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Dietary assessment methods for micronutrient intake: a systematic review on vitamins

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The EURRECA Network of Excellence is working towards the development of aligned micronutrient recommendations across Europe. The purpose of the present study was to define how to identify dietary intake validation studies in adults pertaining to vitamins. After establishing a search strategy, we conducted a MEDLINE and EMBASE literature review. A scoring system was developed to rate the quality of each validation study according to sample size, statistical methods, data collection procedure, seasonality and vitamin supplement use. This produced a quality index with possible scores obtained ranging from 0·5 to 7. Five thousand four-hundred and seventy-six papers were identified. The numbers meeting the inclusion criteria were: for vitamin A, 76; vitamin C, 108; vitamin D, 21; vitamin E, 75; folic acid, 47; vitamin B_{12}, 19; vitamin B_6, 21; thiamine, 49; riboflavin, 49; and niacin, 32. 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 vitamin intakes estimated by FFQ and the reference method were weighted according to the study's quality index and ranged from 0·41 to 0·53 when the reference method was the DR and from 0·43 to 0·67 when the reference was 24-h recalls. A minority of studies (*n* 33) used biomarkers for validation and in these the CC ranged from 0·26 to 0·38. The FFQ is an acceptable method of assessing vitamin intake. The present review provides new insights regarding the characteristics that assessment methods for dietary intake should fulfil.

Dietary assessment: FFQ: Validation: Vitamins

There is ample evidence regarding the role of dietary factors on the development of different chronic diseases. Nevertheless, assessing dietary patterns both at the individual and population levels is a difficult task due to the extensive variability of intake.

Multiple methods have been described to ascertain nutrient intake, with the Food Frequency Questionnaire (FFQ) being the instrument of choice in large nutritional epidemiological studies. Two other dietary instruments that are commonly used are the 24-h dietary recall and the dietary record (DR). It is generally accepted that all these methods have advantages and limitations and none of them is entirely satisfactory.

A universal epidemiological method to ascertain individual dietary intake does not exist. All methods have some kind of errors, although these are not always of a similar magnitude. Thus, it is a difficult task to know what the best method consists of if all of them are imperfect. The objective of a validation method is to compare a nutritional assessment method with another considered as superior, but never as the absolute truth[(1)]. One of the most important issues for avoiding false interpretations is the independence of errors among the different methods evaluated.

Numerous validation studies designed to compare the available methods to assess dietary intake are cited in the scientific literature. The most frequently applied method to ascertain dietary intake is the FFQ, whereas DR and recalls are most utilised as reference methods. The diversity of the results obtained does not allow us to draw conclusions about the selection of an ideal dietary assessment method.

Thus, the aim of this analysis was to identify the most accurate method to assess vitamin intake in the adult population through an extensive review of the literature.

Abbreviations: CC, correlation coefficients; DR, dietary records.

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Material and methods

A MEDLINE and EMBASE literature search was carried out between July 2007 and March 2008. The procedure for the identification and selection of articles was performed in three steps:

At stage 1, a search strategy was established to identify the most relevant studies in the electronic databases.

The search terms used in the electronic databases were divided into two categorical strategies:

(1) *General*. The MeSH terms applied in the general search were: nutrient terms ('nutritional assessment' OR 'diet' OR 'nutritional status' OR 'dietary intake' OR 'food intake'); validity terms ('validity' OR 'validation study' OR 'reproducibility' OR 'replication study' OR 'correlation coefficient' OR 'correlation study') and human studies.
(2) *Vitamin specific*. The MeSH terms applied were: nutrient terms (vitamin names and synonyms) and intake terms: (intake* OR diet).

At stage 2 of the review, titles and abstracts of the selected articles were read by two independent reviewers. Only when they both determined that titles/abstracts met the exclusion criteria were the articles excluded. When a title/abstract could not be rejected with certainty, the full text of the article was obtained and further evaluated. We applied the following exclusion criteria:

(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 the physiological effects of foods, nutrients and in relation to their genetic determinants.
(10) Studies in animals and those without abstracts in PubMed.

At stage 3, the following criteria were considered to select the articles for inclusion:

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

The full text of all articles collected was screened for definitive exclusion or data extraction by a different reviewer from those involved in the acceptance process, with independent duplicate assessment of a random sample of 25 % by a second reviewer. Where the two reviewers disagreed the study was discussed and a consensus decision reached where possible. If this was not possible, then a third reviewer was asked to arbitrate.

The articles included in the present study were categorised according to the total number of days over which the reference methods were applied:

(1) *Long-term intake*. If the reference method was a dietary assessment method (including 24-h recall and estimated and weighed DR) applied 7 or more days.
(2) *Short-term intake*. If the reference method was a dietary assessment method (including 24-h recall and estimated and weighed DR) applied less than 7 d.
(3) *Biomarker*. If the reference method was a biomarker.

To assess the quality of the different validation studies, a quality score system was developed[2]. The studies were scored considering its sample size, the statistics used to validate the method, the procedure of data collection, and the inclusion or not of seasonality and vitamin supplements use, according to the values described in Table 1. The CC obtained for each study were weighed in proportion to the article quality index.

Results

Five thousand four-hundred and seventy-six articles were identified in the initial search strategy. After applying the exclusion criteria, 392 articles from the general search

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
Correlations. Only one selected, which with the highest score	Correlation	0·5
	Adjusted correlations (energy, etc.)	1
	Deattenuated or intra-class correlations	1·5
Agreement	Classification or Bland and Altman plot	0·5
3. Data collection	Gathered by face to face interview	1
4. Seasonality	Considered	0·5
5. Supplements	Included and data considered in analysis	1·5

SES, Socioeconomic status.

Table 2. Distribution of analyses by FFQ validation method and vitamin

	Gold standard			
	Dietary record	Recall	Biomarkers	Other methods
Vitamin A	46	24	2	8
Vitamin C	63	31	13	19
Vitamin D	14	4	1	2
Vitamin E	38	22	21	17
Folic acid	30	12	7	7
Vitamin B_{12}	13	5	1	1
Vitamin B_6	11	5	1	2
Thiamine	38	9	1	1
Riboflavin	39	9	1	1
Niacin	28	5	0	2

remained in the review. We applied the inclusion criteria in stage 3 obtaining the following articles for each vitamin: 76 articles for vitamin A; 108 for vitamin C; 21 for vitamin D; 75 for vitamin E; 47 for folic acid; 19 for vitamin B_{12}; 21 for vitamin B_6; 49 for thiamine; 49 for riboflavin: 30 for niacin, extracted from a total of 124 studies.

In the present review, most of the validation studies used a FFQ as the intake assessment method. For each vitamin, the methods used as gold standards to validate the FFQ are described in Table 2.

To measure the validity of the different FFQ according to the type of reference method utilised, weighted means of the CC were calculated using the quality index value of each study as the weight (Table 3). Weighted CC for the FFQ ranged from 0·41 to 0·53 when the reference method was the DR, and from 0·43 to 0·67 when the recalls were utilised as the gold standard. Only a few studies (*n* 33) used biomarkers as a validation method, which yielded lower correlation values (coefficients between 0·26 and 0·38).

Tables 4–11 describe the purpose and scope of the literature examined in the present review: author and year of publication, population size (ranged from 20 to 860 persons) and sex (majority were females), characteristics of the FFQ (mode of administration, number of food items included in the questionnaire and reference period), characteristics of the reference method (collection of information and total number of days over which the reference method was applied), the use or not of supplements, the correlation coefficient and the quality index.

FFQ v. *dietary record*. The DR was used as the gold standard in most of the validation studies included in the present systematic review. In the majority of the cases, information regarding dietary intake was collected through a self-administered FFQ (82 %) to assess dietary intake in the previous 12 months (58 %). The number of food items included in the questionnaire ranged between 22 and 350. The weighted CC varied according to the number of food items (<100 or ≥ 100 food items) included in the FFQ (Fig. 1).

Only 31 % of the studies included the intake of vitamin supplements in their analyses. There were no large differences in CC between studies that did or did not include information on vitamin supplements (Fig. 2).

In 43·7 % of the cases, the CC were higher when the DR used as the reference method was a weighed DR compared to the use of an estimated DR (Fig. 3).

Most of the DR used as reference methods collected dietary intake for 7 d or more (long-term intake; 74 % of the studies). Fig. 4 shows the difference in the weighted CC according to the number of days included in the DR (long- *v.* short-term intake).

FFQ v. *recall*. When the reference method was the recall, information was more frequently collected through an interviewer-administered FFQ (50 %) instead of being self-administered by the study participants. The number of food items included in the FFQ ranged between 47 and 222. Fig. 5 shows the weighted CC according to the number of food items included in the FFQ.

The proportion of studies in this group including information about vitamin supplement intake was lower than that of those using DR as the gold standard (23 %). Indeed, there were no data on supplement intake for the B-complex vitamins with the exception of one study (Fig. 6).

More than half of the recalls (55·6%) used to validate the FFQ collected dietary information during 7 days or more. When long-term intake was evaluated, the CC for the B-complex vitamins decreased (Fig. 7).

FFQ v. *biomarkers*. The use of biomarkers as the reference method was less frequent, resulting in CC often much lower than 0·40. Folate intake collected through a FFQ was validated using serum folate in three studies. One study used erythrocyte folate as the reference method, and another three studies used both serum and erythrocyte folate as biomarkers. In fifteen studies, vitamin C intake was compared with its blood levels. Plasma concentration of vitamin E was used as the gold standard in seventeen studies validating vitamin E intake. Moreover, in four other studies, adipose tissue concentration was also used as biomarker.

Table 3. Weighted mean correlation coefficients according to reference method used in FFQ validation for each vitamin

	Dietary record	Recall	Biomarkers
Vitamin A	0·45	0·44	0·26
Vitamin C	0·50	0·51	0·28
Vitamin D	0·51	0·61	
Vitamin E	0·49	0·43	0·26
Folic acid	0·51	0·49	0·38
Vitamin B_{12}	0·45	0·59	
Vitamin B_6	0·50	0·52	
Thiamine	0·42	0·56	
Riboflavin	0·53	0·60	
Niacin	0·41	0·67	

Discussion

Our aim was to determine the comparative efficacy of available methods to validate dietary intake. The present review shows that FFQ are the most commonly used method for assessing diet in epidemiological studies. The main advantages are their low cost and their capability to characterise the usual diet in the past, as well as to minimise the risk of serious interviewer[1] and measurement bias, given that they can be self-administered.

The drawbacks of the FFQ include the use of fixed lists of foods, the effect of memory, the difficulties in portion size estimation and the interpretation of questionnaires[1,3]. Among the available reference methods for the validation of FFQ, dietary records (DR) are likely to have the least

Table 4. Description of validation studies regarding vitamins A, C, D and E intake (FFQ vs. dietary records)

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/ no. of days per record)	Nutrient	Coefficient	Quality index
Long-term intake												
Ambrosini *et al.* (2001)[7]	26 W 57 M			28–72	Self-administered	Unknown	1 year	Yes	DR estimated (4/7)	Vitamin A	0·59 W*/0·48 M*	4
Andersen *et al.* (1999)[8]	125 M			20–55	Self-administered	180	Unknown	Yes	DR weighed (5/3)	Vitamin A Vitamin C Vitamin D Vitamin E	0·62† 0·50† 0·61† 0·46†	4
Bautista *et al.* (2005)[9]	45 W 52 M			20–40	Self-administered	60	1 year	No	DR weighed (1/7)	Vitamin A Vitamin C	0·68‡ 0·56‡	2·5
Blalock *et al.* (2003)[10]	27 W 30 M	–			Self-administered	109	1 year	No	DR weighed (1/7)	Vitamin D	0·47†	0·5
Block *et al.* (1990)[11]	102 W			45–70	Self-administered	94	6 months	Yes	DR estimated (3/4)	Vitamin A Vitamin C	0·55‡ 0·71‡	3·5
Block *et al.* (1992)[12]	85			25–50	Self-administered/ interviewer	113	1 year	No	DR estimated (4/3) + four 24-h R	Vitamin C	0·48‡	2·5
Block *et al.* (1992)[12]	85			25–50	Self-administered	98	1 year	No	DR estimated (4/3) + four 24-h R	Vitamin C	0·54‡	2·5
Bonifacj *et al.* (1997)[13]	68 W 30 M	42·4 40·8	12·3 10·6		Interviewer	134	1 year	No	DR weighed (4/7)	Vitamin C Vitamin E	0·35§ 0·65§	3
Brunner *et al.* (2001)[14]	403 W 457 M			39–61	Self-administered	127	1 year	No	DR estimated (1/7)	Vitamin C Vitamin E	0·45 W‖/0·46 M‖ 0·33 W‖/0·41 M‖	3·5
Cardoso *et al.* (2001)[15]	52 W			21–62	Self-administered	120	1 year	No	DR weighed (4/3)	Vitamin A Vitamin C Vitamin E	0·32§ 0·55§ 0·36§	3·5
Chen *et al.* (2004)[16]	104 W 85 M			16–75	Interviewer	39	1 year	No	DR estimated (2/7)	Vitamin C Vitamin E	0·12§ 0·16§	5·5
Date *et al.* (2005)[17]	85			30–69	Self-administered	40	1 year	No	DR weighed (4/3)	Vitamin A Vitamin C	0·35‖ 0·27‖	2·5
Decarli *et al.* (1996)[18]	265 W 130 M			30–69	Interviewer	77	1 year	No	DR weighed (1/7)	Vitamin C Vitamin E	0·48§ 0·34§	4
Egami *et al.* (1999)[19]	42 W 46 M			41–88	First FFQ self-administered	97	1 year	No	DR weighed (4/4)	Vitamin A Vitamin C Vitamin E	0·56§ 0·47§ 0·52§	2·5
Egami *et al.* (1999)[19]	42 W 46 M			41–88	Second FFQ self-administered	97	1 year	No	DR weighed (4/4)	Vitamin A Vitamin C Vitamin E	0·54§ 0·61§ 0·61§	2·5
Engle *et al.* (1990)[20]	34 W 16 M	49·3	9·6		Computerised	85	3 months	Yes	DR estimated (1/7)	Vitamin A	0·40‖	3·5
Friis *et al.* (1997)[21]	122 W			20–29	First FFQ self-administered	92	1 year	No	DR estimated (3/4)	Vitamin A Vitamin C Vitamin D Vitamin E	0·61§ 0·72§ 0·76§ 0·37§	2·5
Friis *et al.* (1997)[21]	122 W			20–29	Second FFQ self-administered	92	1 year	No	DR estimated (3/4)	Vitamin A Vitamin C Vitamin D Vitamin E	0·72§ 0·68§ 0·54§ 0·62§	2·5
Hodge *et al.* (2000)[22]	63 W			16–48	Self-administered	74	1 year	No	DR weighed (1/7)	Retinol Vitamin A Vitamin C	0·45§ 0·28§ 0·60§	3·5
Ishihara *et al.* (2003)[23]	176 W 174 M	58 55			Self-administered	180	Unknown	No	DR weighed (4/7)	Vitamin A Vitamin C	0·47 W‖/0·35 M‖ 0·44 W‖/0·46 M‖	3
Jain *et al.* (1996)[24]	108 W 95 M			35–79	Self-administered	132	1 year	Yes	DR estimated (1/7)	Vitamin A Retinol Vitamin C Vitamin E	0·33 W¶/0·19 M¶ 0·23 W¶/0·44 M¶ 0·39 W¶/0·38 M¶ 0·39 W¶/0·40 M¶	4·5
Jain & McLaughlin (2000)[25]	108 W 95 M			35–79	Self-administered	132	1 year	Yes	DR estimated (1/7)	Vitamin A Retinol Vitamin C Vitamin E	0·54 W**/0·27 M** 0·53 W**/0·37 M** 0·56 W**/0·47 M** 0·48 W**/0·36 M**	5

Table 4. *Continued*

Author and year of publication	No.	Age (years) Mean	Age (years) SD	Age (years) Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/ no. of days per record)	Nutrient	Coefficient	Quality index
Kelemen *et al.* (2003)[26]	58 South Asians, A 64 Chinese, C 85 European, E			35–75	Self-administered	163 169 157	Unknown	Yes	DR estimated (2/7)	Vitamin C Vitamin E	0·69 A§/0·75 C§/0·83 E§ 0·73 A§/0·84 C§/0·77 E§	3·5
Kim *et al.* (2002)[27]	46 W 23 M	38·16	11·7		Self-administered	118	Unknown	No	DR weighed (1/7)	Vitamin A Vitamin C Vitamin E	0·28§ 0·71§ 0·58§	3
Kobayashi *et al.* (2003)[28]	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)	Vitamin C	0·22 W‖/0·42 M‖	4·5
Lee *et al.* (2006)[29]	25 W 58 M	–			First FFQ interviewer	64	6 months	Yes	DR estimated (3/5)	Vitamin A Vitamin C Vitamin E	0·33§ 0·20§ 0·35§	5
Lee *et al.* (2006)[29]	25 W 58 M	–			Second FFQ inter-viewer	64	6 months	Yes	DR estimated (3/5)	Vitamin A Vitamin C Vitamin E	0·15§ 0·30§ 0·53§	5
MacIntyre *et al.* (2001)[30]	59 W 15 M			15–65	Self-administered	145	Unknown	No	DR weighed (1/7)	Vitamin A Vitamin C	0·35† 0·55†	1
Männistö *et al.* (1996)[31]	152 W	51	9		Self-administered	110	1 year	Yes	DR estimated (2/7)	Vitamin C Vitamin D Vitamin E	0·69§ 0·44§ 0·64§	4
Marks *et al.* (2006)[32]	59 W 37 M			25–75	Self-administered	129	6 months	Yes	DR weighed (6/2)	Retinol Vitamin C	0·19 W‖/0·27 M‖ 0·20 W‖/0·63 M‖	5
Martín-Moreno *et al.* (1993)[33]	147			18–74	First FFQ self-administered	118	1 year	No	DR weighed (4/4)	Vitamin A Vitamin C	0·48§ 0·52§	3·5
Martín-Moreno *et al.* (1993)[33]	147			18–74	Second FFQ self-administered	118	1 year	No	DR weighed (4/4)	Vitamin A Vitamin C	0·45§ 0·71§	3·5
McKeown *et al.* (2001)[34]	118			45–74	Self-administered	130	1 year	Yes	DR estimated (2/7)	Vitamin C Vitamin E	0·59 W§/0·70 M§ 0·60 W§/0·40 M§	5
McNaughton *et al.* (2005)[35]	17 W 11 M	48	10·5		Self-administered	129	6 months	Yes	DR weighed (6/2)	Vitamin E	0·34¶	2
Nagata *et al.* (1998)[36]	37			35–66	Self-administered	169	1 year	No	DR estimated (12/1)	Vitamin A Retinol Vitamin C Vitamin E	0·40††§/0·62‡‡§ 0·18††§/0·15‡‡§ 0·17††§/0·69‡‡§ 0·24††§/0·79‡‡§	2
Ogawa *et al.* (2003)[37]	58 W 55 M			45–77	Self-administered	40	1 year	Yes	DR estimated (4/3)	Retinol Vitamin C	0·30 W§/0·38 M§ 0·43 W§/0·58 M§	4·5
Patterson *et al.* (1999)[38]	113 W			50–79	Self-administered	122	3 months	Yes	DR estimated (1/4) + four 24-h (phone) R	Vitamin A Vitamin C Vitamin D Vitamin E	0·56§ 0·74§ 0·73§ 0·83§	4
Pietinen *et al.* (1988a)[39]	190	59·9	4·0		First FFQ self-administered	276	1 year	No	DR estimated (12/2)	Vitamin A Vitamin C Vitamin D Vitamin E	0·55§ 0·70§ 0·58§ 0·76§	3
Pietinen *et al.* (1988a)[39]	190	59·9	4·0		Second FFQ self-administered	276	1 year	No	DR estimated (12/2)	Vitamin A Vitamin C Vitamin D Vitamin E	0·68§ 0·71§ 0·64§ 0·82§	3
Pietinen *et al.* (1988b)[40]	190	59·9	4·0		First FFQ self-administered	44	1 year	No	DR estimated (12/2)	Vitamin A Vitamin C Vitamin E	0·55§ 0·51§ 0·59§	3
Pietinen *et al.* (1988b)[40]	190	59·9	4·0		Second FFQ self-administered	44	1 year	No	DR estimated (12/2)	Vitamin A Vitamin C Vitamin E	0·53§ 0·47§ 0·66§	3
Potischman *et al.* (1999)[41]	219 W			20–54	Self-administered	60 100	1 year	No	DR estimated (2/3) + six 24-h (phone) R	Vitamin C	0·39 (60 items)§ 0·41 (100 items)§	3
Potosky *et al.* (1990)[42]	97 W			45–70	Self-administered	94	6 months	No	DR estimated (3/4)	Vitamin A Vitamin C	0·46‡ 0·60‡	1·5
Riboli *et al.* (1997)[43]	105 W 101 M			50–69	Self-administered	350	1 year	No	DR weighed (6/3)	Retinol Vitamin C Vitamin E	0·44 W**/0·58 M** 0·85 W**/0·62 M** 0·69 W**/0·70 M**	2·5

Table 4. *Continued*

Author and year of publication	No.	Age (years) Mean	Age (years) SD	Age (years) Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/ no. of days per record)	Nutrient	Coefficient	Quality index
Riboli *et al.* (1997)[43]	105 W 101 M			50–69	Self-administered	130	1 year	No	DR weighed (6/3)	Retinol Vitamin C Vitamin E	0·72 W**/0·39 M** 0·71 W**/0·64 M** 0·83 W**/0·65 M**	2·5
Rimm *et al.* (1992)[44]	127 M			40–75	First FFQ self-administered	131	1 year	Yes	DR weighed (2/7)	Vitamin A Retinol Vitamin C Vitamin E	0·61§ 0·59§ 0·79§ 0·78§	4
Rimm *et al.* (1992)[40]	127 M			40–75	Second FFQ self-administered	131	1 year	Yes	DR weighed (2/7)	Vitamin A Retinol Vitamin C Vitamin E	0·48§ 0·75§ 0·92§ 0·92§	4
Roddam *et al.* (2005)[45]	202 W			50–64	Self-administered	18 groups	1 week	No	DR weighed (1/7)	Vitamin C Vitamin D Vitamin E	0·61** 0·27** 0·12**	3
Shimizu *et al.* (1999)[46]	20 W 17 M	>35			Self-administered	169	1 year	No	DR estimated (12/1)	Vitamin A Vitamin C Vitamin E	0·57 W§/0·68 M§ 0·45 W§/0·59 M§ 0·57 W§/0·71 M§	2
Tjonneland *et al.* (1992)[47]	85 W 59 M			40–64	Self-administered	92	Unknown	No	DR estimated (2/7)	Vitamin A Vitamin C Vitamin E	0·45 W**/0·27 M** 0·51 W**/0·64 M** 0·44 W**/0·47 M**	2·5
Tokudome *et al.* (2001)[48]	79 W	48	8		Self-administered	102	1 month	No	DR weighed (4/7)	Vitamin A Vitamin C Vitamin D Vitamin E	0·35§ 0·42§ 0·64§ 0·32§	3·5
Tsubono *et al.* (2001)[49]	58 W 55 M	61 62	8·5 8·5		First FFQ self-administered	141	1 year	Yes	DR estimated (4/3)	Vitamin A Vitamin C	0·36§ 0·42§	4
Tsubono *et al.* (2001)[49]	58 W 55 M	61 62	8·5 8·5		Second FFQ self-administered	141	1 year	Yes	DR estimated (4/3)	Vitamin A Vitamin C	0·33§ 0·20§	4
Tsubono *et al.* (2001)[50]	107 W 94 M			40–59	First FFQ self-administered	44	1 month	Yes	DR estimated (4/7)	Vitamin A Vitamin C	0·48 W§/0·21 M§ 0·17 W§/0·18 M§	4
Tsubono *et al.* (2001)[50]	107 W 94 M			40–59	Second FFQ self-administered	44	1 month	Yes	DR estimated (4/7)	Vitamin A Vitamin C	0·41 W§/0·43 M§ 0·32 W§/0·31 M§	4
Tsugane *et al.* (2003)[51]	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)	Retinol Vitamin C	0·41 W**/0·19 M** 0·16 W**/0·39 M**	4·5
Willett *et al.* (1985)[52]	173 W			34–59	First FFQ self-administered	61	1 year	Yes	DR weighed (4/7)	Vitamin C	0·56**	4
Willett *et al.* (1985)[52]	173 W			34–59	Second FFQ self-administered	61	1 year	Yes	DR weighed (4/7)	Vitamin C	0·75**	4
Willett *et al.* (1987)[53]	29			20–54	Self-administered	116	1 year	Yes	DR weighed (1/365)	Vitamin A Vitamin C	0·70* 0·49*	1·5
Short-term intake												
Baumgartner *et al.* (1998)[54]	132 W			35–74	Interviewer	140	1 month	No	DR estimated (1/4)	Vitamin A Retinol Vitamin C Vitamin E	0·44§ 0·55§ 0·37§ 0·38§	3·5
Fregapane & Asensio (2000)[55]	38			18–61	Self-administered	202	Unknown	No	DR weighed (1/4)	Vitamin A Vitamin C Vitamin D Vitamin E	0·87¶ 0·37¶ 0·59¶ 0·31¶	1·5
George *et al.* (2004)[56]	95 W	20·1	4·3		Self-administered	195	6 months	No	DR estimated (1/3)	Vitamin A Vitamin C Vitamin E	0·65§ 0·55§ 0·28§	3·5
George *et al.* (2004)[56]	50 W	23·1	4·3		Self-administered	195	6 months	No	DR estimated (1/4) + two 24-h (interview) R	Vitamin A Vitamin C Vitamin E	0·42§ 0·51§ 0·59§	3·5
Goulet *et al.* (2004)[57]	71 W			30–65	Interviewer	91	1 month	No	DR estimated (1/3)	Vitamin C	0·19‖	1
Hartwell & Henry (2001)[58]	9 W 16 M	58·1	1·7		Self-administered	162	1 year	No	DR estimated (1/4)	Vitamin C	0·79‡	1·5
Ke *et al.* (2005)[59]	100	–			Self-administered	125	1 year	No	DR weighed (1/4)	Vitamin A Vitamin C Vitamin E	0·44** 0·37** 0·52**	3

Table 4. *Continued*

Author and year of publication	No.	Age (years) Mean	Age (years) SD	Age (years) Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/ no. of days per record)	Nutrient	Coefficient	Quality index
Kristal *et al.* (1997)[60]	829 W			50–79	Self-administered	100	3 months	Yes	DR estimated (1/4)	Vitamin C Vitamin E	0·47** 0·21**	2
Kumanyika *et al.* (2003)[61]	408 W			21–69	Self-administered	68	1 year	No	DR estimated (1/3) + three 24-h (phone) R	Vitamin C Vitamin E	0·60§ 0·26§	2·5
Longnecker *et al.* (1993)[62]	74 W 64 M	49	14		First FFQ self-administered	116	1 year	No	DR estimated (3/2)	Vitamin A Vitamin C Vitamin D	0·60‖ 0·51‖ 0·31‖	2·5
Longnecker *et al.* (1993)[62]	74 W 64 M	49	14		Second FFQ self-administered	116	1 year	No	DR estimated (3/2)	Vitamin A Vitamin C Vitamin D	0·69§ 0·46§ 0·44§	2·5
Martínez *et al.* (1999)[63]	42 W 97 M	66	4		Self-administered	132	1 year	Yes	DR weighed (1/4)	Vitamin A Vitamin C Vitamin E	0·40§ 0·63§ 0·35§	4
Masson *et al.* (2003)[64]	40 W 41 M			19–58	Self-administered	150	2–3 months	No	DR weighed (1/4)	Vitamin A Vitamin C Vitamin D Vitamin E	0·37 W**/− 0·49 M** 0·68 W**/0·64 M** 0·39 W**/0·51 M** 0·52 W**/0·21M**	2·5
Moreira *et al.* (2003)[65]	159 W 87 M			18–29	Interviewer	82	Unknown	No	DR estimated (1/4)	Vitamin A Retinol Vitamin C Vitamin D Vitamin E	0·41 W**/0·55 M** 0·48 W**/0·39 M** 0·51 W**/0·36 M** 0·21 W**/0·23 M** 0·31 W**/0·43 M**	3
Paalanen *et al.* (2006)[66]	157 W 137 M			30–79	Self-administered	128	1 year	No	DR estimated (1/3)	Vitamin A Vitamin C Vitamin D Vitamin E	0·26 W**/0·14 M** 0·51 W**/0·36 M** 0·26 W**/0·36 M** 0·43 W**/0·22 M**	3·5
Parr *et al.* (2002)[67]	34 W 36 M			15–45	Interviewer	164	1 week	No	DR weighed (1/2)	Vitamin A Vitamin C	0·62† 0·49†	4
Sasaki *et al.* (1998)[68]	47 W			38–69	Self-administered	110	1 month	No	DR estimated (1/3)	Vitamin A Vitamin C	0·38§ 0·45§	3
Sauvaget *et al.* (2002)[69]	1872 W 1133 M	57 60	7 11		Self-administered	22	1 year	No	DR weighed (1/1)	Vitamin C	0·17†	1·5
Schröder *et al.* (2001)[70]	44	30·7	10·4		Self-administered	157	Unknown	No	DR weighed (1/3)	Vitamin C Vitamin E	0·40¶ 0·20¶	3
Shimizu *et al.* (1999)[46]	59 W 58 M	53·8 57·9	11·2 10·9		Self-administered	169	1 year	No	DR estimated (1/3)	Vitamin A Vitamin C Vitamin E	0·27 W**/0·42 M** 0·21 W**/0·21 M** 0·39 W**/0·29 M**	2
Tokudome *et al.* (2005)[71]	129 W 73 M			30–70	Self-administered	47	1 year	No	DR estimated (1/3)	Vitamin A Vitamin C Vitamin E	0·22 W§/0·27 M§ 0·52 W§/0·45 M§ 0·17 W§/0·31 M§	3·5
Torheim *et al.* (2001)[72]	48 W 27 M			15–59	Self-administered	69	1 week	No	DR weighed/ estimated (1/2)	Vitamin A Vitamin C	0·46† 0·56†	2

No., number; Suppl., supplements; W, women; M, men; DR, dietary record; 24-h R, 24-h recall.
* Age, sex and energy-adjusted, Pearson correlation coefficient.
† Crude, Spearman correlation coefficient.
‡ Crude, Pearson correlation coefficient.
§ Energy-adjusted, deattenuated correlation coefficient.
‖ Energy-adjusted, Spearman correlation coefficient.
¶ Intra-class correlation coefficient.
** Energy-adjusted, Pearson correlation coefficient.
†† Low-food diversity.
‡‡ High-food diversity.

Table 5. Description of validation studies regarding vitamins A, C, D and E intake (FFQ vs. 24-h recalls)

Author and year of publication	No.	Age (years) Mean	Age (years) SD	Age (years) Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	No. of recalls	Recall administration method	Weekend included	Nutrient	Coefficient	Quality index
Long-term intake														
Boeing *et al.* (1997)[72]	49 W 43 M			35–64	Self-administered	158	–	No	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·29* 0·69* 0·52*	2
Fraser *et al.* (2005)[73]	315	–			Self-administered	202	–	No	Eight, within 6 months	Phone interview	Yes	Vitamin E	0·78*	2·5
Gnardellis *et al.* (1994)[74]	80			25–67	First FFQ self-administered	190	1 year	Yes	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C	0·17 W*/0·24 M* 0·33 W*/0·34 M*	4
Gnardellis *et al.* (1994)[75]	80			25–67	Second FFQ self-administered	190	1 year	Yes	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C	0·78 W*/0·30 M* 0·17 W*/0·46 M*	4
Hebert *et al.* (1998)[75]	30 W 30 M	43·2 52·6	13·6 10·9		First FFQ interviewer	81	1 year	No	Eight, within 1 year	Personal interview	Yes	Vitamin C	0·32*	2·5
Hebert *et al.* (1998)[75]	30 W 30 M	43·2 52·6	13·6 10·9		Second FFQ interviewer	81	1 year	No	Eight, within 1 year	Personal interview	Yes	Vitamin C	0·53*	2·5
Hernández-Ávila *et al.* (1998)[76]	134 W	–			First FFQ self-administered	85	–	No	Sixteen, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin D Vitamin E	0·35* 0·48* 0·48* 0·22*	3
Hernández-Ávila *et al.* (1998)[76]	134 W	–			Second FFQ self-administered	85	–	No	Sixteen, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin D Vitamin E	0·49* 0·49* 0·49* 0·12*	3
Jackson *et al.* (2001)[77]	40 W 33 M	45·4 46	13·5 15·3		First FFQ interviewer	70	–	No	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·27† 0·43† 0·44†	3
Jackson *et al.* (2001)[77]	40 W 33 M	45·4 46	13·5 15·3		Second FFQ interviewer	70	–	No	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·19† 0·31† 0·43†	3
Johansson *et al.* (2001)[78]	99 W 99 M			30–60	Self-administered	84	–	No	Ten, within 1 year	Phone interview	Yes	Vitamin A Vitamin C Vitamin E	0·33 W*/0·36 M* 0·62 W*/0·57 M* 0·42 W*/0·30 M*	2·5
Kabagambe *et al.* (2001)[79]	42 W 78 M	59	10		Interviewer	135	1 year	No	Seven, within 7 months	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·86* 0·71* 0·48*	4
Katsouyanni *et al.* (1997)[80]	38 W 42 M			25–67	First FFQ self-administered	190	1 year	Yes	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C	0·17 W*/0·24 M* 0·33 W*/0·34 M*	3·5
Katsouyanni *et al.* (1997)[80]	38 W 42 M			25–67	Second FFQ self-administered	190	1 year	Yes	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C	0·78 W*/0·30 M* 0·17 W*/0·46 M*	3·5
Malekshah *et al.* (2006)[81]	82 W 49 M	49·9 51·2	9·3 13		Interviewer	150	1 year	No	Twelve, within 1 year	Personal interview	No	Vitamin A Vitamin C Vitamin E	0·59‡ 0·65‡ 0·49‡	3
Mayer-Davis *et al.* (1999)[82]	186 W			40–69	Interviewer	114	1 year	Yes	Eight, within 1 year	Phone interview	Yes	Vitamin A Vitamin C Vitamin E	0·40* 0·75* 0·79*	5
Messerer *et al.* (2004)[83]	248 M			40–74	Self-administered	88	1 year	Yes	Fourteen, within 1 year	Phone interview	Yes	Vitamin A Vitamin C Vitamin D Vitamin E	0·62* 0·81* 0·59* 0·57*	4·5

Table 5. *Continued*

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	No. of recalls	Recall administration method	Weekend included	Nutrient	Coefficient	Quality index
Ocké *et al.* (1997)[84]	58 W 63 M			20–70 20–60	Self-administered	79	1 year	No	Twelve, within 1 year	Six personal interview + six phone interview	Yes	Vitamin A Vitamin C Vitamin E	0·62 W*/ 0·29 M* 0·71 W*/0·43 M* 0·41 W*/0·58 M*	3
Pisani *et al.* (1997)[85]	150 W 47 M	49·4 50·5	8·8 8·3		Self-administered	47	1 year	No	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·46 W*/ 0·37 M* 0·49 W*/0·44 M* 0·38 W*/0·48 M*	2·5
Romieu *et al.* (1999)[86]	110 W			15–54	First FFQ interviewer	116	–	No	Sixteen, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·35* 0·48* 0·22*	2·5
Romieu *et al.* (1999)[86]	110 W			15–54	Second FFQ interviewer	116	–	No	Sixteen, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·49* 0·49* 0·12*	2·5
Sevak *et al.* (1997)[87]	100 W	53·5	8·5		Interviewer	207	–	No	Twelve, within 1 year	Phone interview	Yes	Retinol Vitamin C Vitamin D	0·30* 0·54* 0·78*	3·5
Shu *et al.* (2004)[88]	191 W	55·4	9		Interviewer	77	1 year	No	Twenty-four, within 1 year	Personal interview	Yes	Vitamin C Vitamin E	0·43‡ 0·41‡	4
Van Liere *et al.* (1997)[89]	115 W			35–65	Self-administered	66	1 year	No	Twelve, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·29* 0·69* 0·42*	4
Villegas *et al.* (2006)[90]	195			40–70	Interviewer	81	1 year	No	Twelve, within 1 year	Personal interview	Yes	Vitamin C Vitamin E	0·42§ 0·38§	4
Short-term intake														
Block *et al.* (2006)[91]	89	36·8			Interviewer	103	1 year	Yes	Three, within 2 months	Personal interview	Unknown	Vitamin A Vitamin C	0·53* 0·55*	4·5
Boucher *et al.* (2006)[92]	96 W			25–74	Self-administered	109	–	No	Two, within 18 days	Phone interview	Yes	Vitamin C	0·69*	3
Flagg *et al.* (2000)[93]	223 W 216 M	61			Self-administered	68	1 year	Yes	Four, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·26 W*/ 0·45 M* 0·65 W*/0·65 M* 0·27 W*/0·23 M*	4
Fornés *et al.* (2003)[94]	62 W 42 M	38 27	32·5 23·3		First FFQ interviewer	127	–	No	Six, within 6 months	Personal interview	Yes	Vitamin A Vitamin C	0·48* 0·39*	3
Fornés *et al.* (2003)[94]	62 W 42 M	38 27	32·5 23·3		Second FFQ interviewer	127	–	No	Six, within 6 months	Personal interview	Yes	Vitamin A Vitamin C	0·47* 0·42*	3
Hebert *et al.* (1999)[95]	30 W 30 M	36·1 31·4	9·7 7·7		First FFQ interviewer	92	1 year	No	Six, within 1 year	Personal interview	Yes	Vitamin C	0·55‡	2·5
Hebert *et al.* (1999)[95]	30 W 30 M	36·1 31·4	9·7 7·7		Second FFQ interviewer	92	1 year	No	Six, within 1 year	Personal interview	Yes	Vitamin C	0·53‡	2·5
Kumanyika *et al.* (2003)[61]	408 W			21–69	Self-administered	68	–	Yes	Three, within 1 year	Phone interview	Yes	Vitamin C Vitamin E	0·55* 0·26*	2·5
Kusama *et al.* (2005)[96]	62 W 56 M			23–62	Interviewer	116	3 months	No	Three, within 1 month	Personal interview	Yes	Vitamin A Vitamin C	0·45* 0·31*	4·5
Munger *et al.* (1992)[97]	44 W			34–59	Self-administered	126	1 year	Yes	Five, within 1 year	Phone interview	Yes	Vitamin D Vitamin E	0·51* 0·26*	2·5
Navarro *et al.* (2001)[98]	62	57	14		First FFQ interviewer	127	5 years	No	Four, within 3 months	Personal interview	Yes	Vitamin C Vitamin E	0·73* 0·72*	4

Table 5. *Continued*

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	No. of recalls	Recall administration method	Weekend included	Nutrient	Coefficient	Quality index
Navarro *et al.* (2001)[98]	62	57	14		Second FFQ interviewer	127	5 years	No	Four, within 3 months	Personal interview	Yes	Vitamin C Vitamin E	0·73* 0·67*	4
Olafsdottir *et al.* (2006)[99]	53 W	36	5		Self-administered	130	3 months	Yes	Two, within 1 month	Phone interview	Yes	Vitamin A Vitamin C	0·607‡ 0·501‡	3
Rodríguez *et al.* (2002)[100]	30 W 43 M			22–55	Self-administered	52	3 months	No	Three, within 1 month	Personal interview	Yes	Vitamin A Vitamin C	0·48* 0·19*	3
Segovia *et al.* (2006)[101]	87			30–72	Self-administered	171	6 months	No	Six, within 6 months	Phone interview	Yes	Vitamin A Vitamin C Vitamin E	0·42* 0·96* 0·22*	3
Shai *et al.* (1997)[102]	161	50	0·5		Self-administered	126	–	No	Six, within 1 year	Personal interview	Yes	Vitamin E	0·55*	3
Sichieri & Everhart (1998)[103]	46 W 42 M	–			Interviewer	61	1 year	No	Four, within 2 months	Personal interview	Yes	Retinol Vitamin C	0·18‡ 0·23‡	3
Sudha *et al.* (2006)[104]	68 W 34 M	40·9	12·8		First FFQ interviewer	222	1 year	Yes	Six, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·66* 0·35* 0·35*	6
Sudha *et al.* (2006)[104]	68 W 34 M	40·9	12·8		Second FFQ interviewer	222	1 year	Yes	Six, within 1 year	Personal interview	Yes	Vitamin A Vitamin C Vitamin E	0·59* 0·52* 0·42*	6

No., number; Suppl., supplements; W, women; M, men.
* Energy-adjusted, deattenuated correlation coefficient.
† Energy-adjusted, Pearson correlation coefficient.
‡ Crude, Pearson correlation coefficient.
§ Crude, Spearman correlation coefficient.

Table 6. Description of validation studies regarding vitamins A, C, D and E intake (FFQ vs. biomarkers)

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Biomarkers	Coefficient	Quality index
Andersen *et al.* (1999)[8]	125 M			20–55	Self-administered	180	1 year	Yes	Adipose tissue vitamin E Serum vitamin E	−0·10* − 0·05*	4
Ascherio *et al.* (1992)[105]	162 W 110 M	7·2 55·7	52·7 10		Self-administered	126 131	1 year	Yes	Retinol Plasma vitamin E	0·25 W†/0·08 M† 0·41 W†/0·51 M†	3
Bingham *et al.* (1997)[106]	156			50–65	Self-administered	67	1 year	Yes	Blood vitamin C	0·35*	4
Bodner *et al.* (1998)[107]	155 W 188 M			39–45	Self-administered	–	1 year	Yes	Blood vitamin C	0·41†	3
Boeing *et al.* (1997)[76]	49 W 43 M			35–64	Self-administered	158	–	No	Blood retinol Blood vitamin C Blood vitamin E	0·21† 0·36† 0·18†	2·5
Bolton-Smith *et al.* (1991)[108]	196	–			Self-administered	–	–	No	Serum vitamin C Serum vitamin E	0·56† 0·30†	3·5
Brunner *et al.* (2001)[14]	403 W 457 M			39–61	Self-administered	127	1 year	Yes	Plasma vitamin E	−0·07†	3·5
Coates & Monteilh (1991)[109]	94 W	–			Interviewer	98	1 year	Yes	Serum vitamin E	0·35†	3·5
Dixon *et al.* (2006)[110]	86 W 44 M			20–70	Self-administered	124	1 year	Yes	Serum vitamin E	0·70†	4·5
El-Sohemy *et al.* (2001)[111]	121 W 361 M	59 55	10 11		Self-administered	135	1 year	Yes	Plasma vitamin E Adipose tissue vitamin E	0·16† 0·15†	3·5
Fraser *et al.* (2005)[77]	117 W 76 M	–			Self-administered	202	–	No	Plasma vitamin E	0·45†	2·5
Jacques *et al.* (1993)[112]	82 W 57 M			40–83	Interviewer	116	1 year	Yes	Plasma total vitamin C Plasma vitamin D Plasma vitamin E	0·43† 0·35† 0·53†	4·5
Kabagambe *et al.* (2001)[79]	42 W 78 M	59	10		Interviewer	135	1 year	No	Plasma vitamin E Adipose tissue vitamin E	0·06† 0·13†	4
Kardinaal *et al.* (1995)[113]	47 W 38 M			50–70	Self-administered	95	1 year	No	Plasma vitamin E Adipose tissue vitamin E	0·11‡ 0·20‡	2
Katsouyanni *et al.* (1997)[80]	38 W 42 M			25–67	First FFQ self-administered	190	1 year	Yes	Blood vitamin C	0·30†	4
Katsouyanni *et al.* (1997)[80]	38 W 42 M			25–67	Second FFQ self-administered	190	1 year	Yes	Blood vitamin C	0·14†	4
Knutsen *et al.* (2001)[114]	97 Bl 96 Wh	52·8 47·2	17 15		Self-administered	200	1 year	Yes	Plasma vitamin C Plasma vitamin E	0·195 Bl‡/0·027 Wh‡ 0·279 Bl‡/0·397 Wh‡	3
Kobayashi *et al.* (2003)[28]	99 W 86 M	–			Self-administered	138	1 year	Yes	Blood vitamin C	−0·14 W§/−0·20 M§	4·5
Malekshah *et al.* (2006)[81]	82 W 49 M	49·9 51·2	9·3 13		Interviewer	158	1 year	No	Blood retinol Blood vitamin C Plasma vitamin E	0·32‖ 0·35‖ 0·06†	3
Marshall *et al.* (1997)[115]	162 M	–			–	–	–	No	Blood vitamin E	0·10*	1
McKeown *et al.* (2001)[34]	118			45–74	Self-administered	130	1 year	Yes	Blood vitamin C	0·39*	5

Table 6. *Continued*

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Biomarkers	Coefficient	Quality index
McNaughton *et al.* (2005)[35]	17 W 11 M	48	10·5		Self-administered	129	6 months	Yes	Plasma vitamin E	0·31§	2
Ocké *et al.* (1997)[84]	58 W 63 M			20–70 20–60	Self-administered	79	1 year	No	Serum vitamin E	0·07 W‡/0·21 M‡	3
Olafsdottir *et al.* (2006)[99]	53 W	36	5		Self-administered	130	3 months	Yes	Blood vitamin C	0·32*	3·5
Porrini *et al.* (1995)[116]	33 W 11 M	27·1	6·3		Self-administered	93	–	No	Blood vitamin C Plasma vitamin E	0·069* − 0·22*	1
Romieu *et al.* (1999)[86]	110 W			15–54	First FFQ interviewer	116	–	No	Plasma vitamin E	0·07†	2·5
Romieu *et al.* (1999)[86]	110 W			15–54	Second FFQ interviewer	116	–	No	Plasma vitamin E	−0·01†	2·5
Shai *et al.* (1997)[102]	161	50	0·5		Self-administered	126	–	Yes	Plasma vitamin E	0·19‡	4·5
Sinha *et al.* (1992)[117]	68 M			30–59	Self-administered	–	1 year	Yes	Blood vitamin C	0·43‖	2·5
Willett *et al.* (1983)[118]	59			20–54	Self-administered	99	1 year	Yes	Plasma vitamin E	0·34†	3

No, number; Suppl., supplements; W, women; M, men, Bl, black; Wh, white.
* Crude, Spearman correlation coefficient.
† Multivariable-adjusted correlation coefficient.
‡ Energy-adjusted, deattenuated correlation coefficient.
§ Energy-adjusted, Spearman correlation coefficient.
‖ Crude, Pearson correlation coefficient.

Table 7. Description of validation studies regarding vitamins A, C, D and E intake (Other methods)

Author and year of publication	No.	Age (years) Mean	SD	Range	Method	Gold Standard	Suppl.	Nutrient	Coefficient	Quality index
Ascherio *et al.* (1992)[105]	162 W 110 M	52·7 55·7	7·2 10·6		DR	Plasma vitamin E	No	Vitamin E	0·51*	3
Bingham *et al.* (1994)[119]	127 W			50–65	Oxford FFQ self-administered (127 items)	DR weighed (4/4)	No	Vitamin A Vitamin C	0·55† 0·54†	4
Bingham *et al.* (1994)[119]	127 W			50–65	Cambridge FFQ self-administered (130 items)	DR weighed (4/4)	No	Vitamin A Vitamin C	0·32† 0·41†	4
Bingham *et al.* (1994)[119]	106 W			50–65	Structured 24-h R	DR weighed (4/4)	No	Vitamin A Vitamin C	0·33† 0·35†	4
Bingham *et al.* (1994)[119]	73 W			50–65	DR estimated (1/7)	DR weighed (4/4)	No	Vitamin A Vitamin C	0·35† 0·70†	4
Bingham *et al.* (1997)[106]	156			50–65	DR weighed (4/4)	Blood vitamin C	Yes	Vitamin C	0·51†	4
Bingham *et al.* (1997)[106]	156			50–65	24-h R	Blood vitamin C	Yes	Vitamin C	0·34†	4
Bingham *et al.* (1997)[106]	156			50–65	DR estimated (1/7)	Blood vitamin C	Yes	Vitamin C	0·22†	4
Booth *et al.* (1997)[120]	34 60–80	20–40	17 17		DR weighed (3/4)	Plasma vitamin D Plasma vitamin E	No	Vitamin D Vitamin E	0·32* 0·08*	0·5
Dixon *et al.* (2006)[110]	86 W 44 M			20–70	Four personal interview 24-h R	Serum vitamin E	No	Vitamin E	0·72*	4
EPIC Group of Spain (1997)[121]	91			35–60	First dietary history	Twelve personal interview 24-h R	No	Vitamin A Vitamin C Vitamin E	0·36 W‡/0·30 M‡ 0·79 W‡/0·69 M‡ 0·61 W‡/0·64 M‡	2
EPIC Group of Spain (1997)[121]	91			35–60	Second dietary history	Twelve personal interview 24-h R	No	Vitamin A Vitamin C Vitamin E	0·52 W‡/0·28 M‡ 0·82 W‡/0·69 M‡ 0·65 W‡/0·48 M‡	2
EPIC Group of Spain (1997)[122]	72			35–60	Dietary history	Blood vitamin C Blood vitamin E	No	Vitamin C Vitamin E	0·45‡ 0·33‡	2·5
EPIC Group of Spain (1997)[122]	72			35–60	Twelve personal interview 24-h R	Blood vitamin C Blood vitamin E	No	Vitamin C Vitamin E	0·50‡ 0·36‡	2·5
Fraser *et al.* (2005)[73]	117 W 76 M	–			Eight phone interview 24-h R	Plasma vitamin E	No	Vitamin E	0·48*	2·5
Hankin *et al.* (1991)[123]	262			45–74	Dietary history	DR estimated (4/7)	No	Vitamin A Vitamin C	0·40 W§/0·55 M§ 0·50 W§/0·50 M§	4
Hebert *et al.* (1998)[124]	13 M			21–39	DR weighed (3/4)	Ten phone interview 24-h R	No	Vitamin A Vitamin C	0·68‡ 0·50‡	1
Jain *et al.* (1996)[24]	108 W 95 M			35–79	Dietary history	DR estimated (1/7)	No	Vitamin C Vitamin E	0·42 W§/0·38 M§ 0·31 W§/0·44 M§	4·5
Kabagambe *et al.* (2001)[79]	42 W 78 M	59	10		Personal interview 24-h R	Plasma vitamin E Adipose tissue vitamin E	No	Vitamin E	0·21‖ 0·17‖	4
Katsouyanni *et al.* (1997)[80]	38 W 42 M			25–67	Twelve personal interview 24-h R	Blood vitamin C	No	Vitamin C	0·33*	4
Knutsen *et al.* (2001)[114]	97 Bl 96 Wh	52·8 47·2	17 15		Eight phone interview 24-h R	Plasma vitamin E	Yes	Vitamin E	0·52‖	3
Kobayashi *et al.* (2003)[28]	99 W 86 M	–			DR estimated (4/7 or 2/7)	Blood vitamin C	Yes	Vitamin C	−0·02 W¶/−0·13 M¶	4·5
Malekshah *et al.* (2006)[85]	82 W 49 M	49·9 51·2	9·3 13		Twelve personal interview 24-h R	Blood retinal Blood vitamin C Plasma vitamin E	No	Vitamin A Vitamin C Vitamin E	0·26** 0·37** 0·10**	3

Table 7. *Continued*

Author and year of publication	No.	Age (years) Mean	SD	Range	Method	Gold Standard	Suppl.	Nutrient	Coefficient	Quality index
Matthys *et al.* (2004)[125]	50 W	31	6		Computerised self-administered questionnaire	DR estimated (5/2)	No	Vitamin C	0·60†	2
McKeown *et al.* (2001)[34]	118			45–74	DR estimated (2/7)	Blood vitamin C	Yes	Vitamin C	0·53†	5
McNaughton *et al.* (2005)[35]	1149 W 1116 M	43			Personal interview 48-h R	DR estimated (1/5)	No	Vitamin C Vitamin E	0·53 W†/0·54 M† 0·53 W†/0·56 M†	2
Olafsdottir *et al.* (2006)[99]	53 W	36	5		Two phone interview 24-h R	Blood vitamin C	Yes	Vitamin C	0·373†	3·5
Porrini *et al.* (1995)[116]	33 W 11 M	27·1	6·3		DR weighed (1/7)	Blood vitamin C Plasma vitamin E	No	Vitamin C Vitamin E	0·437† 0·098†	1
Riboli *et al.* (1997)[43]	105 W 101 M			50–69	FFQ self-administered (350 items)	DR estimated (6/3)	No	Vitamin A	0·44 W‡/0·58 M‡	3·5
Riboli *et al.* (1997)[43]	105 W 101 M			50–69	FFQ self-administered (130 items)	DR estimated (6/3)	No	Vitamin A	0·72 W‡/0·39 M‡	3·5
Romieu *et al.* (1999)[86]	110 W			15–54	Personal interview 24-h R	Plasma vitamin E	No	Vitamin E	−0·06*	2·5
Sasaki*et al.* (2000)[126]	44 W 42 M			24–67	Dietary history	Plasma vitamin E	No	Vitamin E	0·17 W‡/−0·26 M‡	1·5
Schröder *et al.* (2001)[70]	44	30·7	10·4		Personal interview 72-h R	DR estimated (1/3)	No	Vitamin C Vitamin E	0·54§ 0·54§	3
Shai *et al.* (1997)[102]	161	50	0·5		Personal interview 24-h R	Plasma vitamin E	Yes	Vitamin E	0·33‖	4·5
Smith *et al.* (1996)[127]	302 W 273 M			18–74	Dietary history	24-h R	No	Vitamin A Vitamin C	0·36 W†/0·32 M† 0·35 W†/0·36 M†	3
Takatsuka *et al.* (1997)[128]	18 W 13 M	47·6 44·2	10·8 9·3		Dietary history	DR weighed (12/1)	No	Vitamin A Vitamin C Vitamin D Vitamin E	0·22‡ 0·44‡ 0·53‡ 0·50‡	2
Van Liere *et al.* (1997)[89]	115 W			35–65	Dietary history	Twelve personal interview 24-h R	No	Vitamin C	0·69‖	4

No., number; Suppl., supplements; W, women; M, men; DR, dietary record; Bl, black; Wh, white*; (24-, 48-, 72-) h R, (24-, 48-, 72-) h recall.
* Multivariable-adjusted correlation coefficient.
† Crude, Spearman correlation coefficient.
‡ Energy-adjusted, Pearson correlation coefficient.
§ Intra-class correlation coefficient.
‖ Energy-adjusted, deattenuated correlation coefficient.
¶ Energy-adjusted, Spearman correlation coefficient.
** Crude, Pearson correlation coefficient.

Table 8. Description of validation studies regarding folic acid and B vitamin intake (FFQ vs. dietary records)

Author and year of publication	No.	Age (years)			FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/no. of days per record)	Nutrient	Coefficient	Quality index
		Mean	SD	Range								
Long-term intake												
Andersen *et al.* (1999)[8]	125 M			20–55	Self-administered	180	–	Yes	DR weighed (5/3)	Thiamine Riboflavin	0·54* 0·51*	4
Bautista *et al.* (2005)[9]	45 W 52 M			20–40	Self-administered	60	1 year	No	DR weighed (1/7)	Folic acid Thiamine Riboflavin B_6 B_{12}	0·66† 0·65† 0·66† 0·48† 0·69†	2·5
Block *et al.* (1990)[11]	102 W			45–70	Self-administered	94	6 months	Yes	DR estimated (3/4)	Thiamine Riboflavin	0·47† 0·57†	3·5
Block *et al.* (1992)[12]	85			25–50	Self-administered/ interview	113	1 year	No	DR estimated (4/3) + four 24-h R	Thiamine Riboflavin Niacin	0·47† 0·45† 0·41†	2·5
Block *et al.* (1992)[12]	85			25–50	Self-administered	98	1 year	No	DR estimated (4/3) + four 24-h R	Thiamine Riboflavin Niacin	0·59† 0·59† 0·58†	2·5
Bonifacj *et al.* (1997)[13]	68 W 30 M	42·4 40·8	12·3 10·6		Interviewer	134	1 year	No	DR weighed (4/7)	Folic acid Riboflavin	0·58‡ 0·70‡	3
Brunner *et al.* (2001)[14]	403 W 457 M			39–61	Self-administered	127	1 year	No	DR estimated (1/7)	Folic acid	0·51 W§/0·45 M§	3·5
Cardoso *et al.* (2001)[15]	52 W			21–62	Self-administered	120	1 year	No	DR weighed (4/3)	Folic acid Thiamine Riboflavin Niacin B_6	0·57‡ 0·45‡ 0·30‡ 0·40‡ 0·41‡	3·5
Chen *et al.* (2004)[16]	104 W 85 M			16–75	Interviewer	39	1 year	No	DR estimated (2/7)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·30‡ 0·05‡ 0·46‡ 0·39‡ 0·05‡ 0·57‡	5·5
Date *et al.* (2005)[17]	85			30–69	Self-administered	40	1 year	No	DR weighed (4/3)	Thiamine Riboflavin	0·36§ 0·31§	2·5
Decarli *et al.* (1996)[18]	265 W 130 M			30–69	Interviewer	77	1 year	No	DR weighed (1/7)	Thiamine Riboflavin	0·42‡ 0·52‡	4
Flood *et al.* (2004)[129]	78	70			Self-administered	145	1 year	No	DR weighed (3/4)	Folic acid B_{12}	0·67‖ 0·18‖	2
Friis *et al.* (1997)[21]	122 W			20–29	First FFQ self-administered	92	1 year	No	DR estimated (3/4)	Folic acid Thiamine Riboflavin B_6 B_{12}	0·66‡ 0·66‡ 0·62‡ 0·74‡ 0·71‡	2·5
Friis *et al.* (1997)[21]	122 W			20–29	Second FFQ self-administered	92	1 year	No	DR estimated (3/4)	Folic acid Thiamine Riboflavin B_6 B_{12}	0·63‡ 0·62‡ 0·66‡ 0·80‡ 0·69‡	2·5
Hodge *et al.* (2000)[22]	63 W			16–48	Self-administered	74	1 year	No	DR weighed (1/7)	Thiamine Riboflavin Niacin	0·49‡ 0·57‡ 0·44‡	3·5
Ishihara *et al.* (2003)[23]	176 W 174 M	58 55			Self-administered	180	–	No	DR weighed (4/7)	Thiamine Riboflavin Niacin	0·32 W§/0·28 M§ 0·55 W§/0·55 M§ 0·22 W§/0·33 M§	3
Ishihara *et al.* (2005)[130]	215, cohort I 350, cohort II	–			Self-administered	138	–	Yes	DR weighed (4/7)	Folic acid	0·47 W‡/0·47 M‡ cohort I 0·63 W‡/0·63 M‡ cohort II	2·5
Jain *et al.* (1996)[24]	108 W 95 M			35–79	Self-administered	132	1 year	Yes	DR estimated (1/7)	Thiamine Riboflavin Niacin	0·25 W¶/0·20 M¶ 0·44 W¶/0·42 M¶ 0·31 W¶/0·43 M¶	4·5

Table 8. *Continued*

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/no. of days per record)	Nutrient	Coefficient	Quality index
Jain & McLaughlin (2000)[25]	108 W 95 M			35–79	Self-administered	132	1 year	Yes	DR estimated (1/7)	Thiamine Riboflavin Niacin	0·41 W‖/0·18 M‖ 0·57 W‖/0·36 M‖ 0·38 W‖/0·48 M‖	5
Kelemen *et al.* (2003)[26]	58 South Asians, A 64 Chinese, C 85 European, E			35–75	Self-administered	163 169 157	Unknown	Yes	DR estimated (2/7)	Folic acid B_6 B_{12}	0·54 A‡/0·54 C‡/ 0·55 E‡ 0·70 A‡/0·70 C‡/ 0·59 E‡ 0·70 A‡/0·67 C‡/ 0·66 E‡	3·5
Kim *et al.* (2002)[27]	46 W 23 M	38·16	11·7		Self-administered	118	Unknown	No	DR weighed (1/7)	Folic acid Thiamine Riboflavin Niacin B_6	0·68‡ 0·48‡ 0·60‡ 0·68‡ 0·68‡	3
Lee *et al.* (2006)[29]	25 W 58 M	–			First FFQ interviewer	64	6 months	Yes	DR estimated (3/5)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·62‡ 0·41‡ 0·53‡ 0·45‡ 0·34‡ 0·20‡	5
Lee *et al.* (2006)[29]	25 W 58 M	–			Second FFQ Inter-viewer	64	6 months	Yes	DR estimated (3/5)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	043‡ 0·70‡ 0·86‡ 0·76‡ 0·26‡ 0·30‡	5
Männistö *et al.* (1996)[31]	152 W	51	9		Self-administered	110	1 year	Yes	DR estimated (2/7)	Thiamine Riboflavin Niacin	0·24‡ 0·45‡ 0·61‡	4
Marks *et al.* (2006)[32]	59 W 37 M			25–75	Self-administered	129	6 months	Yes	DR weighed (6/2)	Thiamine Riboflavin Niacin	0·28 W§/0·67 M§ 0·61 W§/0·52 M§ 0·41 W§/0·54 M§	5
Nagata *et al.* (1998)[36]	37			35–66	Self-administered	169	1 year	No	DR estimated (12/1)	Thiamine Riboflavin	0·30 **‡/0·56 ††† 0·55 **‡/0·82 ††‡	2
Ogawa *et al.* (2003)[37]	58 W 55 M			45–77	Self-administered	40	1 year	Yes	DR estimated (4/3)	Thiamine Riboflavin Niacin	0·31 W‡/0·33 M‡ 0·54 W‡/0·43 M‡ 0·47 W‡/0·33 M‡	4·5
Patterson *et al.* (1999)[38]	113 W			50–79	Self-administered	122	3 months	Yes	DR estimated (1/4) + four 24-h (phone) R	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·69‡ 0·21‡ 0·29‡ 0·45‡ 0·43‡ 0·28‡	4
Potischman *et al.* (1999)[41]	219 W			20–54	Self-administered	60 100	1 year	No	DR estimated (2/3) + six 24-h (phone) R	Folic acid	0·33 (60 items)‡ 0·36 (100 items)‡	3
Potosky *et al.* (1990)[42]	97 W			45–70	Self-administered	94	6 months	No	DR estimated (3/4)	Thiamine Riboflavin	0·62† 0·69†	1·5
Riboli *et al.* (1997)[43]	105 W 101 M			50–69	Self-administered	350	1 year	No	DR weighed (6/3)	Folic acid	0·69 W‖/0·53 M‖	2·5
Riboli *et al.* (1997)[43]	105 W 101 M			50–69	Self-administered	130	1 year	No	DR weighed (6/3)	Folic acid	0·71 W‖/0·42 M‖	2·5
Rimm *et al.* (1992)[44]	127 M			40–75	First FFQ self-adminis-tered	131	1 year	Yes	DR weighed (2/7)	Folic acid Thiamine Riboflavin B_6 B_{12}	0·52‡ 0·69‡ 0·70‡ 0·81‡ 0·41‡	4
Rimm *et al.* (1992)[44]	127 M			40–75	Second FFQ Self-admi-nistered	131	1 year	Yes	DR weighed (2/7)	Folic acid Thiamine Riboflavin B_6 B_{12}	0·77‡ 0·86‡ 0·88‡ 0·85‡ 0·56‡	4

Table 8. *Continued*

Author and year of publication	No.	Age (years) Mean	SD	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/no. of days per record)	Nutrient	Coefficient	Quality index
Roddam *et al.* (2005)[45]	202 W			50–64	Self-administered	18 groups	1 week	No	DR weighed (1/7)	Thiamine Riboflavin Niacin B_6 B_{12}	0·36‖ 0·58‖ 0·40‖ 0·43‖ 0·24‖	3
Tsubono *et al.* (2001)[49]	58 W 55 M	61 62	8·5 8·5		First FFQ self-administered	141	1 year	Yes	DR estimated (4/3)	Thiamine Riboflavin Niacin	0·24‡ 0·52‡ 0·37‡	4
Tsubono *et al.* (2001)[49]	58 W 55 M	61 62	8·5 8·5		Second FFQ self-administered	141	1 year	Yes	DR estimated (4/3)	Thiamine Riboflavin Niacin	0·37‡ 0·40‡ 0·49‡	4
Tsubono *et al.* (2001)[50]	107 W 94 M			40–59	First FFQ self-administered	44	1 month	Yes	DR estimated (4/7)	Thiamine Riboflavin Niacin	0·26 W‡/0·29 M‡ 0·42 W‡/0·32 M‡ 0·12 W‡/0·23 M‡	4
Tsubono *et al.* (2001)[50]	107 W 94 M			40–59	Second FFQ self-administered	44	1 month	Yes	DR estimated (4/7)	Thiamine Riboflavin Niacin	0·24 W‡/0·41 M‡ 0·41 W‡/0·45 M‡ 0·12 W‡/0·15 M‡	4
Tsugane *et al.* (2003)[51]	113 W 102 M	53·5 53·6	5·3 5·2		Self-administered	138	1 year	Yes	DR estimated (4/7 or 2/7)	Thiamine Riboflavin Niacin	0·44 W§/0·41 M§ 0·46 W§/0·43 M§ 0·18 W§/0·35 M§	4·5
Willett *et al.* (1985)[52]	173 W			34–59	First FFQ self-administered	61	1 year	Yes	DR weighed (4/7)	B_6	0·47‖	4
Willett *et al.* (1985)[52]	173 W			34–59	Second FFQ self-administered	61	1 year	Yes	DR weighed (4/7)	B_6	0·58‖	4
Willett *et al.* (1987)[53]	29			20–54	Self-administered	116	1 year	Yes	DR weighed (1/365)	Thiamine Riboflavin Niacin	0·42‡‡ 0·31‡‡ 0·37‡‡	1·5
Short-term intake												
Bacardí-Gascón *et al.* (2003)[131]	34 W			18–35	Self-administered	31	1 year	No	DR weighed (1/5)	Folic acid	0·71*	0·5
Baumgartner *et al.* (1998)[54]	132 W			35–74	Interviewer	140	1 month	No	DR estimated (1/4)	Folic acid	0·41‖	3·5
Fregapane & Asensio (2000)[55]	38			18–61	Self-administered	202	Unknown	No	DR weighed (1/4)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·28¶ 0·28¶ 0·84¶ 0·46¶ 0·27¶ 0·38¶	1·5
French *et al.* (2001)[132]	20 W			18–45	Interviewer	140	6 months	No	DR estimated (1/3)	Folic acid	0·36†	1
French *et al.* (2001)[132]	17 W			18–45	Interviewer	81	6 months	No	DR estimated (1/7)	Folic acid	0·51†	1
George *et al.* (2004)[56]	95 W	20·1	4·3		Self-administered	195	6 months	No	DR estimated (1/3)	Folic acid Thiamine Riboflavin Niacin B_5	0·38‡ 0·34‡ 0·40‡ 0·35‡ 0·34‡	3·5
George *et al.* (2004)[56]	50 W	23·1	4·3		Self-administered	195	6 months	No	DR estimated (1/4) + two 24-h (interview) R	Folic acid Thiamine Riboflavin Niacin B_5	0·41‡ 0·42‡ 0·48‡ 0·40‡ 0·37‡	3·5
Goulet *et al.* (2004)[57]	71 W			30–65	Interviewer	91	1 month	No	DR estimated (1/3)	Folic acid	0·39§	1
Hartwell & Henry (2001)[58]	9 W 16 M	58·1	1·7		Self-administered	162	1 year	No	DR estimated (1/4)	Thiamine	0·57†	1·5
Ke *et al.* (2005)[59]	100	–			Self-administered	125	1 year	No	DR weighed (1/4)	Folic acid	0·43‖	3
Kumanyika *et al.* (2003)[61]	408 W			21–69	Self-administered	68	1 year	No	DR estimated (1/3) + three 24-h (phone) R	Folic acid	0·64‡	2·5
Longnecker *et al.* (1993)[62]	74 W 64 M	49	14		First FFQ self-administered	116	1 year	No	DR estimated (3/2)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·42‡ 0·50‡ 0·63‡ 0·29‡ 0·43‡ 0·72‡	2·5

Table 8. *Continued*

Author and year of publication	No.	Age (years) Mean	Age (years) SD	Age (years) Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	Reference method (no. of records/no. of days per record)	Nutrient	Coefficient	Quality index
Longnecker *et al.* (1993)[62]	74 W 64 M	49	14		Second FFQ self-administered	116	1 year	No	DR estimated (3/2)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·45‡ 0·52‡ 0·57‡ 0·28‡ 0·49‡ 0·78‡	2·5
Martínez *et al.* (1999)[63]	42 W 97 M	66·4			Self-administered	132	1 year	Yes	DR weighed (1/4)	Folic acid Thiamine Riboflavin Niacin	0·53‡ 0·56‡ 0·66‡ 0·63‡	4
Masson *et al.* (2003)[64]	40 W 41 M			19–58	Self-administered	150	2–3 months	No	DR weighed (1/4)	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·78 W‖/0·56 M‖ 0·84 W‖/0·83 M‖ 0·82 W‖/0·72 M‖ 0·57 W‖/0·51 M‖ 0·55 W‖/0·40 M‖ 0·39 W‖/0·24 M‖	2·5
Moreira *et al.* (2003)[65]	159 W 87 M			18–29	Interviewer	82	Unknown	No	DR estimated (1/4)	Folic acid Thiamine Riboflavin B_6 B_{12}	0·53 W‖/0·38 M‖ 0·40 W‖/0·40 M‖ 0·71 W‖/0·59 M‖ 0·62 W‖/0·55 M‖ 0·26 W‖/0·30 M‖	3
Paalanen *et al.* (2006)[66]	157 W 137 M			30–79	Self-administered	128	1 year	No	DR estimated (1/3)	Folic acid Thiamine Riboflavin	0·46 W‖/0·41 M‖ 0·49 W‖/0·26 M‖ 0·65 W‖/0·63 M‖	3·5
Parr *et al.* (2002)[67]	34 W 36 M			15–45	Interviewer	164	1 week	No	DR weighed (1/2)	Thiamine Riboflavin Niacin	0·53* 0·30* 0·43*	4
Sasaki *et al.* (1998)[68]	47 W			38–69	Self-administered	110	1 month	No	DR estimated (1/3)	Thiamine Riboflavin Niacin	0·46‡ 0·58‡ 0·19‡	3
Schröder *et al.* (2001)[70]	44	30·7	10·4		Self-administered	157	Unknown	No	DR weighed (1/3)	Folic acid Niacin B_6	0·21¶ 0·23¶ 0·48¶	3
Tokudome *et al.* (2005)[71]	129 W 73 M			30–70	Self-administered	47	1 year	No	DR estimated (1/3)	Folic acid Thiamine Riboflavin	0·38 W‡/0·36 M‡ 0·10 W‡/0·26 M‡ 0·43 W‡/0·57 M‡	3·5
Torheim *et al.* (2001)[133]	48 W 27 M			15–59	Self-administered	69	1 week	No	DR weighed/estimated (1/2)	Thiamine Riboflavin Niacin	0·40* 0·46* 0·38*	2

No., number; Suppl., supplements; M, men; DR, dietary record; W, women; 24-h R, 24-h recall.
* Crude, Spearman correlation coefficient.
† Crude, Pearson correlation coefficient.
‡ Energy-adjusted, deattenuated correlation coefficient.
§ Energy-adjusted, Spearman correlation coefficient.
‖ Energy-adjusted, Pearson correlation coefficient.
¶ Intra-class correlation coefficient.
‡‡ Age, sex and energy-adjusted, Pearson correlation coefficient.
** Low-food diversity.
†† High-food diversity.

Table 9. Description of validation studies regarding folic acid and B vitamin intake (FFQ vs. 24-h recalls)

Author and year of publication	No.	Age (years)			FFQ administration method	No. of foods	FFQ reference period	Suppl.	No. of recalls	Recall administration method	Weekend included	Nutrient	Coefficient	Quality index
		Mean	sd	Range										
Long-term intake														
Fraser *et al.* (2005)[73]	315	–			Self-administered	202	–	No	Eight, within 6 months	Phone interview	Yes	Folic acid	0·65*	2·5
Hebert *et al.* (1998)[75]	30 W 30 M	43·2 52·6	13·6 10·9		First FFQ inter-viewer	81	1 year	No	Eight, within 1 year	Personal interview	Yes	Thiamine Riboflavin	0·52† 0·61†	2·5
Hebert *et al.* (1998)[75]	30 W 30 M	43·2 52·6	13·6 10·9		Second FFQ inter-viewer	81	1 year	No	Eight, within 1 year	Personal interview	Yes	Thiamine Riboflavin	0·55† 0·61†	2·5
Hernández-Ávila *et al.* (1998)[76]	134 W	–			First FFQ self-administered	85	–	No	Sixteen, within 1 year	Personal interview	Yes	Folic acid Thiamine Riboflavin B_6 B_{12}	0·15* 0·43* 0·43* 0·31* 0·23*	3
Hernández-Ávila *et al.* (1998)[76]	134 W	–			Second FFQ self-administered	85	–	No	Sixteen, within 1 year	Personal interview	Yes	Folic acid Thiamine Riboflavin B_6 B_{12}	0·22* 0·32* 0·51* 0·31* 0·29*	3
Kabagambe *et al.* (2001)[79]	42 W 78 M	59	10		Interviewer	135	1 year	No	Seven, within 7 months	Personal interview	Yes	Folic acid B_6 B_{12}	0·60* 0·47* 1·00*	4
Messerer *et al.* (2004)[83]	248 M			40–74	Self-administered	88	1 year	Yes	Fourteen, within 1 year	Phone interview	Yes	Folic acid B_6	0·50* 0·65*	4·5
Sevak *et al.* (1997)[87]	100 W	53·5	8·5		Interviewer	207	–	No	Twelve, within 1 year	Phone interview	Yes	Folic acid B_{12}	0·77* 0·57*	3·5
Shu *et al.* (2004)[88]	191 W	55·4	9		Interviewer	77	1 year	No	Twenty-four, within 1 year	Personal interview	Yes	Thiamine Riboflavin Niacin	0·59† 0·56† 0·58†	4
Villegas *et al.* (2006)[90]	195			40–70	Interviewer	81	1 year	No	Twelve, within 1 year	Personal interview	Yes	Thiamine Riboflavin Niacin	0·58‡ 0·46‡ 0·52‡	4
Short-term intake														
Bacardí-Gascón *et al.* (2003)[131]	70 W			18–35	Self-administered	31	–	No	One	Personal interview	–	Folic acid	0·37‡	0·5
Boucher *et al.* (2006)[92]	96 W			25–74	Self-administered	109	–	No	Two, within 18 days	Phone interview	Yes	Folic acid Thiamine Riboflavin Niacin B_6 B_{12}	0·76* 0·75* 0·74* 0·75* 0·74* 0·69*	3
Flagg *et al.* (2000)[93]	223 W 216 M	61			Self-administered	68	1 year	Yes	Four, within 1 year	Personal interview	Yes	Folic acid	0·43 W*/ 0·51 M*	4
Hebert *et al.* (1999)[95]	30 W 30 M	36·1 31·4	9·7 7·7		First FFQ inter-viewer	92	1 year	No	Six, within 1 year	Personal interview	Yes	Thiamine Riboflavin	0·77† 0·99†	2·5
Hebert *et al.* (1999)[95]	30 W 30 M	36·1 31·4	9·7 7·7		Second FFQ interviewer	92	1 year	No	Six, within 1 year	Personal interview	Yes	Thiamine Riboflavin	0·85* 1·0*	2·5

Table 9. *Continued*

Author and year of publication	No.	Age (years) Mean	sd	Range	FFQ administration method	No. of foods	FFQ reference period	Suppl.	No. of recalls	Recall administration method	Weekend included	Nutrient	Coefficient	Quality index
Kumanyika *et al.* (2003)[61]	408 W			21–69	Self-administered	68	–	Yes	Three, within 1 year	Phone interview	Yes	Folic acid	0·70*	2·5
Kusama *et al.* (2005)[96]	62 W 56 M			23–62	Interviewer	116	3 months	No	Three, within 1 month	Personal interview	Yes	Thiamine Riboflavin	0·38* 0·29*	4·5
Navarro *et al.* (2001)[98]	62	57	14		First FFQ interviewer	127	5 years	No	Four, within 3 months	Personal interview	Yes	Thiamine Riboflavin Niacin B_6	0·78* 0·86* 0·62* 0·62*	4
Navarro *et al.* (2001)[98]	62	57	14		Second FFQ interviewer	127	5 years	No	Four, within 3 months	Personal interview	Yes	Thiamine Riboflavin Niacin B_6	0·68* 0·82* 0·54* 0·57*	4
Rodríguez *et al.* (2002)[100]	30 W 43 M			22–55	Self-administered	52	3 months	No	Three, within 1 month	Personal interview	Yes	Thiamine Riboflavin Niacin	0·26* 0·49* 1·00*	3
Segovia *et al.* (2006)[101]	87			30–72	Self-administered	171	6 months	No	Six, within 6 months	Phone interview	Yes	Folic acid	0·39*	3
Sudha *et al.* (2006)[104]	68 W 34 M	40·9	12·8		First FFQ interviewer	222	1 year	Yes	Six, within 1 year	Personal interview	Yes	Folic acid	0·29*	6
Sudha *et al.* (2006)[104]	68 W 34 M	40·9	12·8		Second FFQ interviewer	222	1 year	Yes	Six, within 1 year	Personal interview	Yes	Folic acid	0·39*	6
Verkleij-Hagoort *et al.* (2007)[134]	53 W			24–44	Self-administered	121	4 weeks	No	Three, within 3 weeks	Phone interview	Yes	Folic acid B_{12}	0·98* 0·66*	1·5

No., number; Suppl., supplements; W, women; M, men.
* Energy-adjusted, deattenuated correlation coefficient.
† Crude, Pearson correlation coefficient.
‡ Crude, Spearman correlation coefficient.

Table 10. Description of validation studies regarding folic acid and B vitamin intake (FFQ vs. biomarkers)

Author and year of publication	No.	Age (years)			FFQ administration method	No. of foods	FFQ reference period	Suppl.	Biomarkers	Coefficient	Quality index
		Mean	SD	Range							
Drogan *et al.* (2004)[135]	160 W 203 M	160 203	10 9·4		Self-administered	148	1 year	Yes	Plasma folate RBC folate	0·24* 0·13*	3
Fraser *et al.* (2005)[73]	117 W 76 M	–			Self-administered	202	–	No	RBC folate	0·28†	2·5
Hickling *et al.* (2005)[136]	568 W			33–83	Self-administered	19	1 week	Yes	Serum folate	0·49*	3
Jacques *et al.* (1993)[102]	82 W 57 M			40–83	Interviewer	116	1 year	Yes	Plasma folate RBC thiamine RBC riboflavin RBC B_6 Plasma B_{12}	0·63† 0·02† − 0·13† − 0·15† 0·35†	4·5
Pufulete *et al.* (2002)[137]	20 W 16 M			22–65	Self-administered	90	1 year	Yes	Serum folate RBC folate	0·69 W‡/0·85 M‡ 0·41 W‡/0·69 M‡	4
Verkleij-Hagoort *et al.* (2007)[134]	53 W			24–44	Self-administered	121	4 weeks	No	Serum folate RBC folate	0·20‡ 0·28‡	2
Yen *et al.* (2003)[138]	28 W			21–74	Self-administered	122	1 month	Yes	Plasma folate	− 0·26§	2·5

No., number; Suppl., supplements; W, women; M, men; RBC, red blood cells.
* Crude, Pearson correlation coefficient.
† Multivariable-adjusted correlation coefficient.
‡ Energy-adjusted, deattenuated correlation coefficient.
§ Crude, Spearman correlation coefficient.

Table 11. Description of validation studies regarding folic acid and B vitamin intake (Other methods)

Author and year of publication	No.	Age (years)			Method	Gold standard	Suppl.	Nutrient	Coefficient	Quality index
		Mean	SD	Range						
Bacardí-Gascón *et al.* (2003)[131]	34 W			18–35	DR weighed (1/5)	Serum folate	No	Folic acid	0·40*	0·5
Fraser *et al.* (2005)[73]	117 W 76 M	–			Eight phone interview 24-h R	RBC folate	No	Folic acid	0·51†	2·5
Jain *et al.* (1996)[24]	108 W 95 M			35–79	Dietary history	DR estimated (1/7)	No	Thiamine Riboflavin Niacin	0·34 W‡/0·24 M‡ 0·56 W‡/0·40 M‡ 0·35 W‡/0·46 M‡	4·5
McNaughton *et al.* (2005)[35]	1149 W 1116 M	43			Personal interview 48-h R	DR estimated (1/5)	No	Folic acid B_6 B_{12}	0·62 W*/0·57 M* 0·62 W*/0·58 M* 0·34 W*/0·29 M*	2
Pufulete *et al.* (2002)[137]	20 W 16 M			22–65	FFQ self-administered	Serum folate RBC folate	Yes	Folic acid Folic acid	0·69 W†/0·85 M† 0·41 W†/0·69 M†	4
Pufulete *et al.* (2002)[137]	20 W 16 M			22–65	DR weighed (1/7)	Serum folate RBC folate	Yes	Folic acid Folic acid	0·44 W†/0·81 M† 0·72 W†/1·00 M†	4
Schröder *et al.* (2001)[70]	44	30·7	10·4		Personal interview 72-h R	DR estimated (1/3)	No	Folic acid Niacin B_6	0·46‡ 0·28‡ 0·57‡	3
Verkleij-Hagoort *et al.* (2007)[134]	53 W			24–44	Three phone interview 24-h R	Serum folate RBC folate	No	Folic acid Folic acid	0·22§ 0·49§	2
Yen *et al.* (2003)[138]	28 W			21–74	Seven phone/mail interview 24-h R	Plasma folate	Yes	Folic acid	0·354*	2·5

No., number; Suppl., supplements; W, women; M, men; DR, dietary record (no. of records/no. of days per record); (24-, 48-, 72-) h R, (24-, 48-, 72-) h recall; RBC, red blood cells.
* Crude, Spearman correlation coefficient.
† Energy-adjusted, deattenuated correlation coefficient.
‡ Intra-class correlation coefficient.
§ Multivariable-adjusted correlation coefficient.

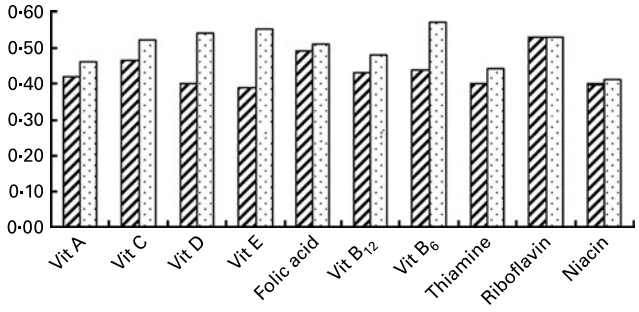

Fig. 1. Weighted correlation coefficients for FFQ *v.* dietary record per vitamin and number of food items included in the FFQ. ▨, foods < 100; ⊡, Foods ≥ 100.

correlated errors, whereas dietary histories as gold standards are considered the least appropriate[1].

The validity of other methods was also evaluated. However, their relatively low number and the many different reference methods that were used led us to focus on FFQ. The vast majority of FFQ were self-administered. Despite the fact that data collection was simplified, their incompleteness is a serious handicap as well as their lack of precision, given the large interpersonal variability in diet recalls[3]. In a review of FFQ validation studies, Cade *et al.*[4] found that CC always improved, with the exception of vitamin C, when questionnaires were administered by an interviewer compared to those that were self-administered.

Time-frame concordance between FFQ and the reference method is even more crucial. The period of time which the dietary intake is referring to depends on the objectives of the study[5]. Usually, FFQ are designated to measure diet during the preceding year, whereas the reference methods do not cover the same time period. Multiple DR or recalls must be collected during the study period, and there is also a need to take into account seasonal variability, especially if we are interested in vitamin intakes, which are highly influenced by market availability. We have found that dietary intakes correlate better when the number of days covered by the reference method increases, except for B-complex vitamins when recall methods were used.

The order in which the FFQ and the reference method are applied is also decisive, considering that the results of the first measurement can affect those collected later on. We recommend that FFQ data be collected before gold standard measurement[5]. In many studies that were reviewed, FFQ

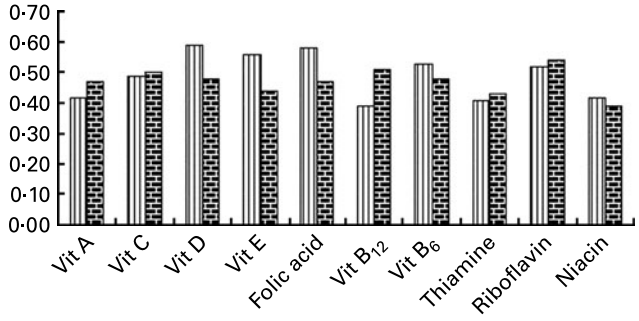

Fig. 2. Weighted correlation coefficients distributed by vitamin supplement intake. ▥, Supplement; ⊞, no supplement.

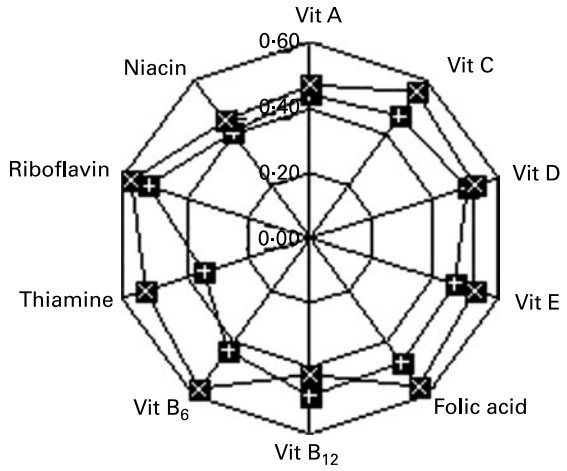

Fig. 3. Weighted correlation coefficients distributed by type of dietary record (weighed *v.* estimated dietary record). ⊞, estimated dietary record; ⊠, weighed dietary record.

were applied twice, before and alter the reference period for the gold standard, in order to evaluate its reproducibility. However, the results depend on the vitamins considered.

The number of foods included in the FFQ has been classically considered as a key component to assure validity of dietary intakes. Using a meta-analysis, Molag *et al.*[6] highlighted this point as the major determinant for ranking individuals according to their intakes. In the same vein, we have also found an improvement of the correlation when the numbers of food items surpassed 100: shorter questionnaires (<100 food items) yielded worse CC (mean 0·47) than those including more items (0·52), the latter having less variation as well.

However, it is also clear that the administration of longer FFQ is more expensive and participation rates may decrease. The use of extensive food lists is said to give less reliable results than shorter forms[1], or even less information. The foods to be included in a FFQ should be restricted to those that are the principal source of the nutrient(s) of interest, and the frequency of their consumption must also be considered.

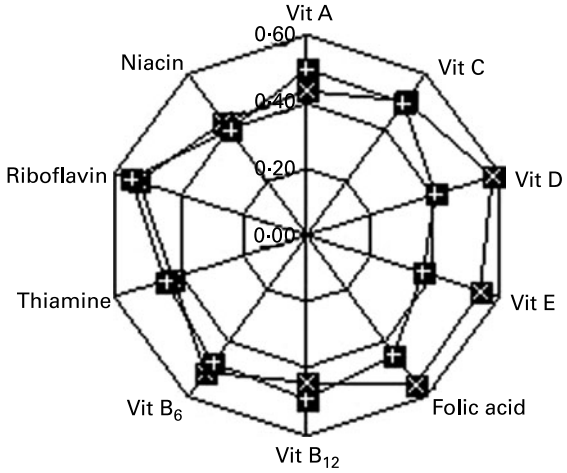

Fig. 4. Weighted correlation coefficients distributed by number of days registered. ⊠, long-term intake; ⊞, short-term intake.

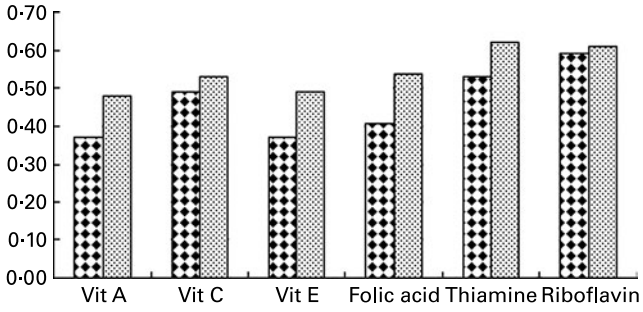

Fig. 5. Weighted correlation coefficients for FFQ *v.* recall per vitamin and number of foods items included in the FFQ. ▦, foods < 100; ⚄, foods ≥ 100.

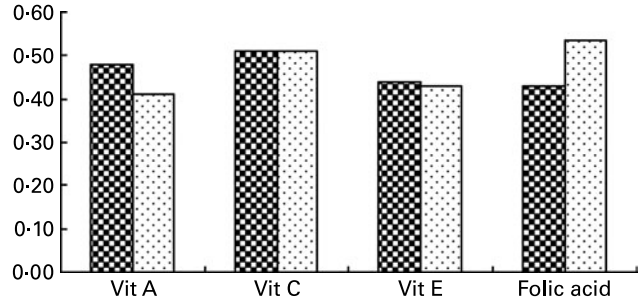

Fig. 6. Weighted correlation coefficients distributed by vitamin supplement intake. Several vitamins were not included in the figure because of the small number of studies collecting vitamin supplement use. ⚄, supplements; ⚀, no supplements.

Supplements should be present in any dietary data assessment. We observed that data from FFQ and the reference method correlate better when specific questions about supplement intake are included, provided that they are asked for with the same emphasis. We stress the need to ask for the type and dosage of supplement use.

DR were the most commonly used reference method to validate the vitamin intakes measured by FFQ. We find narrower ranges of CC when DR are used, and so they may be less variable than recalls. Correlations are probably suboptimal when

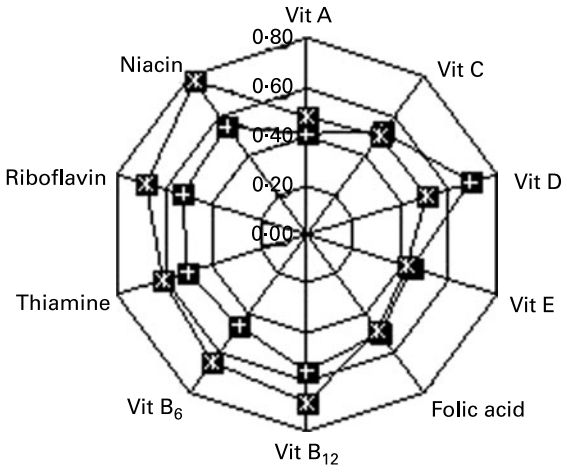

Fig. 7. Weighted correlation coefficients distributed by the number of days registered in the recalls. ⊞, long-term intake; ⊠, short-term intake.

methods are used which share the inherent errors associated to FFQ, such as lack of memory and estimation of portion sizes.

Biomarker characteristics are responsible for the observed low correlations. Specifically, for vitamin C, plasma levels only show recent intake. Concerning vitamin E, for which more biomarker-based validation studies have been done, correlation is even worse, given that only four studied its level in adipose tissue, which is the more appropriate marker for usual vitamin E intake.

In any case, the highest correlation coefficient observed, weighed by quality, was 0·5. In light of this, we recommend the application of correction factors to any population-based nutrition study.

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