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Dietary assessment methods on *n*-3 fatty acid intake: a systematic review

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In order to assess nutritional adequacy, valid estimates of nutrient intake are required. Specifically, the EURopean micronutrient RECommendations Aligned (EURRECA) Network of Excellence needs clear guidelines for assessing the validity of reported micronutrient intakes and *n*-3 fatty acid (FA) intakes. The aim of the present study was to review the validity of methods used to measure the usual *n*-3 FA intake of a population. A systematic literature search was conducted for studies validating the methodology used for measuring the dietary intake of *n*-3 FA. The quality of the validation studies and the quality of the different dietary assessment methods were assessed using scoring systems developed by EURRECA. Fourteen papers, describing twenty studies, were identified for inclusion. According to the score system developed by EURRECA, all the studies were ranked as average, except two that were ranked as poor. The correlation coefficients between FA in subcutaneous fat and dietary intake of *n*-3 FA from four FFQ, one weighed record and one 24-h recall ranged between 0·40 and 0·60. Correlations between intake of *n*-3 FA from five FFQ, one dietary history and three weighed records and blood lipids were similar to the ones observed for subcutaneous fat. The summarised quality of the *n*-3 FA estimates derived from the FFQ was judged as good or acceptable according to the EURRECA scoring system. The literature describes subcutaneous fat as the best reference method, and the studies where this was used had moderate correlation coefficients and no dietary intake method was superior to any other.

Omega 3 fatty acids: Dietary assessment methods

Nutritional epidemiological research has to deal with measurement errors and inter- and intra-individual variability, which are specific for each micronutrient. Public health decisions must rely on valid and precise estimates of micronutrient intake. There is a need to reach a consensus about the best available methods for assessing micronutrient intake at the population level. The European project EURopean micronutrient RECommendations Aligned (EURRECA) reviews all literature in regard to validation of methods used to assess intake of micronutrients and *n*-3 FA. In this review of literature, dietary methods used to assess intake of *n*-3 FA are presented. The effect of dietary fats on health and disease has been of interest for many decades. The various health benefits of consuming the long-chain *n*-3 PUFA (LC *n*-3 PUFA), particularly eicosapentaenoic acid EPA and docosahexaenoic acid (DHA), have been reported widely[(1)]. The LC *n*-3 PUFA are obtained predominantly from fish, seafood, meat and eggs[(1)] and in recent years from enriched food products such as bread, milk, margarine and eggs[(1)]. The aim of the present paper was to review the validity of methods used to measure the usual *n*-3 FA intake of a population.

Methods of this review

A systematic literature search was performed in December 2007 and March 2008. The literature search was conducted in Medline OvidSP and EMBASE using the following terms: 'fatty acids'; 'assessment'; 'correlat*'; 'diet'; 'energy'; 'fish'; 'history'; 'marine'; 'nutrient'; 'oil'; 'omega'; 'omega-3'; 'questionnaire*'; 'recall'; 'record'; 'studies'; 'validat'; 'validation' including MeSH-terms. In total, 5572 articles were selected using Medline Ovid SP, while 1314 were identified from EMBASE. A new search was conducted after new guidelines from EURRECA using the search terms: 'validity' or 'validation study' or 'reproducibility' or 'replication study' or 'correlation coefficient' or 'correlational study' or 'validity'/syn or 'validation study'/syn or 'reproducibility'/syn or 'replication study'/syn or 'correlation coefficient'/syn or 'correlational study'/syn, in addition to those included of *n*-3 FA. The search

Abbreviations: ALA, α-linolenic acid; EURRECA, EURopean micronutrient RECommendations Aligned; FA, fatty acids; LC *n*-3 PUFA, long-chain *n*-3 PUFA.

On behalf of EURRECA's RA 1.1 'Intake Methods' members: Serra-Majem L (Coordinator), Cavelaars A, De Groot L, De Vries J, Dhonukshe-Rutten R, Doreste JL, Frost-Andersen L, García-Álvarez A, Glibetic M, Gurinovic M, Henríquez-Sánchez P, Naska A, Ngo J, Novakovic R, Ortiz-Andrellucchi A, Øverby NC, Pijls L, Ranic M, Ribas-Barba L, Ristic-Medic D, Román-Viñas B, Ruprich J, Saavedra-Santana P, Sánchez-Villegas A, Tabacchi G, Tepsic J, Trichopoulou A, van't Veer P, Vucic V, Wijnhoven TMA.

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was rerun in EMBASE, however, no further articles were included from this search.

To find the articles included in this review, the following exclusion criteria were used: (1) articles assessing exclusively macronutrients and/or energy; (2) studies describing the content of nutrients in foods, 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 focusing only on statistical methods; (9) studies evaluating the physiological effects of foods, nutrients and in relation to their genetic determinants; (10) studies in animals, written in other languages rather than English, Spanish, French, Italian, Portuguese and those without abstract in Pubmed. After reading the title or abstract of all these (*n* 6886) articles, thirty-seven articles were left. The literature lists in the selected papers were checked and more articles were included. Last, we asked other experts to suggest relevant papers. Two papers were identified after consulting others (EURRECA). In total, fourteen articles were included in the results, including twenty studies (sixteen validation studies and four calibration studies).

Methods used in the included studies

Validated dietary methods

Tables 1 and 2 show descriptive information of the selected articles for this analysis. In the fourteen articles included in the review, eleven different FFQ had been validated (some articles present validation of more than one instrument)[1–9]. All the FFQ were designed to capture the usual diet, however, the time period covered ranged from the habitual diet over the last 3 months[9] or the last 12 months[6]. Some questionnaires specifically asked only about *n*-3 FA rich food[1], while others covered the whole diet with 102–200 food items included in the questionnaire[2,4–6,7,8,10]. A dietary history questionnaire had been validated in one study[11]. Weighed records had been validated in four studies[8,12–14] and 24-h recalls in one study[10].

Applied reference methods

Adipose tissue biopsy (subcutaneous fat). Adipose tissue FA were determined using chromatography and calculating the area under the curve for each of the FA. All the studies using FA in tissue reported the same procedure with only slight modifications[2,4,10,12].

Serum or plasma lipids. After extraction and isolation, the serum/plasma phospholipids were quantified by GLC after methylation[3,7,8,11,13,14]. Some expressed the serum phospholipids as mg FA/l serum[3], while most used percent of total FA methyl esters[4,5,11,13] or both[7]. For detailed descriptions, refer to each particular study.

Table 1. Description of the fourteen studies included in this review validating intake of *n*-3 fatty acids (sorted by publication date)

Author	Year pub	Country	*n*	Age (years)		Dietary method which was validated	Reference method 1	Reference method 2
				Mean	SD			
Hunter *et al.*[2]	1992	USA	118	45–65		FFQ	Subcutaneous fat aspirates from the lateral buttock	
Marckmann *et al.*[12]	1995	Denmark	24	20–29		3 × 7-d weighed food records	FA composition of subcutaneous fat	
Hjartåker *et al.*[3]	1997	Norway	234	40–42		FFQ	Serum phospholipids FA composition	
Andersen *et al.*[4]	1999	Norway	119*/135	20–55		FFQ	Subcutaneous adipose tissue of the buttock	Blood sample
Sasaki *et al.*[11]	2000	Japan	86	19–58		DHQ	Serum FA	
Kobayashi *et al.*[13]	2001	Japan	87	50–59		7-d food weighed record	FA composition of serum phospholipids	
Tokudome *et al.*[5]	2001	Japan	79	32–66		FFQ	28-d weighed food records	
Kuriki *et al.*[14]	2003	Japan	94	35–55		7-d weighed record	Plasma FA	
Knutsen *et al.*[10]	2003	USA	49†/72	48	15·2	FFQ and eight different 24-h recall	Adipose tissue from the buttock	
Paalanen *et al.*[6]	2006	Finland	294	30–79		FFQ	Food records	
Sullivan *et al.*[1]	2006	Australia	53	19–58		FFQ	Erythrocyte FA and plasma FA	
Hodge *et al.*[7]	2007	Australia	4439	40–69		FFQ	Plasma total lipids	
McNaughton *et al.*[8]	2007	Australia	43	28–75		FFQ	Phospholipid FA	2 × 6 d weighed record
Sullivan *et al.*[9]	2008	Australia	45	19–58		FFQ	Food records 3 d	

FA, fatty acids; pub, publication; DHQ, diet history questionnaire.
*Adipose tissue samples/blood samples.
†Black/white subjects.

Table 2. Crude and adjusted correlations for dietary methods *v.* reference methods in the fourteen studies included in this review

Author	*n*	Dietary method which was validated	Reference method	Crude	Energy adjusted
Hunter *et al.* [2]	118	FFQ 1	Subcutaneous fat	EPA: 0·43*†	EPA: 0·47†
Hunter *et al.* [2]	118	FFQ 2	Subcutaneous fat	EPA: 0·48*†	EPA: 0·47†
Andersen *et al.* [4]	119	FFQ	Subcutaneous fat	ALA: 0·42*† EPA: 0·52*† DPA: 0·39*† DHA; 0·49*†	
Knutsen *et al.* [10]	49‡/72	FFQ	Adipose tissue (buttock)	ALA: 0·29§/0,49‖	
Marckmann *et al.* [12]	24	3 × 7-d weighed food records	Subcutaneous fat	EPA 0·40¶ DHA 0·66†¶	
Knutsen *et al.* [10]	49‡/72	Eight different 24-h recall	Adipose tissue (buttock)	ALA: 0·51/0·41‖ EPA: 0·19/−0·04‖ DHA: 0·32/0·05‖	ALA: 0·68†/0·62†‖** EPA: 0·23/−0·05‖** DHA: 0·54†/0·06‖**
Sullivan *et al.* [1]	53	FFQ	Erythrocyte FA	Total *n*-3 PUFA: 0·50*§ EPA: 0·40*§ DPA: 0·05* DHA: 0·39*§	
Sullivan *et al.* [1]	53	FFQ	Plasma FA	Total LC *n*-3 PUFA: 0·54*§ EPA: 0·54*§ DPA: 0·09* DHA: 0·48*§	
Hodge *et al.* [7]	4439	FFQ	Plasma phospholipid FA	Total *n*-3 §§: 0·31* ALA: 0·07* EPA: 0·18* DHA: 0·4*	Total *n*-3: 0·57*†† ALA: 0·24*†† EPA: 0·40*†† DHA: 0·78*††
McNaughton *et al.* [8]	43	FFQ	Plasma phospholipid FA	Total *n*-3 0·38*§ ALA: 0·00* EPA: 0·21* DPA: −0·05* DHA: 0·32*§	
Hjartåker *et al.* [3]	234	FFQ	Serum phospholipid FA	EPA: 0·58*‡† DHA: 0·53*‡†	
Andersen *et al.* [4]	135	FFQ	Serum FA	ALA: 0·28*† EPA: 0·51*† DPA: 0·38*† DHA; 0·52*†	
Sasaki *et al.* [11]	42/44‡‡	DHQ	Serum phospholipids FA	ALA: −0·1/0·26‡‡¶ EPA: 0·64/0·61†‡‡¶ DPA: 0·00/0·17‡‡¶ DHA: 0·46/0·46‡‡¶§ Marine origin: *n*-3: 0·48/0·58†‡‡¶	ALA: −0·22/0·36 EPA: 0·64/0·65 DPA: 0·07/0·20 DHA: 0·44§/0·59† Marine origin *n*-3: 0·51†/0·69†
McNaughton *et al.* [8]	43	Weighed records	Plasma phospholipid FA	Total *n*-3 PUFA: 0·33*§ ALA: 0·09* EPA: 0·22* DPA: 0·25* DHA: 0·43*§	
Kuriki *et al.* [14]	94	7-d weighed record	Plasma FA	Only adjusted presented	ALA: 0·35§/0·19‡‡ EPA: 0·57§/0·60‡‡† DHA: 0·57§/0·3‡‡† Adjusted for age and BMI
Kobayashi *et al.* [13]	87	7-d food weighed record × 4 and × 2 (in one area)	Serum phospholipids FA	Total *n*-3: 0·66†¶ ALA: 0·07¶ EPA: 0·75†¶ DPA: 0·49†¶ DHA: 0·50†¶	Total *n*-3 0·76†¶§§ ALA: 0·09¶§§ EPA: 0·89†¶§§ DPA: 0·54†¶§§ DHA: 0·61†¶§§
Tokudome *et al.* [5]	79	FFQ	28-d weighed food records	Total *n*-3: 0·34/0·30‖‖ ALA: 0·48/0·44‖‖ EPA: 0·25/0·26‖‖ DHA: 0·26/0·29‖‖	Total *n*-3: 0·27/0·22‖‖¶¶ ALA: 0·32/0·27‖‖¶¶ EPA: 0·39/0·32‖‖¶¶ DHA: 0·43/0·31‖‖¶¶
Paalanen *et al.*.[6]	294	FFQ	3-d weighed records		Total LC *n*-3 FA: 0·35/0·20‡‡

Table 2. *Continued*

Author	*n*	Dietary method which was validated	Reference method	Crude	Energy adjusted
McNaughton *et al.* [8]	43	FFQ	Weighed records 2 d every 2nd month for 12 months	Total *n*-3: 0·39*§ ALA: 0·45*§ EPA: 0·40*§ DPA: 0·50*§ DHA: 0·52*§	
Sullivan *et al.* [9]	45	FFQ	Weighed records 3 d	Total *n*-3 PUFA: 0·75*† EPA: 0·64 DPA: 0·62 DHA: 0·72	

FA, fatty acids; ALA, α-linolenic acid; DHQ, diet history questionnaire; LC, long chain.
* Spearman correlation.
† Significant at $P<0·001$.
‡ Marine intake of *n*-3 FA.
§ Significant at $P<0·05$.
‖ Non-Hispanic blacks/non-Hispanic whites.
¶ Pearson correlation.
** Corrected after attenuation correction factor.
†† Corrected for the reliability coefficients of FFQ and phospholipids.
‡‡ Men/women.
§§ Deattenuated with the within-to-between person variance ratio for intake of FA.
‖‖ Pearson/Spearman correlations.
¶¶ Deattenuated, energy adjusted and log-transformed.

Weighed records. Weighed records, whose number of recording days ranged from 3 to 28 d, were used as reference method in four studies[5,6,8,9].

Classification and quality score system. The studies were classified into three different types of studies according to the reference method used: (1) the reference was a dietary assessment method, and the reference method assessed an intake of <7 d; (2) the reference was a dietary assessment method, and the reference method assessed an intake of >7 d; (3) the reference method was a biomarker. The studies that were classified into groups 1 and 2 were referred to as calibration studies, while the studies classified into group 3 were considered as a validation study.

To assess the quality of the different calibration/validation studies, a quality score system was developed[15]. The studies were scored according to sample size, statistics used, data collection, if seasonality was considered and whether supplements were included or not, and a total quality score was calculated. All the studies were ranked as average according to this quality score system, apart from two studies[12,14] that were ranked as poor. These two studies[12,14] were not included in the further judgement of the quality of the dietary assessment methods.

When judging the quality of the dietary assessment methods, evaluations were done for the FFQ and the weighed records separately. No consideration was given to 24-h recalls[10] and diet history questionnaire[11] because there was only one validation study on each of these methods. For the quality rating of the dietary method, summarised crude and adjusted correlation coefficients were calculated according to which reference method was used and which FA was presented (Tables 3 and 4). The crude correlation coefficients (R_{crude}) were calculated by adding all specific correlation coefficients from each study and then dividing by the number of studies included. The adjusted correlation coefficient ($R_{adjusted}$) was calculated by several steps: first, for each study the correlations between the intake of a specific FA and the reference method were multiplied with the quality score of the specific study. Then these figures were summarised and divided by the total quality score (adding the specific quality score of the included studies). The summarised adjusted correlation for each FA according to the reference method used was classified into poor ($r<0·30$), acceptable (r 0·30–0·50), good (r 0·51–0·70) and very good ($r>0·70$) and this is presented in Figs. 1 and 2.

Results

Details of the fourteen papers selected for inclusion are given in Table 1. In the presented studies, the numbers of participants varied from 24 to 4439. The age distribution ranged from 19 to 75 years, with mean ages from 30 to 40 years. In total, eleven different FFQ and the weighed records in four different settings (varying number of days and season) and one 24-h dietary recall were validated against subcutaneous fat, serum or plasma FA or other dietary methods.

Subcutaneous fat

Four different FFQ were validated against subcutaneous fat[2,4,10]. The crude correlation coefficients varied from 0·39 to 0·66 for α-linolenic acid (ALA), EPA and DHA. All the correlations were significant. Hunter *et al.* [2] validated two FFQ against subcutaneous fat. When adjusting the correlations, a slight increase was observed for one FFQ, while no changes were observed for the other (Table 2). Only Andersen *et al.* [4] presented quartile agreement between intake of FA measured with FFQ compared with FA in adipose tissue, and found that men who consumed FA in the highest quartile had adipose tissue levels that were significantly higher than men who consumed FA in the lowest or next lowest quartile[4].

Table 3. Summary quality rating of the FFQ assessing different *n*-3 fatty acid intake according to reference method: short-term or long-term dietary instruments or biomarkers (R_{crude} and $R_{adjusted}$* values)

FFQ	*n*	R_{crude}	$R_{adjusted}$	Classification
Biomarkers (reference method)				
Total *n*-3 fatty acids	4	0·43	0·42	Acceptable
DHA	7	0·44	0·45	Acceptable
DPA	5	0·17	0·19	Poor
EPA	9	0·42	0·43	Acceptable
ALA	5	0·25	0·22	Poor
Long term (reference method >7 d)				
Total *n*-3 fatty acids	2	0·36	0·36	Acceptable
DHA	2	0·40	0·40	Acceptable
DPA	1	0·52	0·52	Good
EPA	2	0·33	0·33	Acceptable
ALA	2	0·46	0·46	Acceptable
Short term (reference method <7 d)				
Total *n*-3 fatty acids	1	0·75	0·75	Very good
DHA	1	0·72	0·72	Very good
DPA	1	0·62	0·62	Good
EPA	1	0·64	0·64	Good

DPA, docosapentaenoic acid; ALA, α-linolenic acid.
* $R_{adjusted}$: correlations between intake and the reference method were multiplied with the quality score of the specific study. These figures were then totalled and divided by the total quality score (sum of the specific quality score of the included studies).

One study validated weighed records (3 × 7 d) against subcutaneous fat[12]. Crude correlations were given for EPA (*r* 0·4) and DHA (*r* 0·66), with only DHA being significant.

Knutsen *et al.* [10] validated eight different 24-h recalls of intake of ALA, EPA and DHA against subcutaneous fat. They found high adjusted correlations of 0·68/0·62 (men/women) for ALA, while the correlations for EPA and DHA were lower (Table 2).

Blood

Five different FFQ were validated against erythrocytes, plasma or serum[1,3,4,7,8]. Sullivan *et al.* [1] validated FA estimated from a FFQ against both FA from erythrocytes and from plasma[1]. For intake of total *n*-3 PUFA, EPA and DHA estimated from the FFQ, the correlation coefficients were higher when validated against plasma FA compared with erythrocytes (*n*-3 PUFA, 0·54 *v.* 0·50; EPA, 0·54 *v.* 0·40; DHA, 0·48 *v.* 0·39); however, all the correlations were

Table 4. Summary quality rating of the weighed records that assess different *n*-3 fatty acid intake according to biomarkers (R_{crude} and $R_{adjusted}$* values)

Weighed records	*n*	R_{crude}	$R_{adjusted}$	Classification
Biomarkers (reference method)				
Total *n*-3 fatty acids	2	0·50	0·50	Acceptable
DHA	2	0·47	0·47	Good
DPA	2	0·17	0·19	Poor
EPA	2	0·69	0·69	Good
ALA	2	0·08	0·08	Poor

DPA, docosapentaenoic acid; ALA, α-linolenic acid.
* $R_{adjusted}$: correlations between intake and the reference method were multiplied with the quality score of the specific study. These figures were then totalled and divided by the total quality score (sum of the specific quality score of the included studies).

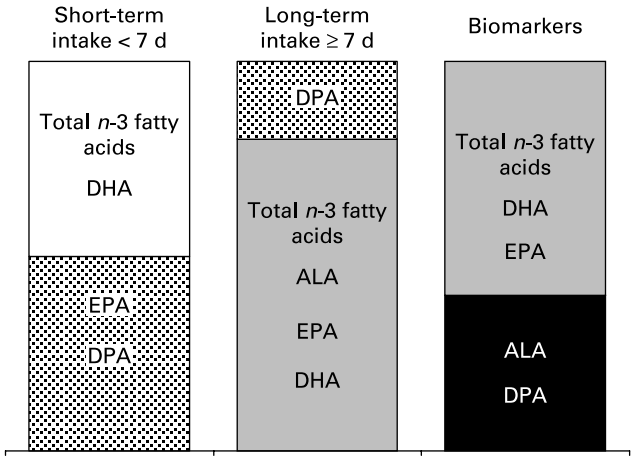

Fig. 1. Summary quality rating of the FFQ that assess different *n*-3 fatty acids intake according to reference method: short-term or long-term dietary instruments or biomarkers. ■, Poor <0·30; ■, acceptable 0·30–0·50; ⊡, good 0·51–0·70; □, very good >0·70. Correlation coefficient is adjusted by study' quality score.

significant[1]. Andersen *et al.* [4], Hjartåker *et al.* [3] and Hodge *et al.* [7] reported significant correlations of approximately 0·50–0·60 between dietary intake of EPA and DHA estimated from the FFQ and concentrations of EPA and DHA in serum or plasma. McNaughton *et al.* [8] observed a lower correlation coefficient of both EPA (*r* 0·21) and DHA (*r* 0·32), but only the last was significant. Hjartåker *et al.* [3] also presented relative weight of EPA and DHA in serum phospholipids according to quartiles of fatty fish filet frequency consumption and reported significant increases in serum phospholipids with increasing quartile of fatty fish filet measured with the FFQ[3].

One dietary history questionnaire was also validated against serum FA and high crude and adjusted correlations were reported for intake of EPA (*r* 0·64) for men[11]. This questionnaire was self-administered and was somewhat similar to a FFQ.

Three studies have validated weighed records (all with seven or more days) against serum or plasma FA[8,13,14].

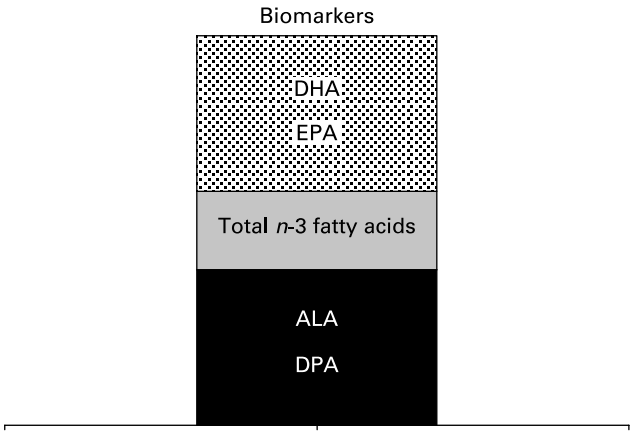

Fig. 2. Summary quality rating of the weighed records that assess different *n*-3 fatty acids intake according to biomarkers. ■, Poor <0·30; ■, acceptable 0·30–0·50; ⊡, good 0·51–0·70. Correlation coefficient is adjusted by study' quality score.

Kobayashi *et al.*[13] presented a very high correlation coefficient for EPA, crude: *r* 0·75 and adjusted: *r* 0·89 and also good correlations for DHA and total *n*-3 FA from weighed records validated against serum FA. Kuriki *et al.*[14] obtained adjusted correlations for dietary intake of EPA measured with weighed records against plasma concentration of EPA (*r* 0·57) and for DHA (*r* 0·57), while McNaughton showed a correlation of 0·43 for DHA measured with weighed records validated against DHA concentration in plasma[8]. All the three studies presented low correlations for ALA[8,13,14].

Weighed records

Four FFQ were validated against weighed food records[5,6,8,9]. Tokudome *et al.*[5] and Paalanen *et al.*[6] showed non-significant correlation coefficients between dietary intake of total *n*-3 FA from the two methods[5,6], while Sullivan *et al.*[9] obtained significant correlations varying from 0·64 to 0·75 for total *n*-3 FA, EPA and DHA[9]. McNaughton *et al.*[8] also presented significant correlations (total *n*-3 FA, *r* 0·39; EPA, *r* 0·40; DHA, *r* 0·52)[8], although somewhat lower than those observed by Sullivan *et al.*[9].

Tokudome *et al.*[5] demonstrated the percentage difference of FA intake estimated from 28 d of weighed records and a FFQ. For total *n*-3 PUFA the average difference was 5 %, for ALA −6 %, and for EPA 22 % and DHA 18 %, the last two being significantly different[5]. Paalanen *et al.*[6] presented the difference in the mean intakes measured with the FFQ and the food records, and found that *n*-3 PUFA in the FFQ were 149 and 188 % of what was observed with food records for men and women, respectively[6]. McNaughton *et al.*[8] presented the agreements between the weighed food records and the FFQ. For total intake of long-chain FA, there was an exact agreement of 42 %. For EPA and DHA the agreement was 42 and 51 %, respectively[8]. Sullivan *et al.*[9] presented quintile agreement between the FFQ and the food records based on *n*-3 PUFA intakes, and found that 49 % were classified into the same quintile[9].

In Tables 3 and 4, the crude and adjusted correlation coefficients are calculated for the FFQ and the weighed records according to the EURRECA scoring system. In addition to the four studies already excluded from this quality rating (the two studies ranked as poor, one study with a 24-h recall and one study with a diet history questionnaire), two studies had to be excluded because originally only adjusted correlations were presented[6,14]. The results from Tables 3 and 4 are depicted in Figs. 1 and 2. The adjusted correlations between dietary intake of each FA and the FA from the reference method are presented according to reference method. For each reference method, the summarised adjusted correlations ($R_{adjusted}$) for each FA were classified into poor, acceptable, good or very good (see Method). The numbers of studies in which the summarised crude and adjusted correlation were based on differ according to the reference method category. Figure 1 shows that the FFQ gave acceptable estimates for total *n*-3 FA, EPA and DHA when using biomarkers as the reference method. When using more than 7 d of records as the reference method the same results were observed. Using less than 7 d of records as the reference method the total intake of total *n*-3 FA, EPA and DHA was rated as very good and good, however, this only included one study. Figure 2 shows that weighed records gave acceptable estimates of total *n*-3 FA while estimates for DHA and EPA were qualified as good.

Discussion

In this review, sixteen validation studies and four calibration studies from fourteen papers were described. The newly developed EURRECA scoring system was used to evaluate the quality of the validation studies and the quality of the estimates from dietary assessment methods.

In a validation study, the reference method used should be as accurate as possible[4]. A validation study is also called a relative validation/calibration study, when one dietary method is compared to another dietary method, most often FFQ *v.* several days of food records. The limitations with this approach are the considerable individual day-to-day variation, which reduces the possibility of obtaining a true measure of usual intake with few recording days, as well as reporting bias since both self-administered dietary assessment questionnaires and dietary records are based on self-reporting[4]. FFQ often report an overestimated intake of energy and nutrients[6], while food records often underreport energy intake and nutrients[16,17]. An alternative to relative validations is biomarkers, whose primary advantage is that these measurements are objective and that the sources of errors for a biomarker and a dietary assessment method are independent[4]. PUFA are largely exogenic, meaning that there is no synthesis of PUFA in the body and that intake in diet and supplements are the major source, making the correlations with biomarkers easier[7,18]. There are several choices of a biomarker for the measurement of LC *n*-3 PUFA, and those presented in this review were FA in adipose tissue, erythrocytes and plasma. Adipose tissue FA are generally considered the best source of assessing long-term FA intake[10,18]. Erythrocytes may be a useful marker as they can provide an indication of the previous 120-d intake of LC *n*-3 PUFA[1]. Plasma FA reflect intake of FA over the past few days or more[7].

Most of the included studies have presented the correlations. The correlation coefficients obtained from the validation studies can reflect the capability of the method to rank individuals according to FA intake.

Subcutaneous fat

FA estimated from four different FFQ[2,4,10], one weighed record[12] and one recall[10] were validated against subcutaneous fat, which the literature describes as the best reference method. The correlation coefficients observed in all the studies were in the range 0·40–0·66 for ALA, EPA and DHA. Of the studies using subcutaneous fat as the reference, the study by Marckmann *et al.*[12] was ranked with a low quality score, while the others were ranked with average scores. Marckmann *et al.*[12] had a low score due to a small number of study participants. In summary, none of the dietary methods validated against subcutaneous fat and presented here seem to be superior than the others in relation to ranking the dietary intake of *n*-3 PUFA.

Blood

Dietary intake of *n*-3 PUFA estimated from five different FFQ[1,3,4,7,8], one diet history questionnaire[11] and three weighed record studies[8,13,14] was validated against FA in serum, plasma or erythrocytes. Both FA in plasma, erythrocytes and serum are found to be good biomarkers of LC *n*-3 PUFA[1,3]. The correlation coefficients observed between the intake of FA measured by most FFQ[1,3,4], the diet history questionnaire[1], one of the weighed records[14] *v.* FA in blood parameters were at the same level (*r* 0·40–0·60). The best correlation was observed in the study by Kobayashi *et al.*[13] comparing the dietary intake of FA from weighed records with FA in serum phospholipids (EPA, *r* 0·89). However, there was no clear tendency among the three studies comparing FA from weighed records with FA in blood[8,13,14] showing that this was the best way to measure intake of *n*-3 FA.

All the studies validated against blood samples were qualified as average except the one by Kuriki *et al.*, which was classified as poor. Most correlation coefficients from the studies comparing dietary intake with FA in blood parameters were in the same range as the ones observed for FA in adipose tissue (*r* 0·40–0·60). There was one study with a lower correlation[8] and one with a correlation higher than this range[13]. For ALA most studies presented low correlations between dietary intake and blood parameters.

The estimation of summarised crude correlations and adjusted correlations for all the validation studies of FFQ using biomarkers as the reference method indicates that the FFQ give acceptable values for total *n*-3 FA, EPA and DHA. The summarised crude and adjusted correlations for the two studies validating weighed records against biomarkers indicate acceptable estimates for total *n*-3 FA, while the estimates for EPA and DHA were good. As expected, the weighed records seem to be superior to the FFQ in reference to estimating intake of EPA and DHA. However, it is important to remember that only two studies were included for the weighed records (Fig. 2), therefore it is difficult to reach strong conclusions.

Weighed record

Four FFQ were validated against weighed food records[5,6,8,9]. All the studies were ranked as average according to the quality score. The studies indicated that the FFQ overreported an average intake of *n*-3 FA compared with weighed records. Two of the studies presented a relatively good classification and good correlation between the two dietary assessment methods[8,9]. Biomarkers were more accurate to rank individuals than different dietary methods. One limitation with food records is that subjects are prone to underestimate their food intake when they keep food records[16], and that the true food consumption of *n*-3 FA most likely lies somewhere between the weighed records and the FFQ (see earlier Discussion).

The aim of this review was to evaluate the validity of methods used to measure the usual *n*-3 FA intake of a population. According to the systematic review, none of the dietary assessment methods used to assess *n*-3 FA seem to be superior to another. Most studies presented the correlation coefficients ranging from 0·40 to 0·60. By using the summarised weighed correlations suggested by EURRECA, it was indicated that the quality of total *n*-3 FA, EPA and DHA intake estimated from the FFQ was acceptable.

This review confirmed the view that the FFQ to assess *n*-3 FA should not be validated against another dietary method, and that validation studies of dietary methods for measuring intakes of *n*-3 FA could be improved.

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