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Dietary assessment methods for intakes of iron, calcium, selenium, zinc and iodine

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The EURopean micronutrient RECommendations Aligned (EURRECA) Network of Excellence is working towards developing aligned micronutrient recommendations across Europe. The purpose of the present study was to conduct a review of methods used in validation studies carried out in adults assessing dietary intake of EURRECA priority minerals. A search strategy and inclusion criteria were defined and a scoring system was developed to rate the quality of each validation study that produced a quality index with possible scores obtained ranging from 0·5 to 7. A MEDLINE and EMBASE literature review was conducted. Articles/validation studies meeting the inclusion criteria included: 79/88 for Fe; 95/104 for Ca; 13/15 for Se; 29/30 for Zn; 7/9 for iodine. The most frequently used method to ascertain dietary intake was the Food Frequency Questionnaire (FFQ), whereas dietary records (DR) and 24 h recalls were the most used reference methods. The correlation coefficients (CC) between study mineral intakes estimated by FFQ and the reference method were weighted according to the study's quality index and obtained acceptable to good ratings, ranging from 0·36 to 0·60 when the reference method was DR and from 0·41 to 0·58 when the reference was 24 h recalls. A minority of studies (*n* 9) used biomarkers for validation and among these, five included iodine obtaining a CC of 0·47. The FFQ was seen as a valid method for assessing mineral intake, particularly for Ca and, to a lower extent, for iodine and Zn. Se and Fe showed only acceptable correlations. The present review provides new insights regarding the characteristics that assessment methods for dietary mineral intakes should fulfil.

Dietary assessment: FFQ: Validation: Minerals

Although various methods exist for estimating food and nutrient intake, not one of them is ideal. Identifying the best method of micronutrient intake assessment constitutes an important challenge for nutritional epidemiology. The role of diet and its association with the prevention and treatment of chronic diseases is well documented in the literature. However, assurance of a dietary instrument's ability to adequately assess intake remains a daunting task, primarily due to measurement errors and inter- and intraindividual variability of dietary intake(1–3).

The Food Frequency Questionnaire (FFQ) is commonly used in nutritional epidemiology, as it presents considerable advantages in terms of practicality and economy. However, the utility of FFQ may be limited due to poor design and inappropriate application(1–5). What is more, all other intake methods, such as dietary records (DR) and 24 h recalls (24HR), that are also utilised in epidemiological studies present limitations as well(3).

Validation studies measure the degree of association between a given intake method as compared with a reference method or 'more accurate' gold standard for intake assessment(4,6,7). The overriding concern for validation studies is to avoid flawed designs, especially in the choice of a method, which could lead to erroneous results and interpretations. In light of this, quality criteria are critically needed to assess the robustness of validation studies and their design.

The present work was conducted within the context of Research Activity 1.1, 'Intake methods' of the European Community's 'EURopean micronutrient RECommendations Aligned (EURRECA)' Network of Excellence, whose aim is to harmonise nutrient recommendations across Europe(8). Systematic literature reviews were carried out to identify the best methods for assessing vitamin and mineral intake in the general population as well as in targeted groups with potential for higher nutritional risk.

Abbreviations: CC, correlation coefficients; DR, dietary records; 24HR, 24 h recalls; UIE, urinary iodine excretion.

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The present article summarises the review of the literature targeting studies that validated the intake of EURRECA priority minerals: Fe; Ca; Se; Zn; iodine, with the purpose of ascertaining the most accurate method to assess mineral intake in the adult population.

Materials and methods

A MEDLINE and EMBASE search was conducted to identify validation studies on mineral intake assessment that were carried out between July 2007 and March 2008. The procedure for the identification and selection of articles incorporated the following three steps:

The first phase consisted of conducting a general and then a specific search.

The general search strategy was applied in all the reviews carried out as part of the Research Activity 1.1 on addressing intake validation methods. This did not specify study nutrients or target population groups. The search terms included: MeSH nutrient terms (‘nutritional assessment’, ‘diet’, ‘nutritional status’, ‘dietary intake’ or ‘food intake’); validity terms (‘validity’, ‘validation study’, ‘reproducibility’, ‘replication study’, ‘correlation coefficient’ or ‘correlation study’); human studies.

A mineral-specific search was conducted independent of the general search in the same databases applying the following terms: MeSH nutrient terms (Fe, Ca, Se, Zn, iodine and synonyms); intake terms (intake* or diet).

The second phase included the initial selection of articles based on the application of exclusion criteria. Titles and abstracts of the articles identified in the search were read by two independent reviewers. Articles were excluded only when both agreed that title/abstract met the given exclusion criteria. When a title/abstract could not be rejected with certainty, the full text of the article was obtained and further evaluated. The following exclusion criteria were applied:

(1) Articles exclusively assessing macronutrients and/or energy;
(2) Studies describing the content of foods in nutrients, additives or contaminants;
(3) Studies in diseased or institutionalised persons exclusively;
(4) Articles presenting reference values for food consumption, nutrient intake, biochemical markers and anthropometric measurements;
(5) Articles establishing associations between food consumption, nutrient intake, biological variables, biochemical markers and anthropometric measurements;
(6) Studies relating diseases to food consumption or nutrient intake;
(7) Intervention studies and other therapeutic studies with nutrients or drugs related to the metabolism of these nutrients;
(8) Calibration studies and those discussing statistical methods;
(9) Studies evaluating physiological effects of foods and nutrients in relation to their genetic determinants;
(10) Studies in animals;
(11) Studies in languages other than English, Spanish, French, Italian, Portuguese and German and those without abstracts in PubMed.

The third phase consisted of the final selection with one researcher applying the following inclusion criteria to articles from phase 2:

(1) Studies regarding validation results for mineral intake (those articles analysing only reproducibility or supplement use were excluded from the present analysis).
(2) Studies based on the adult population (those articles only evaluating children, adolescents, pregnant women or the elderly were excluded from the present analysis).

The full texts of all articles were screened for either definitive exclusion or data extraction by a different reviewer from the one involved in phase 2 of the selection process, with independent duplicate assessment of a random sample of 25 % by yet another reviewer. Where any two reviewers disagreed, the study was discussed and a consensus decision was reached where possible. If this was not possible then a third reviewer was asked to arbitrate.

The articles included in the present review were grouped into the following categories according to the reference method used and time frame applied:

Long-term intake. If the reference method was a dietary assessment method (including 24HR and estimated and weighed DR) applied for 7 or more days.

Short-term intake. If the reference method was a dietary assessment method (including 24HR and estimated and weighed DR) applied for <7 days.

Biomarker. If the reference method was a biomarker.

To assess the quality of the different validation studies, a quality score system was developed(9). The studies were scored taking into consideration their sample size, the statistics used in analysis, data collection procedures and the inclusion or not of seasonality and mineral supplement use (Table 1). The correlation coefficients (CC) obtained for each study were weighted according to the article’s quality index, with the aim of being able to compare results with those from other studies. The average weighted CC per study mineral was calculated, based on the weighted CC for each mineral, categorised by studies using the same method of mineral intake assessment and reference. This allowed for the comparison among different validation methods assessed over various studies for a given mineral(9).

Results

In phase 1 of the search, 5476 studies were identified. After applying exclusion criteria, 391 articles were selected, of which a final selection of 109 articles were identified after applying inclusion criteria. The number of articles analysing each of the minerals under study in the present review were: 79 for Fe (88 validation studies); 95 for Ca (104 validation studies); 13 for Se (15 validation studies); 29 articles for Zn (30 validation studies) and 7 for iodine (9 validation studies). A single article could include the validation of various minerals as well as different questionnaires or reference methods for the same mineral.

Most of the validation studies selected in the present review (all except ten) utilised FFQ as the intake assessment method and DR or 24HR as the reference method. Table 2 describes the numbers of studies employing FFQ for each mineral and

Table 1. Quality criteria to score validation studies on micronutrient intake

Variables	Specific variable	Score
1. Sample and sample size	Non-homogeneous sample (sex, SES, smoking and obesity)	0·5
	$n > 100$ ($n > 50$ for biomarkers)	0·5
2. Statistics		
Group level	Compare/test means or medians or differences	1·0
Correlations. Only one selected, that with the highest score	Correlation	0·5
	Adjusted correlations (energy, etc.)	1·0
	Deattenuated or intraclass correlations	1·5
Agreement	Classification or Bland & Altman plot	0·5
3. Data collection	Gathered by face-to-face interview	1·0
4. Seasonality	Considered	0·5
5. Supplements	Included and data considered in analysis	1·5

SES, Socioeconomic status.

the methods used as gold standards (DR or 24HR) for their validation. Tables 3–6 describe the studies included in the review according to the methods used: Table 3 included FFQ *v.* DR, Table 4 included FFQ *v.* 24HR, Table 5 included FFQ *v.* biomarkers; Table 6 included other methods. After categorising studies based on the type of reference method utilised, the weighted mean of the CC was calculated using the quality index value of each study(9). Table 7 and Fig. 1 summarise the study quality-weighted mean CC for each mineral, which also took into consideration whether the application of the reference method was short or long term. Mean CC for the FFQ ranged from 0·36 for Se to 0·60 for iodine when the reference method was the DR and from 0·41 for Zn to 0·58 for Ca when the reference method was 24HR. When using biomarkers as the reference method, only iodine was used to calculate the average CC (mean CC was 0·47), as both Se and Fe had only two studies each for their validation (Table 5). Table 6 shows validation studies that used other methods (for assessing intake and/or the reference method) than those previously classified in Tables 3–5. The CC obtained by other methods ranged from 0·48 for Fe to 0·53 for Ca. Most of the mean CC obtained in the present review were >0·40, reflecting an acceptable level of correlation.

The detailed descriptions of the studies included in the present review (Tables 3–6) reflect: the authors and year of publication; the population size (ranging from 10 to 2265 people); the age and sex (majority females); the characteristics of the FFQ (mode of administration, number of food items included in the questionnaire and reference period); the characteristics of the reference method (information on total number of days over which the reference method was applied); the use or not of supplements; the mineral which was analysed; the CC of each mineral (globally or by sex, and differentiated by FFQ1 and FFQ2 when the same FFQ was administered two times); the quality index. Tables 3–5 refer to a specific intake instrument that was applied as the reference method, when compared with the FFQ (Table 3 refers to dietary record; Table 4 refers to 24HR; Table 5 refers to biomarkers), Table 6 refers to a combination of other methods.

FFQ v. *dietary record*

The dietary record (DR) was used as the reference method in most of the validation studies included in the present review (Table 3). In the majority of cases, information regarding dietary intake was collected through a self-administered FFQ (79 %) to assess dietary intake in the previous year (57 %). The number of food items included in the questionnaire ranged from 10 to 630. The weighted CC varied slightly according to the number of food items (<100 or ≥100 food items) included in the FFQ (Fig. 2), being somewhat higher for FFQ with ≥100 food items. In the case of iodine, there were no articles identified in the present review having more than 100 food items.

Very few studies included the assessment of intake from mineral supplements in their analyses (32 %). However, no large differences were noted in the mean of weighted CC for the studies that did or did not include such information (Fig. 3). In this figure, evaluations of Se and iodine that assessed mineral supplement intake were not included due to the small number of studies identified for each mineral.

The mean CC of Zn, Fe and Se were higher when the reference method was a weighed DR compared with the use of an estimated DR. In contrast, mean CC for Ca were slightly higher with estimated DR than with weighed DR (Fig. 4). For iodine only, the mean CC of estimated DR was calculated as there were no articles applying a weighed DR.

Most of the DR used as reference methods collected dietary intake for 7 d or more (long-term intake; 65 % of the studies). Table 7 shows the differences for mean CC according to the number of days included in the DR (long- and short-term intake). Zn, Fe and Se (the latter with only two studies) presented higher mean CC with long-term rather than short-term application. There were no differences observed in the mean coefficient for Ca in both long- or short-term

Table 2. Distribution of studies validating FFQ according to the reference method utilised and study mineral

	Reference method			
	Dietary records		24 h recalls	
Mineral studied	Long-term intake	Short-term intake	Long-term intake	Short-term intake
Fe	36	16	10	15
Ca	40	21	8	16
Se	7	2	1	1
Zn	13	5	5	6
Iodine	0	3	0	1

Table 3. Description of validation studies that use Food Frequency Questionnaire to assess iron, calcium, selenium, zinc and iodine intake and dietary records as the reference method

Author, year	Sample (*n* sex)	Age (years)			FFQ administration method	Number of food items	FFQ reference period	Supplement use assessed	Reference method (number of records/ number of days per record)	Nutrient studied	Correlation coefficient	Quality Index of the study
		Mean	SD	Range								
Long-term intake												
Andersen *et al.*, 1999(17)	125 M			20–55	Self-administered	180	Unknown	Yes	DR weighed (5/3)	Fe	0·44*	4·0
										Ca	0·50*	
Bautista *et al.*, 2005(18)	45 W			20–40	Self-administered	60	1 year	No	DR weighed (1/7)	Fe	0·28†	2·5
	52 M									Ca	0·73†	
										Zn	0·64†	
Blalock *et al.*, 2003(19)	30			19–62	Self-administered	109	1 year	No	DR estimated (1/7)	Ca	0·57†	1·5
Block *et al.*, 1990(20)	102			45–70	Self-administered	94	6 months	Yes	DR estimated (3/4)	Fe	0·54†	3·5
										Ca	0·55†	
Block *et al.*, 1992(21)	85			25–50	Self-administered/ Interview	113	1 year	No	DR estimated (4/3) + 4 24 h Recalls	Fe	0·41†	2·5
										Ca	0·49†	
Block *et al.*, 1992(21)	85			25–50	Self-administered	98	1 year	No	DR estimated (4/3) + 4 24 h Recalls	Fe	0·48†	2·5
Bonifacj *et al.*, 1997(22)	68 W	42·4	12·3		Interviewer	134	1 year	No	DR weighed (4/7)	Fe	0·80‡	3·0
	30 M	40·8	10·6									
Brunner *et al.*, 2001(23)	403 W			39–61	Self-administered	127	1 year	No	DR estimated (1/7)	Fe	0·53 W§	3·5
	457 M										0·53 M§	
Cardoso *et al.*, 2001(24)	52 W			21–62	Self-administered	120	1 year	No	DR weighed (4/3)	Fe	0·67‖	3·5
										Ca	0·49†	
Chen *et al.*, 2004(25)	104 W			16–75	Interviewer	39	1 year	No	DR estimated (2/7)	Fe	0·28‖	5·5
	85 M									Ca	0·23‖	
										Se	0·34‖	
										Zn	0·30‖	
Date *et al.*, 2005(26)	85			30–69	Self-administered	40	1 year	No	DR weighed (4/3)	Fe	0·28§	2·5
										Ca	0·35§	
Decarli *et al.*, 1996(27)	265 W			30–69	Interviewer	77	1 year	No	DR weighed (1/7)	Fe	0·56‡	4·0
	130 M											
Egami *et al.*, 1999(28)	42 W			41–88	Self-administered	97	1 year	No	DR weighed (4/4)	Fe	FFQ_1 0·44‡/FFQ_2 0·42‡	2·5
	46 M									Ca	FFQ_1 0·70‡/FFQ_2 0·83‡	
										Zn	FFQ_1 0·53‡/FFQ_2 0·49‡	
Engle *et al.*, 1990(29)	34 W	49·3	9·6		Self-microcomputer	85	3 months	Yes	DR estimated (1/7)	Ca	0·53§	3·5
	16 M											
Friis *et al.*, 1997(30)	122 W			20–29	Self-administered	92	1 year	No	DR estimated (3/4)	Fe	FFQ_1 0·56‡/FFQ_2 0·59‡	2·5
										Ca	FFQ_1 0·59‡/FFQ_2 0·64‡	
										Zn	FFQ_1 0·49‡/FFQ_2 0·67‡	
Heath *et al.*, 2000(31)	49 W	22	3		Computerised	206	1 month	No	DR weighed (1/11)	Fe	0·52§	2·0
										Ca	0·36*	
Heath *et al.*, 2005(32)	49 M	<40			Computerised	630	1 month	No	DR weighed (4/3)	Fe	0·76*	2·0
										Ca	0·32*	
										Zn	0·75*	
Hodge *et al.*, 2000(33)	63 W			16–48	Self-administered	74	1 year	No	DR weighed (1/7)	Fe	0·51‡	3·5
										Ca	0·59‡	
										Zn	0·58‡	
Ishihara *et al.*, 2003(34)	176 W	58			Self-administered	180	Unknown	No	DR weighed (4/7)	Fe	0·51 W§/0·54 M§	3·0
	174 M	55								Ca	0·54 W§/0·65 M§	
										Se	0·18 W§/0·26 M§	
Jain *et al.*, 1996(35)	108 W			35–79	Self-administered	132	1 year	Yes	DR estimated (1/7)	Fe	0·30 W¶/0·19 M¶	4·5
	95 M									Ca	0·52 W¶/0·64 M¶	
Jain & McLaughlin, 2000(36)	108 W			35–79	Self-administered	132	1 year	Yes	DR estimated (1/7)	Fe	0·45 W‖/0·27 M‖	5·0
	95 M				Category based					Ca	0·42 W‖/0·47 M‖	
Karita *et al.*, 2003(37)	113 W	Adults			Self-administered	138	1 year	No	DR semi-weighed (4/7)	Se	0·26 W§/0·34 M§	4·0
	102 M											

Table 3. *Continued*

Author, year	Sample (*n* sex)	Age (years)			FFQ administration method	Number of food items	FFQ reference period	Supplement use assessed	Reference method (number of records/ number of days per record)	Nutrient studied	Correlation coefficient	Quality Index of the study
		Mean	SD	Range								
Kim *et al.*, 2002(38)	46 W	38·2	11·7		Self-administered	118	Unknown	No	DR weighed (1/7)	Fe	0·62‡	4·0
	23 M									Ca	0·63‡	
										Zn	0·64‡	
Lee *et al.*, 2006(39)	25 W				Interviewer	64	6 months	Yes	DR estimated (3/5)	Fe	FFQ_1 0·65‡/FFQ_2 0·71‡	5·0
	58 M									Ca	FFQ_1 0·46^5/FFQ_2 0·43‡	
MacIntyre *et al.*, 2001(40)	59 W			15–65	Self-administered	145	Unknown	No	DR weighed (1/7)	Fe	0·22*	1·0
	15 M									Ca	0·26*	
Männistö *et al.*, 1996(41)	152 W	51	9		Self-administered	110	1 year	Yes	DR estimated (2/7)	Fe	0·46**	4·0
Marks *et al.*, 2006(42)	59 W			25–75	Self-administered	129	6 months	Yes	DR weighed (6/2)	Fe	0·33 W§/0·47 M§	5·0
	37 M									Ca	0·61 W§/0·73 M§	
										Zn	0·50 W§/0·20 M§	
McKeown *et al.*, 2001(43)	88 W			45–74	Self-administered	130	1 year	Yes	DR estimated (2/7)	Fe	0·87 W‡/0·87 M‡	5·0
	58 M									Ca	0·78 W‡/0·70 M‡	
Montomoli *et al.*, 2002(44)	206 W			25–75	Self-administered	10	Unknown	Yes	DR estimated (1/14)	Ca	0·90†	5·0
Nagata *et al.*, 1998(45)	37			35–66	Self-administered	169	1 year	No	DR estimated (12/1)	Fe	0·31††/0·86‡‡‡	2·0
										Ca	0·65††/0·87‡‡‡	
Ogawa *et al.*, 2003(46)	58 W			45–77	Self-administered	40	1 year	Yes	DR estimated (4/3)	Fe	0·47 W‡/0·35 M‡	5·0
	55 M									Ca	0·67 W‡/0·57 M‡	
Patterson *et al.*, 1999(47)	113 W			50–79	Self-administered	122	3 months	Yes	DR estimated (1/4)	Fe	0·75‡	4·0
									+ 4 24 h Recalls	Ca	0·78‡	
									(phone)	Se	0·37‡	
										Zn	0·59‡	
Peitinen *et al.*, 1988(48)	190 M	59·9	4·0		Self-administered	276	1 year	No	DR estimated (12/2)	Ca	FFQ_1 0·73¶/FFQ_2 0·74¶	3·0
										Se	FFQ_1 0·50¶/FFQ_2 0·62¶	
										Zn	FFQ_1 0·69¶/FFQ_2 0·67¶	
Pietinen *et al.*, 1988(49)	190 M	59·9	4·0		Self-administered	44	1 year	No	DR estimated (12/2)	Se	FFQ_1 0·40‖/FFQ_2 0·44‖	3·0
Potosky *et al.*, 1990(50)	97 W			45–70	Self-administered	94	6 months	No	DR estimated (3/4)	Fe	0·48†	1·5
										Ca	0·60†	
Riboli *et al.*, 1997(51)	105 W			50–69	Self-administered	350	1 year	No	DR weighed (6/3)	Ca	FFQ_1 0·63 W‖/0·58 M‖	3·5
	101 M										FFQ_2 0·58 W‖/0·75 M‖	
										Se	FFQ_1 0·60 W‖/0·53 M‖	
											FFQ_2 0·59 W‖/0·56 M‖	
										Zn	FFQ_1 0·47 W‖/0·41 M‖	
											FFQ_2 0·51 W‖/0·25 M‖	
Rimm *et al.*, 1992(52)	127 M			40–75	Self-administered	131	1 year	Yes	DR weighed (2/7)	Fe	FFQ_1 0·41‡/FFQ_2 0·54‡	4·0
										Ca	FFQ_1 0·48‡/FFQ_2 0·61‡	
										Zn	FFQ_1 0·63‡/FFQ_2 0·71‡	
Sebring *et al.*, 2007(53)	341	38	11		Self-administered	124	1 year	Yes	DR estimated (1/7)	Ca	0·21†	3·5
Sebring *et al.*, 2007(53)	341	38	11		Self-administered	87	1 year	Yes	DR estimated (1/7)	Ca	0·33†	3·5
Sebring *et al.*, 2007(53)	341	38	11		Self-administered	25	1 week	Yes	DR estimated (1/7)	Ca	0·37†	3·5
Shimizu *et al.*, 1999(54)	20 W	59·7	10·9		Interviewer	169	1 year	No	DR estimated (1/12)	Ca	0·75 W‡	2·5
	17 M	53·8	11·2								0·78 M‡	
Tjonneland *et al.*, 1992(55)	85 W			40–64	Self-administered	92	–	No	DR estimated (2/7)	Fe	FFQ_1 0·48 W§§/0·56 M§§	2·5
	59 M										FFQ_2 0·47 W§§/0·50 M§§	
										Ca	FFQ_1 0·39 W§§/0·71 M§§	
											FFQ_2 0·38 W§§/0·72 M§§	
Tokudome *et al.*, 2001(56)	79 W	48	8		Self-administered	102	1 month	No	DR weighed (4/7)	Fe	0·52‡	3·5
										Ca	0·64‡	
										Zn	0·36‡	
Tsubono *et al.*, 2001(57)	58 W	61	8·5		Self-administered	141	1 year	Yes	DR estimated (4/3)	Fe	FFQ_1 0·30‡/FFQ_2 0·14‡	4·0
	55 M	62	8·5							Ca	FFQ_1 0·60‡/FFQ_2 0·42‡	

Table 3. *Continued*

Author, year	Sample (*n* sex)	Age (years)			FFQ administration method	Number of food items	FFQ reference period	Supplement use assessed	Reference method (number of records/ number of days per record)	Nutrient studied	Correlation coefficient	Quality Index of the study
		Mean	SD	Range								
Tsubono *et al.*, 2001[58]	107 W 94 M			40–59	Self-administered	44	1 month	Yes	DR estimated (4/7)	Fe	FFQ$_1$ 0·19 W‡/0·27 M‡ FFQ$_2$ 0·31 W‡/0·32 M‡	4·0
										Ca	FFQ$_1$ 0·44 W‡/0·42 M‡ FFQ$_2$ 0·39 W‡/0·57 M‡	
Tsugane *et al.*, 2003[59]	113 W 102 M	53·5 55·6	5·3 5·2		Self-administered	138	1 year	Yes	DR estimated (4/7 or 2/7)	Fe	0·32 W§/0·47 M§	4·5
										Ca	0·45 W§/0·51 M§	
Willett *et al.*, 1987[60]	29			20–54	Self-administered	116	1 year	No	DR weighed (1/365)	Fe	0·40‖‖	1·5
										Ca	0·57‖‖	
Short-term intake												
Baumgartner *et al.*, 1998[61]	132 W			35–74	Interviewer	140	1 month	No	DR estimated (1/4)	Ca	FFQ$_1$ 0·57‖/FFQ$_2$ 0·68‖	2·5
Chee *et al.*, 2002[62]	230 W			50–66	Interviewer	78	3 month	Yes	DR estimated (1/3)	Ca	0·56†	3·0
Fregapane & Asensio, 2000[63]	38			18–61	Self-administered	202	Unknown	No	DR weighed (1/4)	Fe	0·34§§	1·5
										Ca	0·68§§	
										Zn	0·30§§	
George *et al.*, 2004[64]	95 W	20·1	4·3		Self-administered	195	6 month	No	DR estimated (1/3)	Fe	0·32‡	3·5
										Ca	0·58‡	
										Zn	0·25‡	
George *et al.*, 2004[64]	50 W	23·1	4·3		Self-administered	195	6 month	No	DR estimated (1/4) + 2 24 h Recalls (interview)	Fe	0·41‡	3·5
										Ca	0·57‡	
										Zn	0·44‡	
Goulet *et al.*, 2004[65]	71 W			30–65	Interviewer	91	1 month	No	DR estimated (1/3)	Fe	0·53§	1·0
										Ca	0·56§	
Hartwell & Henry, 2001[66]	9 W 16 M	58·1	1·7		Self-administered	162	1 year	No	DR estimated (1/4)	Fe	0·64†	1·5
										Ca	0·63†	
Ke *et al.*, 2005[67]	100	Middle age			Self-administered	125	1 year	No	DR weighed (1/4)	Fe	0·36‖	3·0
										Ca	0·49‖	
										Zn	0·42‖	
										Se	0·35‖	
Kristal *et al.*, 1997[68]	1015 W			50–79	Self-administered	100	3 month	Yes	DR estimated (1/4)	Ca	FFQ$_1$ 0·54‖/FFQ$_2$ 0·53‖	3·5
Kumanyika *et al.*, 2003[69]	408 W			21–69	Self-administered	68	1 year	No	DR estimated (1/3) + 3 24 h Recalls (phone)	Fe	0·42‡/0·53‡	2·5
										Ca	0·32‡/0·58‡	
Longnecker *et al.*, 1993[70]	74 W 64 M	49	14		Self-administered	116	1 year	No	DR estimated (3/2)	Fe	FFQ$_1$ 0·43‡/FFQ$_2$ 0·52‡	2·5
										Ca	FFQ$_1$ 0·74‡/FFQ$_2$ 0·69‡	
Martínez *et al.*, 1999[71]	42 W 97 M	66·4			Self-administered	113	1 year	Yes	DR estimated (1/4 non consecutive)	Fe	FFQ$_1$ 0·57/FFQ$_2$ 0·39/ mean FFQ$_1$ − FFQ$_2$ 0·58‡**	4·0
										Ca	FFQ$_1$ 0·48/FFQ$_2$ 0·34/ mean FFQ$_1$ − FFQ$_2$ 0·54‡**	
Masson *et al.*, 2003[72]	40 W 41 M			19–58	Self-administered	150	2–3 months	No	DR weighed (1/4)	Fe	0·64 W‖/0·63 M‖	2·5
										Ca	0·78 W‖/0·52 M‖	
Moreira *et al.*, 2003[73]	246			18–29	Self-administered	89	1 year	No	DR estimated (1/4)	Iodine	0·75‖	2·5
Moreira *et al.*, 2003[73]	159 W 87 M			18–29	Interviewer	82	Unknown	No	DR estimated (1/4)	Fe	0·45 W‖/0·43 M‖	4·0
										Ca	0·61 W‖/0·53 M‖	
										Se	0·22 W‖/0·20 M‖	
										Zn	0·47 W‖/0·58 M‖	
Paalanen *et al.*, 2006[74]	157 W 137 M			30–79	Self-administered	128	1 year	No	DR estimated (1/3)	Fe	0·53 W‖/0·44 M‖	3·5
										Ca	0·53 W‖/0·46 M‖	
Parr *et al.*, 2002[75]	34 W 36 M			15–45	Interviewer	164	1 week	No	DR weighed (1/2)	Fe	0·35†	4·0
										Ca	0·19*	
Rasmussen *et al.*, 2001[76]	254 W			25–65	Self-administered	53	1 year	Yes	DR estimated (1/4)	Iodine	0·52	2·0
Rasmussen *et al.*, 2001[76]	254 W			25–65	Self-administered	53	1 year	No	DR estimated (1/4)	Iodine	0·49	2·0
Sasaki *et al.*, 1998[77]	47 W			38–69	Self-administered	110	1 month	No	DR estimated (1/3)	Fe	0·40‡	3·0

Table 3. *Continued*

Author, year	Sample (*n* sex)	Age (years)			FFQ administration method	Number of food items	FFQ reference period	Supplement use assessed	Reference method (number of records/ number of days per record)	Nutrient studied	Correlation coefficient	Quality Index of the study
		Mean	SD	Range								
Shimizu *et al.*, 1999(78)	59 W	5·97	10·9		Interviewer	169	1 year	No	DR estimated (1/3)	Ca	0·59 W‖/0·51 M‖	2·5
	58 M	53·8	11·2									
Tokudome *et al.*, 2005(79)	129 W			30–70	Self-administered	47	1 year	No	DR weighed (1/3)	Fe	0·44 W‡/0·58 M‡	4·0
	73 M									Ca	0·59 W‡/0·49 M‡	
Torheim *et al.*, 2001(80)	48 W			15–59	Self-administered	69	1 week	No	DR weighed/DR estimated (1/2)	Fe	0·40*	3·0
	27 M									Ca	0·37*	
Welten *et al.*, 1996(81)	87 W	13			Interviewer	61	1 month	No	Dietary history (1/1)	Ca	0·69 W/0·58 M	3·5
	77 M											
Xu *et al.*, 2000(82)	21 W	63·6	6·6		Interviewer	110	Unknown	No	DR estimated (1/4)	Ca	0·86§§	3·5

M, men; W, women; DR, dietary record; FFQ_1/FFQ_2 Repetition of the same questionnaire.
* Spearman crude.
† Pearson crude.
‡ Deattenuated and energy adjusted.
§ Spearman energy-adjusted.
‖ Pearson energy-adjusted.
¶ Intraclass and energy-adjusted.
** Triads method.
†† Low food diversity.
‡‡ High food diversity.
§§ Intraclass correlation coefficients.
‖‖ Pearson age, sex and energy-adjusted.

Table 4. Description of validation studies that use Food Frequency Questionnaire to assess iron, calcium, selenium, zinc and iodine intake and 24 h recalls as the reference method

		Age (years)												
Author, year	Sample (*n* sex)	Mean	SD	Range	FFQ administration method	Number of food items	FFQ reference period	Supplement use assessed	Number of recalls	Recall administration method	Weekend included	Nutrient studied	Correlation coefficient	Quality index of the study
Long-term intake														
Boeing *et al.*, 1997[83]	49 W			35–64	Self-administered	158	Unknown	No	Twelve within 1 year	Personal interview	Yes	Fe	0·69*	3·0
Hebert *et al.*, 1998[84]	30 W 30 M	43·2 52·6	13·6 10·9		Interviewer	81	1 year	No	Eight within 1 year	Personal interview	Yes	Fe Ca Zn	FFQ_1 0·55†/ FFQ_2 0·49† FFQ_1 0·50†/ FFQ_2 0·42† FFQ_1 0·33†/ FFQ_2 0·61†	2·0
Hernández *et al.*, 1998[85]	134 W	Unknown			Self-administered	85	Unknown	No	Sixteen within 1 year	Personal interview	Yes	Fe Ca Zn	FFQ_1 0·32*/ FFQ_2 0·36* FFQ_1 0·53*/ FFQ_2 0·60* FFQ_1 0·25*/ FFQ_2 0·29*	3·0
Jackson *et al.*, 2001[86]	40 W 33 M	45·4 46·0	13·5 15·3		Interviewer	70	Unknown	No	Twelve within 1 year	Personal interview	Yes	Fe Ca	FFQ_1 0·21‡/ FFQ_2 0·39‡ FFQ_1 0·25‡/ FFQ_2 0·40‡	3·0
Johansson *et al.*, 2001[87]	99 W 99 M			30–60	Self-administered	84	Unknown	No	Ten within 1 year	Phone interview	Yes	Fe Ca	0·03 W*/0·45 M* 0·51 W*/0·44 M*	2·5
Kabagambe *et al.*, 2001[88]	42 W 78 M	59	10		Interviewer	135	1 year	No	Seven within 7 months	Personal interview	Yes	Fe Ca Zn	0·46* 0·78* 0·38*	4·0
Katsouyanni *et al.*, 1997[89]	38 W 42 M			25–67	Self-administered	190	1 year	Yes	Twelve within 1 year	Personal interview	Yes	Fe Ca Zn	FFQ_1 0·18 W*/0·33 M* FFQ_2 0·29 W*/0·32 M* FFQ_1 0·60 W*/0·69 M* FFQ_2 0·54 W*/0·45 M* FFQ_1 0·31 W*/0·70 M* FFQ_2 0·38 W*/0·46 M*	4·0
Messerer *et al.*, 2004[90]	248 M			40–74	Self-administered	88	1 year	Yes	Fourteen within 1 year	Phone interview	Yes	Fe Ca Se Zn	0·38* 0·77* 0·75* 0·57*	4·5
Sevak *et al.*, 2004[91]	100 W	53·5	8·5		Interviewer	207	Unknown	No	Twelve within 12 months	Phone interview	Yes	Fe	0·60*	3·5
Van Liere *et al.*, 1997[92]	115 W			35–65	Self-administered	66	1 year	No	Twelve within 1 year	Personal interview	Yes	Fe Ca	0·63* 0·53*	4·0
Short-term intake														
Block *et al.*, 2006[93]	89	36·8			Interviewer	103	1 year	Yes	Three within 2 months	Personal interview		Fe Ca	0·54* 0·58*	4·5
Flagg *et al.*, 2000[94]	223 W 16 M	61			Self-administered	68	1 year	Yes	Four within 1 year	Personal interview	Yes	Fe Ca Zn	0·35 W*/0·28 M* 0·66 W*/0·57 M* 0·18 W*/0·14 M*	4·0
Fornés *et al.*, 2003[95]	62 W 42 M	38 27	32·5 23·3		Interviewer	127	Unknown	No	Six within 6 months	Personal interview	Yes	Fe Ca	FFQ_1 0·41*/ FFQ_2 0·35* FFQ_1 0·65*/ FFQ_2 0·49*	4·0
Hebert *et al.*, 1999[96]	30 W 30 M	36·1 31·4	9·7 7·7		Interviewer	92	1 year	No	Six within 1 year	Personal interview	Yes	Fe Ca Zn	FFQ_1 0·59*/ FFQ_2 0·73* FFQ_1 0·86*/ FFQ_2 0·89* FFQ_1 0·58*/ FFQ_2 0·72*	2·0

Table 4. *Continued*

		Age (years)												
Author, year	Sample (*n* sex)	Mean	SD	Range	FFQ administration method	Number of food items	FFQ reference period	Supplement use assessed	Number of recalls	Recall administration method	Weekend included	Nutrient studied	Correlation coefficient	Quality index of the study
Kumanyika *et al.*, 2003(97)	408 W			21–69	Self-administered	68	Unknown	Yes	Three within 1 year	Phone interview	Yes	Fe Ca	0·67* 0·79*	2·5
Kusama *et al.*, 2005(98)	62 W 56 M			23–62	Interviewer	116	3 months	No	Three within 3 months	Personal interview	Yes	Fe Ca	0·25* 0·16*	4·0
Navarro *et al.*, 2001(99)	62	57	14		Interviewer	127	5 years	No	Four within 3 months	Personal interview	Yes	Fe Ca	FFQ_1 0·75*/ FFQ_2 0·74* FFQ_1 0·86*/ FFQ_2 0·84*	4·0
Olafsdottir *et al.*, 2006(100)	53 W	36	5		Self-administered	130	3 months	Yes	Two within 1 month	Phone interview	Yes	Fe Ca	0·31† 0·37†	3·0
Osowski *et al.*, 2007(101)	47 W 34 M			17–74	Self-administered	138	1 year	Yes	Four within 1 year	Personal interview	Unknown	Ca	0·59§	4·5
Ribeiro *et al.*, 2006(102)	35 W 34 M	35·4	11·8		Interviewer	52	181 days	No	Three within 3 months	Personal interview	Unknown	Fe Ca Zn	0·58* 0·52* 0·50*	2·5
Rodríguez *et al.*, 2002(103)	30 W 43 M			22–55	Self-administered	52	3 months	No	Three within 1 month	Personal interview	Yes	Fe Ca	0·38* 0·84*	3·0
Segovia-Siapco *et al.*, 2007(104)	48 W 39 M			30–72	Self-administered	171	6 months	No	Six within 6 months	Phone interview	Yes	Fe Ca Zn	0·60* 0·70* 0·31*	3·0
Serra-Majem *et al.*, 1994(105)	155			18–74	Interviewer	56	1 year	No	One within in month	Interview	Yes	Fe Ca Zn Iodine	0·45‡ 0·61‡ 0·51‡ 0·79‡	4·0
Sevak *et al.*, 2004(106)	100 W	53·5	8·5		Interviewer	207	Unknown	No	Twelve within 1 year	Phone interview	Yes	Fe Ca	0·60* 0·55*	3·5
Sichieri & Everthart 1998(107)	46 W 42 M				Interviewer	61	1 year	No	Four within 2 months	Personal interview	Yes	Fe Ca	0·43† 0·55†	3·5
Sudha *et al.*, 2006(108)	68 W 34 M	40·9	12·8		Interviewer	222	1 year	Yes	Six within 1 year	Personal interview	Yes	Fe Ca Se Zn	FFQ_1 0·42*/ FFQ_2 0·44* FFQ_1 0·27*/ FFQ_2 0·35* FFQ_1 0·43*/ FFQ_2 0·42* FFQ_1 0·39*/ FFQ_2 0·47*	5·5

W, women; M, men; FFQ_1/FFQ_2 Repetition of the same questionnaire.
* Deattenuated and energy-adjusted.
† Pearson crude.
‡ Pearson energy-adjusted.
§ Spearman crude.

Table 5. Description of validation studies on iron, selenium or iodine intake using biomarkers as the reference method

Author, year	Sample (*n* sex)	Age (years) Mean	SD	Range	Intake method	Supplement use assessed	Biomarkers	Nutrient studied	Correlation coefficient	Quality index of the study
Karita *et al.*, 2003(37)	95 W 85 M	Adults			FFQ self-administered (138 foods)	No	Se serum Se erythrocyte	Se	−0·02 W*/0·16 M* 0·13 W*/0·15 M*	4·0
Karita *et al.*, 2003(37)	95 W 85 M	Adults			DR semi-weighed (4/7)	No	Se serum Se erythrocyte	Se	−0·04 W*/0·01 M* 0·11 W*/0·21 M*	4·0
Olafsdottir *et al.*, 2006(100)	53 W			31–41	FFQ self-administered (130 foods)	Yes	Serum ferritin	Fe	−0·23†	3·5
Olafsdottir *et al.*, 2006(100)	53 W	36	5		2 24 h recalls, Phone	Yes	Serum ferritin	Fe	0·19‡	3·5
Nelson *et al.*, 1987(109)	56 W			25–64	FFQ self-administered (<100 foods)	Yes	Urinary iodine excretion	Iodine	0·24†	3·5
Rasmussen *et al.*, 1999(110)	7 W 3 M			30–46	DR weighed (1/4)	No	Urinary iodine excretion	Iodine	0·46‡	2·5
Rasmussen *et al.*, 2001(76)	254 W			25–65	FFQ self-administered (53 Foods)	Yes	Urinary iodine excretion	Iodine	0·66‡	4·0
Rasmussen *et al.*, 2002(111)	108 W			25–65	DR weighed (1/4)	Yes	Urinary iodine excretion	Iodine	0·79‡	2·5
Brug *et al.*, 1992(112)	436 W 376 M	Adults			FFQ self-administered (<100 foods)	No	Urinary iodine excretion	Iodine	0·16	2·5

W, women; M, men; DR, dietary records.
* Spearman energy-adjusted.
† Pearson crude.
‡ Spearman crude.

administration. Iodine was excluded from this analysis, as there was only one article in the long-term category.

FFQ v. *24 h recall*

When the reference method was the 24HR, the information was more frequently collected through short-term (62 %) instead of long-term administration (Table 4). Differences in mean CC were observed for Fe (higher value with short-term application) but not for Ca and Zn (Table 7). The interview-administered FFQ (54 %) was more frequently applied than self-administered questionnaires. The number of food items included in the FFQ ranged from 52 to 222. Fig. 5 shows the mean CC according to the number of food items included in the FFQ; slightly higher values were observed for Ca and Zn when the number of foods in the FFQ was <100.

The proportion of studies in this reference category including information about mineral supplements (31 %) was similar to those using DR as the gold standard. Mean CC of Fe, Ca and Zn were higher without supplements (Fig. 6).

Biomarkers as reference method

The use of biomarkers as the reference methods was less frequently observed (Table 5). A total of nine validation studies utilised biomarkers; five for iodine and two each for Se and Fe. Five studies utilised FFQ to assess intake, three applied four weighed DR and one administered two 24HR. The mean CC for iodine when compared with biomarkers was 0·47, showing an acceptable correlation of $>0{\cdot}4$. Urinary iodine excretion (UIE) was used as the biomarker for iodine in all the articles. Two studies used serum and erythrocyte Se as the reference method for Se; and in two others, Fe intake was compared with serum ferritin.

Other methods

The classification of the others category included studies that employed the use of a diet assessment instrument that was not a ‘standard’ FFQ and/or non-standard reference methods (i.e. not applying DR, 24HR or biomarkers; Table 6). An example of studies in this category are those that utilised FFQ that were validated by weighed DR but used PETRA scales instead of the usual method of having subjects weigh food with subsequent recording in the DR. Such scales are accurate to ± 1 g and automatically record verbal descriptions and weights of food on a dual track cassette, thus, avoiding the necessity for subjects to keep written records. Moreover, these scales do not disclose the weights of foods eaten by the subject. Twenty validation studies comprised the others category: all of them except one analysed Ca; eight Fe; two Se; one Zn. Four of the studies in this category included the intake of mineral supplements in their analyses. When we compared the mean weighted CC for each mineral, a classification of ‘good’ was obtained for Ca (0·54) and Se (0·52, but only with two studies) and acceptable for Fe (0·48). Zn was excluded from the analysis as only one article was identified in the present review in the category of other methods.

Table 6. Description of studies validating intakes of iron, calcium and selenium that used methods for assessing intake/reference methods other than standard FFQ *v.* Dietary Records or 24 h recalls or biomarkers as the reference method

Author, year	Sample (*n* sex)	Age (years)			Intake method	Reference method	Supplement use assessed	Nutrients studied	Correlation coefficient	Quality index of the study
		Mean	SD	Range						
Bingham *et al.*, 1994(113)	106 W			50–65	FFQ self-administered (127 foods) Oxford	DR weighed (4/4) Using PETRA scales	No	Fe Ca	0·43* 0·50*	4·0
Bingham *et al.*, 1994(113)	106 W			50–65	FFQ self-administered (130 foods) Cambridge	DR weighed (4/4) Using PETRA scales	No	Fe Ca	0·26* 0·32*	4·0
Bingham *et al.*, 1994(113)	106 W			50–65	24 h recall structured	DR weighed (4/4) Using PETRA scales	No	Fe Ca	0·36* 0·57*	4·0
Bingham *et al.*, 1994(113)	106 W			50–65	DR estimated (1/7)	DR weighed (4/4) Using PETRA scales	No	Fe Ca	0·83* 0·67*	4·0
Bingham *et al.*, 1997(114)	127 W			50–65	FFQ	DR weighed (4/4) Using PETRA scales	Yes	Ca	0·50*	4·0
Bingham *et al.*, 1997(114)	146 W			50–65	24 h recall	DR weighed (4/4) Using PETRA scales	Yes	Ca	0·28*	4·0
Bingham *et al.*, 1997(114)	73 W			50–65	DR estimated (1/7)	DR weighed (4/4) Using PETRA scales	Yes	Ca	0·67*	4·0
Galasso *et al.*, 1994(115)	49 W			30–69	Four 24 h recall Telephone	Four 24 h recall Face to face interview	No	Ca	0·52†	1·5
Jain *et al.*, 1996(35)	108 W 95 M			35–79	Diet history interviewer	DR estimated (1/7)	No	Fe	0·38 W‡/0·48 M‡	4·5
Lasfargues *et al.*, 1990(116)	250 W 250 M			17–60	Short self-administered FFQ (NAQA)	Diet history	No	Ca	0·54 W†/0·58 M†	3·0
Lyu *et al.*, 1998(117)	158 W 167 M			45–74	FFQ Telephone	FFQ face-to-face interview	No	Ca	0·70 W§/0·68 M§	4·0
Matthys *et al.*, 2004(118)	50 W	31	6		Diet history, computerised	DR estimated (5/2)	No	Fe Ca	0·52* 0·45*	2·0
McNaughton *et al.*, 2005(119)	1149 W 1116 M	43			48 h recall Personal	DR estimated (1/5)	No	Fe Ca	0·58 W*/0·55 M* 0·65 W*/0·55 M*	2·0
Riboli *et al.*, 1997(51)	105 W 101 M			50–69	FFQ (130 foods) + DR estimated (1/14)	DR weighed (6/3)	No	Ca	FFQ$_1$ 0·65 W‖/0·55 M‖ FFQ$_2$ 0·73 W‖/0·70 M‖	3·5
								Se	FFQ$_1$ 0·22 W‖/0·44 M‖ FFQ$_2$ 0·44 W‖/0·46 M‖	
								Zn	FFQ$_1$ 0·31 W‖/0·57 M‖ FFQ$_2$ 0·44 W‖/0·58 M‖	
Sato *et al.*, 2005(120)	74 W			15–79	FFQ (26 foods)	DR weighed (1/1)	No	Ca	0·51†	2·5
Schaffer *et al.*, 1997(121)	190			30–79	Short FFQ Phone interviewer	Longer FFQ face-to-face interview (69 items)	No	Ca Se	0·75¶ 0·75¶	2·0
Smith *et al.*, 1996(122)	302 W 273 M			18–74	Diet history, interviewer	24 h recall	No	Fe Ca	0·44 W*/0·55 M* 0·36 W*/0·49 M*	3·0
Takatsuka *et al.*, 1997(123)	18 W 13 M	47·6 44·2			Simplified diet history questionnaire. FFQ (31 items)	DR estimated (12/1)	No	Ca	0·69‖	2·0
Ward *et al.*, 2004(124)	76 W			17–21	Calcium rapid assessment method	DR (1/6)	Yes	Ca	0·42‖§	3·5
Welten *et al.*, 1995(125)	160			27–29	Quantitative dairy questionnaire	Diet history	No	Ca	0·64†	2·5

W, women; M, men; DR, dietary record.

* Spearman crude.

† Pearson crude.

‡ Intraclass and energy-adjusted.

§ Intraclass correlation coefficients.

‖ Pearson energy-adjusted.

¶ Pearson age, sex and energy-adjusted.

Table 7. Mean of weighted correlation coefficients according to reference method used in FFQ validation studies for each study mineral

	Reference method					
	Dietary records			24 h recalls		
	Long-term intake	Short-term intake	All	Long-term intake	Short-term intake	All
Fe	0·49	0·45	0·48	0·45	0·48	0·45
Ca	0·55	0·55	0·55	0·58	0·57	0·57
Se	0·39	0·27*	0·36			0·57
Zn	0·52	0·40	0·49	0·44	0·41	0·42
Iodine		0·60	0·60			0·79†

* Only two studies.
† Only one study.

Discussion

In the validation of methods used for intake assessment, it is essential to verify if the method of interest approximates 'true intake' to the greatest extent possible. All intake methods present limitations, and as such, it is necessary to analyse bias or variables that could lead to misleading results. Therefore, a large number of possible study design errors should be controlled, as they can cause bias in validation studies. To deal with the quality of micronutrient intake validation, a quality index was developed, which considered important points for design of the validation studies such as: homogeneity of the sample; sample size; statistical analysis; interviewer administration; seasonality; supplement use (Table 1)(9). The quality index was the total sum of the points reaching a maximum of 7 points. In the present review, the quality index score ranged from 3·2 for other methods and DR to 3·5 for 24HR. When we compare this to the analysis conducted on vitamins, the quality index scores were of the same magnitude(10). Despite the fact that the quality index scores obtained in the present review did not by any means approximate the maximum score, this analysis shows the importance of applying such an index, which can be applied for quality control and guidance in the design of validation studies.

In general, FFQ validation is usually conducted by comparing data obtained with those derived from DR or 24HR. The present review shows that FFQ were the most commonly used method for assessing dietary mineral intake in epidemiological studies. The same was found in the analyses of the vitamin reviews(10) as well as other review articles(5). The reason for the popularity of this intake assessment method can be found in its low cost of administration as compared with other instruments such as food records or recalls. Brown(11), in 2006, wrote that the cost:benefit ratio should be taken into consideration when identifying instruments for use in research. The main benefit of FFQ administration is its ability to characterise usual diet in the past over a period of a year, months or weeks. However, there may be certain biases such as memory recall, number of food items, portion size and interpretation(6,12), which constitute factors that need to be addressed in FFQ development and application.

With regard to FFQ validation, the dietary record is one of the most used correlation methods as it has fewer correlation errors as compared with other reference methods(6). This has been attributed to the fact that both methods employ different modes to evaluate intake. The dietary record does not rely on memory, whereas the FFQ does and also employs cognitive processes for calculating the frequency of intake.

Currently, other methods (apart from the FFQ) have been utilised for intake assessment, which have also been validated. These methods aim to decrease costs and time taken to conduct an interview. As such, this accounts for the reason that the vast majority of FFQ tend to be self-administered.

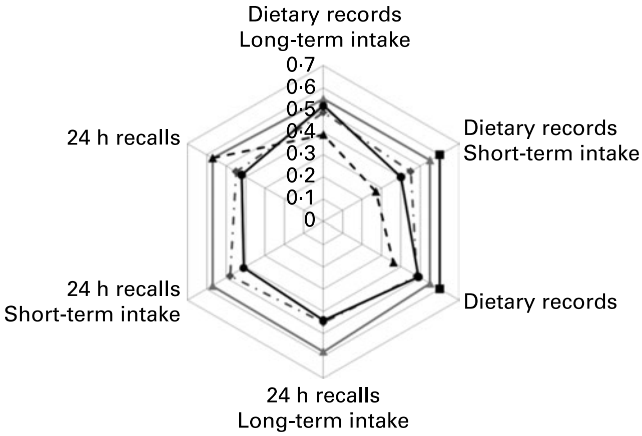

Fig. 1. Mean of quality-weighted correlation coefficients by reference method used in FFQ validation studies for each study mineral. -◆-, Iron; —▲—, calcium; -▲-, selenium; -•-, zinc; -■-, iodine.

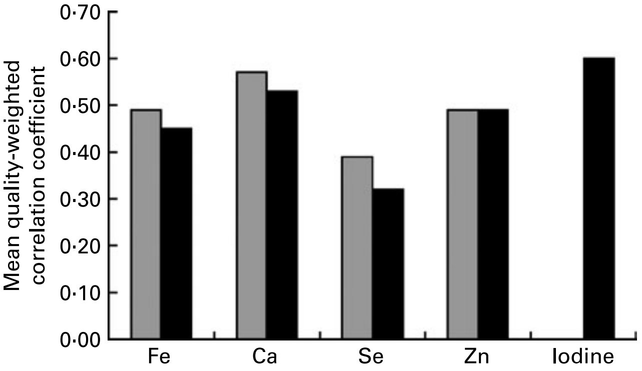

Fig. 2. Mean quality-weighted correlation coefficient of validation studies using FFQ to assess mineral intake and dietary records as the reference method by study mineral and number of FFQ food items. ▨, Foods in the FFQ > 100; ■, foods in the FFQ < 100.

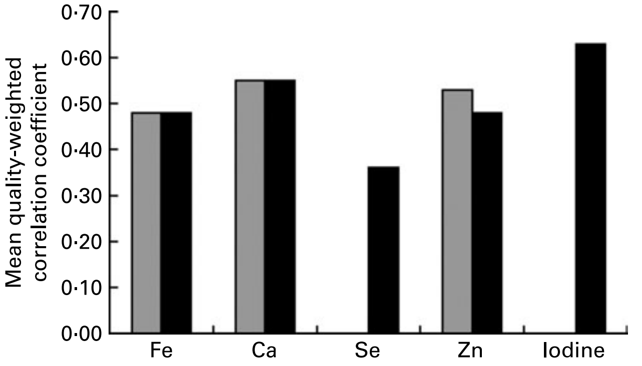

Fig. 3. Mean quality-weighted correlation coefficient of validation studies using FFQ to assess mineral intake and dietary records as the reference method by study mineral and mineral supplement intakes. ▨, With supplement; ■, no supplement.

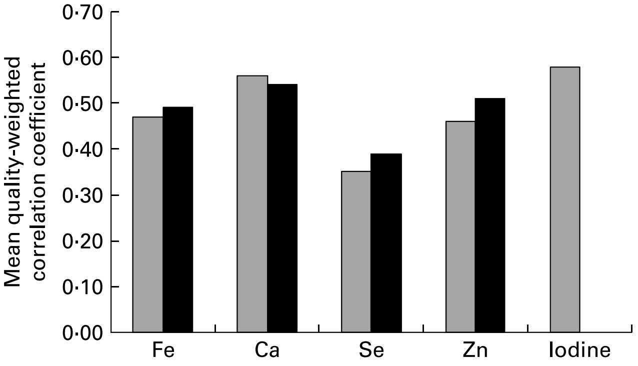

Fig. 4. Mean quality-weighted correlation coefficient of validation studies using FFQ to assess mineral intake and weighed or estimated dietary records (DR) as the reference method by study mineral. ▨, DR estimated; ■, DR weighed.

However, the data can be incomplete or have unlikely responses that can contribute to misleading results due to a lack of precision or large differences in intraindividual variation. This can be reduced by employing interview (face to face) administration to allow for immediate verification in data collection(5).

The periods of time that are referred to in evaluating intake by FFQ or reference methods are essential for validation. It should be defined in the objectives of the study(13). Generally, the FFQ is developed to assess the previous year, and the reference method assesses another time period. For this reason, it is necessary to conduct multiple DR and recalls to cover the same period as that covered by the FFQ. Seasonality should be considered in both methods, especially for micronutrients, and including minerals. Food availability throughout the period of 1 year is highly variable, as intake of fruits, vegetables, pulses, grains and fish, among others, varies from season to season. We have found better correlations of dietary intake in long-term (more than 7 d) assessment periods using DR for Zn and Fe. However, the dietary recall for Fe was slightly better correlated with short-term administration and obtained somewhat higher values with long-term administration for Zn. For Ca, no differences were seen in CC for either short- or long-term administration by records or recalls.

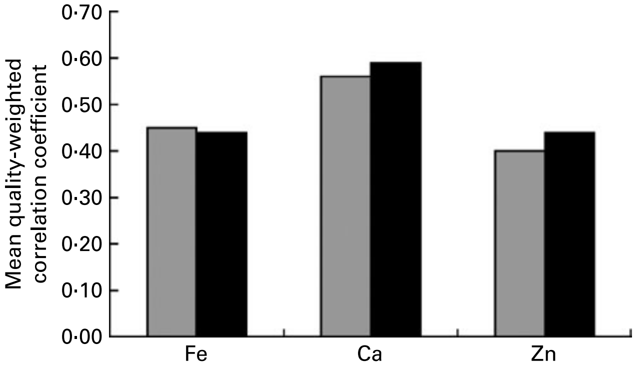

Fig. 5. Mean quality-weighted correlation coefficient of validation studies using FFQ to assess mineral intake and 24 h recalls as the reference method by study mineral and number of FFQ food items. ▨, Foods in the FFQ > 100; ■, foods in the FFQ < 100.

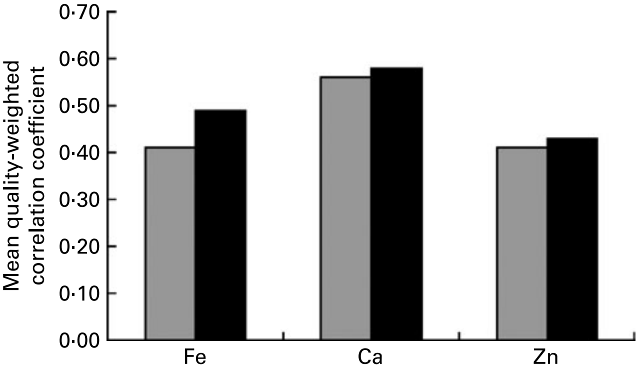

Fig. 6. Mean quality-weighted correlation coefficient of validation studies using FFQ to assess mineral intake and 24 h recalls as the reference method by study mineral and mineral supplement intakes. ▨, With supplement; ■, no supplement.

The number of food items to include in an FFQ should be based on the objectives of a given study(6). Typically, FFQ may contain 100 or more food items. If an investigator is interested in estimating the intake of a single nutrient or certain food groups, the food list can be reduced to a range of 15–30 foods; however, this limited food list needs to be measured previously(14). Reducing the number of food items is taken into consideration to avoid lengthy FFQ(5) and to avoid fatigue response. In the present review, for studies validating FFQ with DR, Fe, Ca and Se had better correlations with a longer food list. When 24HR were administered, Ca and Zn showed better correlations with reference methods when compared against short FFQ food lists (<100 food items). Fe was better correlated in studies using longer food lists and employing DR as the reference method, but no changes were observed with recalls. The primary role of the food list is to include the principal sources of nutrients deemed of interest to the study and the frequency of their consumption. With respect to minerals, there are many food sources of these nutrients that may be better accounted for by using a longer list.

Supplement use should be evaluated in an interview, specifying the type and dosage consumed. Zn, in particular, obtained very good correlations with DR when supplementation was included as part of intake assessment. In the present review, many validation studies did not take supplementation into account. Similar results were observed in the review on vitamins(10). However, supplement use should be included as an ‘additional’ question(5). In any case, it is important that both the validating questionnaire and the reference method similarly include or exclude supplements. However, if biomarkers are used, which are considered as markers that assess intake independent of measured intake, there will probably be a difference in correlation between the methods according to the inclusion or not of supplements in the validating questionnaire. In the present review, biomarkers *v.* FFQ were considered only for iodine, as there was a limited number of studies for Fe and Se, as well as a currently existing lack of adequate biomarkers for these minerals. As such, three studies took supplementation into consideration and two studies did not, showing better weighted CC for the studies assessing supplement use (0·55) than those that excluded this information (0·31).

Table 8. Classification of mineral intake validation studies based on mean weighted correlation coefficients obtained from each reference method used in validating intakes of iron, calcium, selenium, zinc and iodine

	FFQ *v.* dietary records			FFQ *v.* 24 h recalls			
	Long-term intake	Short-term intake		Long-term intake	Short-term intake		Other Methods
Good (0·51–0·70)	Ca Zn	Ca Iodine	Ca Iodine	Ca	Ca	Ca Se* Iodine*	Ca
Acceptable (0·30–0·50)	Fe Se	Fe Zn	Fe Se Zn	Fe Zn	Fe Zn	Fe Zn	Fe
Poor (< 0·30)		Se					

* Only one study.

The present study showed that validation studies for iodine using biomarkers as the reference method was acceptable (weighted CC was more than 0·40); there were five studies that used UIE. The review of vitamins showed that studies using biomarkers to validate intake presented low correlations(10); however, the review of validation of *n*-3 fatty acid intake using biomarkers (total *n*-3 fatty acids, DHA and EPA) presented acceptable correlations(15), which is similar to the results in the present study. For each Se and Fe, there were only two studies; therefore, average CC could not be calculated. This shows the need for further research that employs biomarkers to validate the intake of minerals. Moreover, despite the fact that UIE in 24 h urine samples is considered the best method to assess iodine intake, estimates show high intraindividual variability, and therefore, its use as a marker for usual intake is compromised. Brug *et al.* (16) reported the estimates of variance components and reproducibility of UIE. They found that 0·45 was due to intraindividual and 0·06 to interindividual variation. Correlations between consecutive UIE were 0·21 for men and 0·27 for women. It is, therefore, crucial to develop additional biomarkers for usual mineral intake and status that take into account genetic and other individual variability.

DR were the most commonly used reference method to validate mineral intakes measured by FFQ. We found good and acceptable ranges of mean CC with recalls and records for all minerals. The greatest difference in CC was seen for Se, which was considerably higher for recalls (0·57) than records (0·36). This could in part be explained by the limited number of studies for this mineral: only one article applied recalls and nine used DR as the reference method.

In the classification of other methods, more articles addressed Ca and Fe assessment as compared with other minerals included in the present review. Ca and Fe presented good and acceptable correlations, respectively. Other methods, consisting of those that deviate from the traditional FFQ *v.* DR, 24HR or biomarker validation, reflect the tendency of studies whose focus is on one particular mineral or certain food groups or those employing novel methods to conduct diet assessments. However, further research on the validation of methods applying different intake instruments is required.

The aim of the present article was to review the validity of methods used to measure mineral intake. The present review showed that FFQ was the main intake method utilised. Most studies presented CC ranging from 0·30 to 0·60. The summary of the mean weighted correlations obtained by the EURRECA quality scoring system indicated that there were no differences in using FFQ for Ca when compared with records, recalls or other methods as the reference standard. All the reference methods obtained a good classification of the mean weighted CC (Table 8). For Fe and Zn, records, recalls and other validation methods had an acceptable correlation with FFQ, and for iodine, records, recalls and biomarker validation showed acceptable CC with FFQ. For Se, records had acceptable correlation. The FFQ was seen as a valid method for assessing mineral intake, particularly for Ca and, to a lower extent, for iodine and Zn. Moreover, methods evaluating Se and Fe intake obtained only acceptable correlations. Including the assessment of supplements increased correlations for Zn, but not for Ca and Fe, and the number of items of FFQ ($n > 100$) also increased validity for Fe, Ca and Se. Finally, using weighed DR as the reference method improves the correlation with FFQ for Zn, Se and Fe, but not for Ca, as compared with estimated DR. The present review showed that an FFQ is an acceptable tool for assessing mineral intake, although certain aspects need to be considered to improve its performance.

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