted 0·42 Attenuation and energy adjusted 0·45	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 73
Robinson *et al.* (1996)(23) UK (4)	FFQ *v.* 4-d EDR	Spearman CC Food only Crude 0·32 Energy adjusted 0·42 Food only + supplement Crude 0·33 Energy adjusted 0·43	Median (25th and 75th centiles) mg FFQ: 10·1 (8·1, 11·8) EDR: 8·0 (6·3, 10·0)
Brown *et al.* (1996)(22) USA (4)	FFQ *v.* 4-d WDR	Spearman CC Deattenuated 0·60 Deattenuated density 0·40 Observed 0·41 Observed density† 0·21	Mean (SD) mg 4-d WDR: 13·3 (5·5) FFQ: 13·7 (4·6)
Mn			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC 0·40**	Mean estimated intake FFQ: 1·8 mg 24HR: 2·1 mg % classified into the same quintile: 66·7 %
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·36 Energy adjusted 0·47 Attenuation and energy adjusted 0·52	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 66
Se			
Mouratidou *et al.* (2006)(15) UK (4)	FFQ *v.* 24HR	Pearson CC −0·03	Mean estimated intake FFQ: 39·9 μg 24HR: 36·4 μg % classified into the same quintile: 49·6 %
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·13 Energy adjusted 0·40 Attenuation and energy adjusted 0·46	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 62
Iodine			
Brantsaeter *et al.* (2007)(13) Norway (5)	FFQ *v.* WDR	Spearman CC 0·48**	Median dietary intake FFQ: 138 μg/d WDR: 133 μg/d
	FFQ *v.* BM	Spearman CC Urine iodine excretion‖ 0·42**	
	WDR *v.* BM	Spearman CC Urine iodine excretion‖ 0·52**	
Mouratidou *et al.* (2006)(14) UK (4)	FFQ *v.* 24HR	Pearson CC −0·03	Mean estimated intake FFQ: 79·2 μg 24HR: 82·8 μg % classified into the same quintile: 52·8 %
Erkkola *et al.* (2001)(19) Finland (4·5)	FFQ *v.* 10-d EDR	Pearson CC Unadjusted 0·24 Energy adjusted 0·44 Attenuation and energy adjusted 0·51	Overall proportion categorised in the same or an adjacent quintile of food record quintile (%) 65

24HR, 24-h recall; EDR, estimated dietary records; WDR, weighed dietary records; BM, biomarker; PFFQ, Pregnancy FFQ; HSFFQ2, Harvard Service FFQ after the week 12; HSFFQ3, Harvard Service FFQ at 28 gestational week.

Significance: * $P<0·05$; ** $P<0·01$; *** $P<0·001$.

† Density refers to nutrients per 4184 kJ (1000 kcal).

‡ Adjusted for total energy intake.

§ Adjusted for total energy intake and corrected for random within-person variation.

‖ Supplement and non-supplement users.

Dietary records (DR) varying in the number of recording days (from 4 to 10 d) were used as the reference method in a total of five studies. The number of repeated 24-h recalls ranged from two to six, which were administered in person or by telephone.

Biomarkers

A total of seven publications analysed BM(2,13,14,18,20,24,28), which were used to validate six FFQ and one DH. Some articles presented validation of more than one instrument, of which two studies also validated WDR using BM as reference methods(13,14). The BM analysed were: erythrocyte sum *n*-3, α-linolenic acid, DHA and EPA in erythrocyte cell membranes; plasma retinol; plasma 25-hydroxyvitamin D concentration (this is a sensitive marker of medium- to long-term vitamin D availability from both dietary and endogenous sources); plasma β-carotene; plasma tocopherol; erythrocyte folic acid; serum folate; erythrocyte folate concentrations (these reflect tissue stores and are a long-term indicator than serum folate); urine iodine excretion.

Discussion

In the present review, seventeen studies(2,13–28) are described. The aim of this analysis was to determine the reliability of methods used to measure the usual intake of vitamins and minerals in pregnant women and how these were validated. The different studies included in the present review were classified according to which reference method was used, those reflecting short-term intake, long-term intake or BM. To rate the different studies, a quality score system was developed by the EURRECA network. A total score was calculated according to the weighted mean of the correlations that had been adjusted by the quality of the different validation studies, and all methods were scored into the categories: poor; acceptable; good; very good. Assessing dietary intake in pregnant women is complicated due to various factors that are dependent on the period of gestation. Poor correlation between instruments may be partly explained by appetite fluctuations and nausea, which may also influence those methods assessing long-term intake(29).

Short-term intake

Ten studies were classified in group 1 with a reference method that reflected short-term intake, in which six applied 24-h recalls(15,16,21,25–27), two used WDR(13,22) and one applied an EDR(23). A DH was used as the reference method in only one study(17). Different FFQ were validated for which wide variations in the number of food items were observed (55–360 items). Mouratidou *et al.* (15) used a sixty-two-item FFQ that yielded higher energy and macronutrients intakes except for alcohol. Highly significant correlations were demonstrated by these authors for most nutrients, from 0·19 for added sugar and Zn to 0·47 for fibre. For most nutrients, positive correlations between the two methods were observed; however, this was not the case for retinol and biotin. In the present study, the percentage of participants classified into the same quintile ranged from 49·6 % for Se and niacin to 66·7 % for Mn. The results of Baer *et al.* (16) indicated that the Harvard Service FFQ has similar validity during the first and second trimester, as shown by the average deattenuated correlation coefficients of 0·48 and 0·47 for week 12 and week 28 in FFQ compared to the 24-h recalls. These correlations are comparable to those observed among other groups of pregnant women(19,21,22,27). Suitor *et al.* (27) examined the validity of the Harvard Service FFQ for the assessment of total energies and seven nutrients (protein, Ca, Fe, Zn, vitamins A, B_6 and C) among ninety-five low-income pregnant women, comparing intakes estimated from the FFQ to those estimated from three 24-h recalls. With the exception of vitamin A, all of the deattenuated correlation coefficients for nutrient intakes were $>0{\cdot}50$. Wei *et al.* (21) extended these results in the same group of women by examining the validity of the Harvard Service FFQ for the assessment of seventeen additional nutrients; they reported a mean deattenuated correlation of 0·47, with correlations ranging from 0·03 for vitamin B_{12} to 0·90 for Zn. In general, there was good agreement for many nutrients when comparing nutrient intakes assessed in a population of pregnant women by FFQ and 24-h recalls. However, overestimation in the intake of some nutrients was observed when determined by the FFQ than when determined by 24-h recalls. The effects of certain limitations of the 24-h recall method, e.g. reliance on memory and high day-to-day variation, might have been decreased by the collection of more than two dietary recalls(15).

Robinson *et al.* (23) observed that the FFQ estimates of nutrient intake were higher when compared with the 4-d EDR. This may be the result of the standard portion sizes used in the FFQ being too large, of over-reporting of the frequency of consumption of foods in the FFQ, or of under-reporting of foods consumed in records, both in amount and in frequency. Good agreement between the FFQ and 4-d WDR regarding dietary supplement use and total intake estimates was found by Brantsaeter *et al.* (13). In Brown *et al.* (22), 4-d WDR were also used to estimate dietary intake, but 4 d for each period were likely to be insufficient to capture a representative estimate of nutrient intake that has large day-to-day variability. Repeated measures of dietary intake would have allowed for greater control of within-person variability and improved comparative correlations(22).

Zhou *et al.* (17) represents the only validation study of a single nutrient checklist designed to assess Fe intake in pregnant women. There was no difference in mean Fe intake reported in the DH and the Fe checklist, and there were good correlations between Fe intakes estimated from both methods. The correlation was strengthened when the contribution of Fe from supplements was included. Other validation studies of FFQ in pregnant women were designed for multiple nutrient assessments(15,16,19,23,26,27), and they reported low correlations for Fe (*r* 0·39–0·60) between FFQ and DR(19,23) or between FFQ and 24-h recall (*r* 0·32–0·56)(15,16,26,27). Other studies reported comparable correlations for Fe (*r* 0·67) between FFQ and DR(22), or between FFQ and 24-h recall (*r* 0·68)(21). A simple assessment tool, such as an Fe checklist to identify pregnant women with low-Fe intake that need further assessment and appropriate intervention, could be useful for clinical practice and in research for assessing Fe intake of groups in large-scale studies.

Table 6. Classification of the dietary assessment methods utilised for studies in pregnant women according to the quality weighted mean of the correlations for each micronutrient

	FFQ *v.* 24HR	FFQ *v.* EDR	FFQ *v.* WDR	FFQ *v.* BM	WDR *v.* BM	DH *v.* BM	Checklist *v.* DH
Good 0·51–0·70	*n*-3 fatty acids, folate, thiamin, riboflavin, Fe, Zn	Retinol, β-carotene, thiamin, riboflavin, niacin, vitamins B_6, C, pantothenic acid, Na, Ca, Mn, iodine	Vitamins D, C, folic acid, Fe, Zn	Folic acid	Vitamin D		Fe
Acceptable 0·30–0·50	Vitamins E, B_6, C, niacin, Ca, Mg, P, Mn	*n*-3 fatty acids, vitamins A, D, E, B_{12}, folate, biotin, Mg, Fe, Cu, Zn, Se	*n*-3 fatty acids, vitamins A, E, retinol, β-carotene, folate, Ca, iodine	*n*-3 fatty acids, vitamin D, iodine	*n*-3 fatty acids, β-carotene, folate, folic acid, iodine		
Poor <0·30	Vitamins A, D, B_{12}, retinol, β-carotene, pantothenic acid, biotin, Na, K, Cu, Se, iodine		Na	Vitamins A, E, retinol, β-carotene, folate	Retinol, vitamin E	Vitamin D	

24HR, 24-h recall; EDR, estimated dietary records; WDR, weighed dietary records; BM, biomarker; DH, diet history.

Long-term intake

Likewise, another two studies were classified into group 2, where the reference method reflected long-term intake (one EDR(14) and one WDR(19)). Mikkelsen *et al.* (14) analysed FFQ against 7-d WDR and showed that correlation between the two dietary methods was *r* 0·39 for protein intake, whereas other studies had found higher correlations(19,22,23). In Mikkelsen's study, when the women were classified into quintiles of protein intake estimated from the FFQ, a significant increasing trend in intake estimated from 7-d WDR was observed. Significant correlations ranging from 0·35 to 0·56 were found by these authors when comparing the two dietary methods, and the highest correlations were found for folic acid from dietary supplements. In a study of 113 Finnish women in their third trimester of pregnancy, Erkkola *et al.* (19) obtained an average deattenuated correlation coefficient of 0·53 for forty-five nutrients assessed by a 181-item FFQ and two 5-d EDR. These authors observed that the intake of food and nutrients was higher as determined by FFQ than intake assessed using two 5-d EDR. Earlier validation studies conducted in pregnant women have reported similar overestimates using FFQ compared with DR or 24-h recalls(23,25–27). Overestimation may reflect difficulties in comparing the standard portion size offered with the portion that is actually consumed. The use of a DR is likely to have the least correlated errors as this method does not depend on memory (recorded after each meal). In contrast, the major sources of error with FFQ are due to restrictions imposed by memory and perception of portion sizes.

Biomarkers

Anderson *et al.* (28) showed the correlation between maternal dietary history of vitamin D intake and maternal serum 25-hydroxyvitamin D levels. These results presented poor classification and weak correlation between the two assessment methods (*r* 0·072). Other validation studies in pregnant women reported better correlations for vitamin D (*r* 0·45)(13) between FFQ and BM or between WDR and BM (*r* 0·51)(13).

On the other hand, six FFQ(2,13,14,18,20,24) were validated against BM. These assessment methods presented poor correlations for five nutrients, acceptable correlations for three nutrients and only one nutrient presented a good correlation (folic acid, *r* 0·55 for total folic acid). Rondó *et al.* (2) compared plasma concentrations of vitamin A in 710 women after delivery with a simplified FFQ that included fifty-five food items and observed poor correlations between methods (*r* 0·11). There were very few studies comparing vitamin A intake, as reported on a FFQ with the corresponding biochemical indicator of vitamin A status. In countries where vitamin A deficiency is not a public-health problem, plasma carotenoids showed a higher statistically significant correlation with dietary questionnaires (although weak) than plasma levels of retinol(30–32). Dietary intake of *n*-3 PUFA estimated from five different FFQ(13,14,18,20,24) was validated against fatty acids in serum, plasma or erythrocytes. The best correlation was observed in the study by Rifas-Shiman *et al.* (20) comparing the dietary intake of fatty acids from a modified version of the Willett

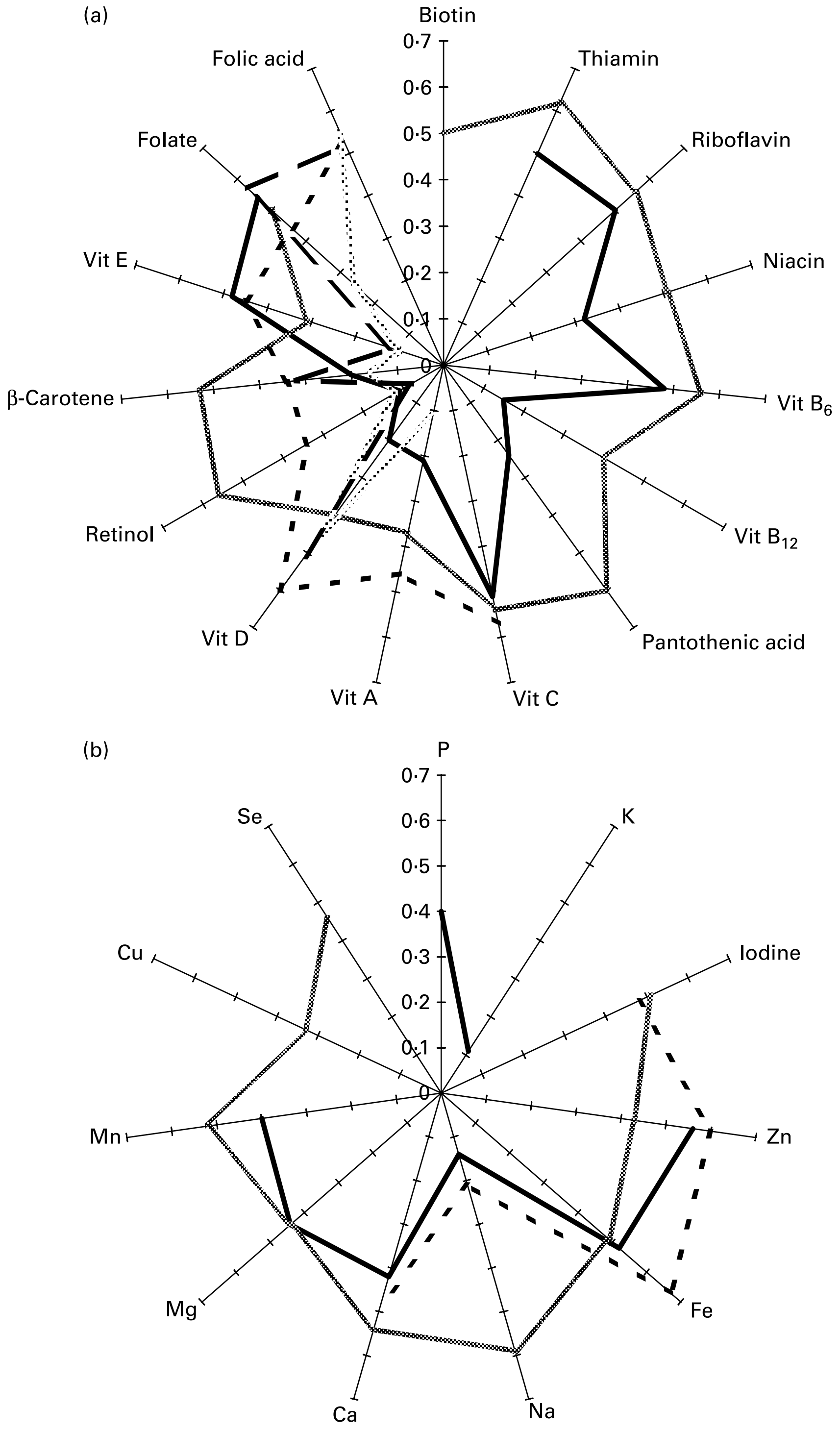

Fig. 2. Comparison of different dietary assessment methods in pregnant women by vitamins and minerals. Vit, Vitamin; EDR, estimated dietary records; WDR, weighed dietary records; 24HR, 24-h recall; BM, biomarker; DH, diet history. (a) ▬, FFQ *v.* 24HR; ▨, FFQ *v.* EDR; – –, FFQ *v.* WDR; ░, FFQ *v.* BM; ▬, WDR *v.* BM; ▨, DH *v.* BM. (b) ▬, FFQ *v.* 24HR; ▨, FFQ *v.* EDR; – –, FFQ *v.* WDR; ░, FFQ *v.* BM; ▬, WDR *v.* BM; ▨, checklist *v.* BM.

semi-quantitative food frequency questionnaire with blood levels of fatty acids (*r* 0·98). The Pearson correlation coefficients observed in Parra *et al.*(18) among α-linolenic acid, DHA and EPA in erythrocytes against crude dietary concentration were 0·32, 0·35 and 0·36, respectively. After adjustment for total energy intake, these correlations remained similar. The present study showed that the FFQ is adequate to identify the highest and lowest quartiles of *n*-3 fatty acid intake among pregnant women. A correlation coefficient of 0·32 for α-linolenic acid is relatively high

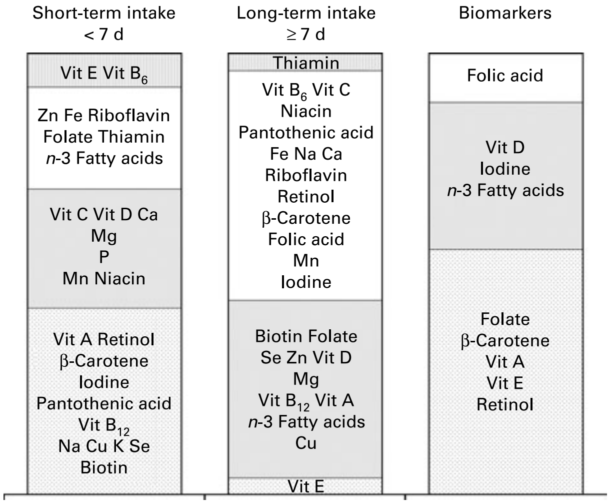

Fig. 3. Validation of FFQ studies that assess *n*-3 fatty acids and micronutrient intake in pregnant women using as reference method: short-term or long-term dietary instruments or biomarkers. ⊡, Poor $<$0·30; ▨, acceptable 0·30–0·50; ⧅, good 0·51–0·70; ▤, very good $>$0·70. Correlation coefficients weighted by diet quality score.

compared with findings from other observational studies correlating biochemical markers to estimated dietary intake. In a similar analysis, Olsen *et al.*(24) reported a correlation coefficient of 0·02 for α-linolenic acid. Mikkelsen *et al.*(14) observed that the estimated intake of *n*-3 fatty acids from the FFQ (r 0·37, $P<$0·001) was significantly correlated with erythrocyte EPA. Moreover, there was no correlation between total intake and plasma retinal, and the intake estimated from the FFQ did not correlate with protein excretion (however, one 24-h urine sample is a short-term BM of intake), whereas total folic acid intake was significantly correlated with erythrocyte folic acid level. Brantsaeter *et al.*(13) demonstrated a strong association between BM concentration/excretion and self-reported intake of those nutrients as calculated from the FFQ. A major strength of the present study was that it included BM that reflected long-term as well as short-term intakes. Poor correlations were found between 4-d WDR and plasma concentrations of retinol and tocopherol, and plasma concentrations did not differ between supplement and non-supplement users for tocopherol. This is in agreement with studies in pregnant as well as non-pregnant populations(33). Seasonal differences in the correlations between vitamin D intake and BM concentration found in Brantsaeter's study(13) were similar to those described in non-pregnant populations(31,34). Likewise, the calculated folate intake was more strongly correlated with serum folate than with erythrocyte folate. In other population studies, serum folate has also been found to be strongly correlated with intake(31).

Additionally, two WDR were validated against BM(13,14), and these assessment methods showed poor correlation for two nutrients (retinol and vitamin E) and acceptable correlation for five nutrients, whereas protein and vitamin D presented a good classification. Blood sampling and 24-h urine collections were done close to when DR were conducted, so a stronger association between the DR and BM than between FFQ and BM could be expected, at least for BM with a relatively short elimination time. In this manner, Brantsaeter *et al.*(13) observed a stronger association between erythrocyte *n*-6:*n*-3 fatty acid ratio and dietary intake *n*-6:*n*-3 fatty acid ratio for the FFQ than for the 4-d WDR, indicating that the FFQ reflects true long-term intake better than 4-d WDR.

Conclusion

The aim of the present review was to determine the reliability of methods used to measure the usual intake of vitamins and minerals in pregnant women and to evaluate how these were validated. When comparing different validation methods, the FFQ presents better correlations when EDR are used as the reference method. The FFQ administered to pregnant women showed a wide variety of included food items, ranging from 55 to 360. The frequency categories reported were from three to ten. Further research is needed to clarify the optimal number of food items and frequency categories to be included in questionnaires targeting this population group. FFQ appeared to be the most reliable for measuring short-term intakes of vitamins E and B6 and short- and long-term intakes of thiamin. They were also good for measuring short-term intakes of Zn, Fe, riboflavin and folate, and long-term intakes of vitamins B$_6$, C, niacin, pantothenic acid, Fe, Na, Ca, riboflavin, retinol, β-carotene, folic acid, Mn and iodine. For *n*-3 fatty acids, the best ranking was observed when analysing FFQ applying short-term reference methods (r 0·51) than when BM (r 0·41) were used as reference methods. When frequency methods were used for assessing micronutrient intake, the inclusion of dietary supplements improved their reliability for most nutrients, except for vitamin A ($r<$ 0·3). When FFQ methods were used for assessing folic acid intake, similar correlations were observed when both long-term intake (r 0·53) and BM (r 0·55) were used as reference methods. Both long-term intake and BM reference methods showed stronger correlations in folic acid intake (r 0·53 and 0·55, respectively) than in folate intake

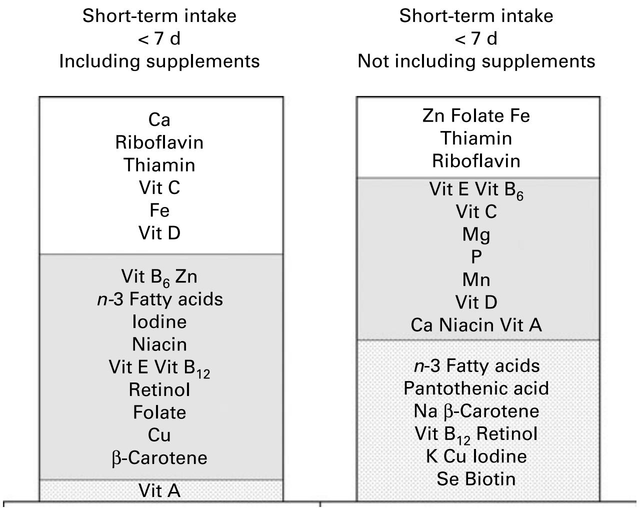

Fig. 4. Validation of FFQ studies that assess *n*-3 fatty acids and micronutrient intake in pregnant women, including or not including dietary supplements, using as reference method short-term dietary instruments. ⊡, Poor $<$0·30; ▨, acceptable 0·30–0·50; ⧅, good 0·51–0·70. Correlation coefficients weighted by diet quality score.

(r 0·48 and 0·26, respectively). The information on folic acid in dietary supplements is better defined than the folate content of the diet. Thus, it is crucial to take into account the use of dietary supplements. These are very popular, especially among pregnant women. Apart from folic acid, BM do not add any more certainty as to the reliability of intake methods. On comparing FFQ methods used for assessing micronutrient intake with long-term reference methods, acceptable or good correlations except for vitamin E were obtained. Intake of this vitamin correlated better with short-term daily intake ($r > 7$) rather than with long-term daily intake. Nelson *et al.* (35) estimated that the number of days required to rank vitamin E intake with desired precision was sixteen. In studies where the reference method reflected long-term intake, 7-d WDR or two 5-d EDR were applied. Repeated measures of dietary intake would have allowed for greater control of within-person variability and improved comparative correlations. The DR should cover at least four weekdays and one weekend day including information on the use of dietary supplements. The use of a booklet with pictures of common foods and mixed dishes is recommended to facilitate the estimation of portion sizes.

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