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Systematic Review on N-3 and N-6 Polyunsaturated Fatty Acid Intake in European Countries in Light of the Current Recommendations – Focus on Specific Population Groups

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Keywords

N-3 polyunsaturated fatty acid · N-6 polyunsaturated fatty acid · Dietary intake · Dietary recommendations

Abstract

Background: Earlier reviews indicated that in many countries adults, children and adolescents consume on an average less polyunsaturated fatty acids (PUFAs) than recommended by the Food and Agriculture Organisation/World Health Organisation. ***Summary:*** The intake of total and individual n-3 and n-6 PUFAs in European infants, children, adolescents, elderly and pregnant/lactating women was evaluated systematically. ***Results:*** The evaluations were done against recommendations of the European Food Safety Authority. ***Key Messages:*** Fifty-three studies from 17 different European countries reported an intake of total n-3 and n-6 PUFAs and/or individual n-3 or n-6 PUFAs in at least one of the specific population groups: 10 in pregnant women, 4 in lactating women, 3 in infants 6–12 months, 6 in children 1–3 years, 11 in children 4–9 years, 8 in adolescents 10–18 years and 11 in elderly >65 years. Mean linoleic acid intake was within the recommendation (4 energy percentage [E%]) in 52% of the countries, with inadequate intakes more likely in lactating women, adolescents and elderly. Mean α-linolenic acid intake was within the recommendation (0.5 E%) in 77% of the countries. In 26% of the countries, mean eicosapentaenoic acid and/or docosahexaenoic acid intake was as recommended. These results indicate that intake of n-3 and n-6 PUFAs may be suboptimal in specific population groups in Europe.

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Introduction

N-3 and n-6 polyunsaturated fatty acids (PUFAs) – particularly the longer chain, more unsaturated members of these families, and also the plant-derived essential members – play a vital role in human health from conception onwards: through every stage of human development, maturation and aging, including roles in cell membrane composition, metabolism, signal transduction and amplification, and in gene expression [1]. An adequate intake (AI) of PUFAs is of critical importance during early life and plays an essential role in supporting growth and development. In addition, for the general population an AI of n-3 and n-6 PUFAs is recommended for the prevention of cardiovascular diseases [2]. However, specific population groups may have relatively higher requirements of these fatty acids and thus are more at risk of inadequate intake. These specific population groups include pregnant and lactating women because of increased PUFA requirements for growth, neurological and immune function of their infants [3, 4]. Similarly, infants, children and adolescents have relatively high nutrient requirements compared to adults to support rapid growth and development, but complementary foods, school meals and dietary habits during childhood and adolescence may not provide sufficient amounts of nutrients, notably PUFAs [5–8]. Finally, elderly have altered nutrient requirements because of changes in body composition and physical activity and the presence of disease, and altered nutrient intake because of low variety of food consumed, reduced appetite, loss of sensory appreciation of food, dentition and swallowing problems, the presence of disease and social issues, and thus may be at risk of inadequate PUFA intake, besides other important micronutrients [9].

Recent reviews on dietary fat and fatty acid intake in different countries around the world [10–14] are mainly based on data from national dietary surveys that do not include a representative subsample of these specific subgroups of the population. Moreover, in many of these dietary surveys, intake data of individual PUFAs are not reported. Therefore, the aim of this systematic review is to evaluate the available data on n-3 and n-6 PUFA intake in 7 specific population groups in Europe: (1) pregnant women, (2) lactating women, (3) infants (6–12 months), (4) young children (1–3 years), (5) older children (4–10 years), (6) adolescents (10–18 years) and (7) elderly (>65 years). First, an overview of the current available recommendations for PUFA intake in European countries is given. Second, the available intake data are summarised and reported for each group, followed by a discussion of the gaps between reported intake and the European Food Safety Authority (EFSA) recommendations. Third, an overview of studies describing the main food sources of the various PUFAs in these population groups is presented.

Methods

A more detailed description of the methods employed is given in online supplementary text 1 (for all online suppl. material, see www.karger.com/doi/10.1159/000456723).

Evaluation of Current Recommendations for PUFA Intake in European Countries

For the evaluation of current recommendations for PUFA intake in European countries, we updated the systematic review on dietary reference intake, nutritional goals and dietary guidelines for fats and fatty acids by Aranceta and Pérez-Rodrigo [15] that was published in 2012 with PUFA recommendations for specific population groups in Europe, using the search strategy by Aranceta and Pérez-Rodrigo [15], excluding trans fatty acids. The search was conducted using PubMed and Scopus from January 2011 (date of Aranceta search) to April 20, 2015. In addition, a manual search on individual European country recommendations was performed via Google with latest update done in October 2016.

Evaluation of Current Intake of Total and Specific N-3 and N-6 PUFAs in the European Diet for Specific Population Groups

Criteria for Considering Studies in This Review

Type of study. Observational studies and national dietary surveys were the primary focus of this review. Randomised control trials or other experimental studies were included only if they reported baseline data and/or data for the control group.

Type of exposure. Studies were included if they reported data on intake of at least one of the following: α-linolenic acid (ALA), eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), docosahexaenoic acid (DHA), total n-3 PUFAs, linoleic acid (LA), arachidonic acid (ARA) or total n-6 PUFAs. We excluded studies reporting only the total PUFA intake without any distinction on individual classes as mentioned above.

Type of population. The following 7 subgroups of the population were the focus of interest in this review: pregnant women, lactating women, infants (6–12 months), young children (1–3 years), older children (4–10 years), adolescents (10–18 years), elderly (>65 years). The age ranges are defined in accordance with the EFSA Comprehensive European Consumption Database [16]. Studies in specific disease populations were excluded. Only studies conducted in European countries were included. Inclusion and exclusion criteria can be found in the abstract review form at PROSPERO with registration number CRD42014014717.

Period of time for exposure measurement. Studies conducted after January 1, 2000 were eligible for inclusion. Studies conducted before 2000, but reported in a publication published after 2000, were excluded.

Search Methods for Identification of Studies

PubMed, Scopus and Cochrane Central Register of Controlled Trials (CENTRAL) databases were searched for papers published from January 2000 until November 2015, using text words with appropriate truncation and relevant indexing terms. The search was in the form (n-3 and n-6 PUFA terms) and (terms for intake) and (terms for the specific subgroup considered) and (limit to humans) and (limit to 2000 – current). The full search strategy for the Ovid MEDLINE database can be accessed via PROSPERO file CRD42014014717; the searches of other databases were based on this strategy. Reference lists of all eligible papers and relevant systematic reviews were searched for additional studies.

Data Selection

The titles and abstracts of studies identified by the search were screened by a single reviewer, and clearly irrelevant studies were excluded. The full text reports of all potentially relevant studies were obtained and assessed independently for eligibility by 2 independent reviewers. The systematic review software Covidence (www.covidence.org) was used to facilitate screening of literature. Any disagreement was resolved by discussion.

Data Extraction

Standardised forms were used for data extraction and management. For each included study, the following data were extracted and brought together into one large database: name of first author, year of publication, year(s) of data collection, participant characteristics (age, sex, *n*, the subgroup they belong to), method used for dietary assessment and intake data on total energy (MJ/day), total fat (g/day and energy percentage [E%]), total PUFAs (g/day and E%), total n-6 PUFAs (g/day and E%), LA (g/day and E%), ARA (mg/day), total n-3 PUFAs (g/day and E%), ALA (g/day and E%), EPA (mg/day), DPA (mg/day), and DHA (mg/day). When necessary, units of measurement were converted to a standard form (g/day, mg/day, or E%) expressed in mean and SD to facilitate comparison across studies. When only median and quartiles were given, the mean was calculated as the average of the median, 25th (P25) and 75th (P75) percentiles. The standard deviation was calculated as P75-P25/1.35. Unpublished data for countries that participated in the HELENA study in adolescents were included based on personal communication with the researchers involved, as the original publication only reported data of the overall international sample [17].

Data Assessment

All fatty acid intake data were evaluated against the EFSA recommendations [18], which are the most recent recommendations that are set by a recognised Europe-wide health authority. Because of the absence of total n-3 and total n-6 PUFA intake recommendations, ALA and LA recommendations were used to evaluate total n-3 or n-6 PUFA intake. ALA and LA are the biggest contributors to total n-3 and n-6 PUFA intake, respectively. Per country and population group, intake data were extracted to evaluate whether the intake of different PUFAs was in line with the EFSA recommendations. Where multiple datasets were available for one country and specific population group, the average of these datasets was calculated (weighted for *n*). This average was used to define whether the intake data were in line or below the relevant EFSA recommendation.

Evaluation of Major Dietary Contributors to PUFA Intake

Another literature search was undertaken in PubMed to find data on dietary sources of PUFAs in the considered population subgroups and data on the PUFA composition of human milk. The search was conducted with terms describing fatty acids, diet and habits. The full search strategy can be found on PROSPERO with registration number CRD42014014717. In addition, all identified publications with intake data were screened for relevant data on food sources. For data on dietary sources excluding human milk, studies were excluded, if the data were collected before 2000. For data on human milk, publications from 1990 onwards were included because of limited available data published after 2000.

Results

Evaluation of Recommendations for PUFA Intake in European Countries

In addition to the EFSA and Food and Agriculture Organisation (FAO)/World Health Organisation (WHO) recommendations, we identified 6 individual country and 4 multi-country recommendations for PUFA intake. In general, recommendations were developed by scientific experts and health authorities after commissioning expert systematic evidence-based reviews of mainly human observational and intervention studies to guide the authority's decision. Table 1 gives an overview of the recommendations identified.

The criteria used to set specific recommendations (Table 1) are not always clearly described, but include provision for adequate growth for infants and children, prevention of clinical deficiency and provision for good health, encompassing prevention of cardiovascular diseases after the age of 2 years.

Mostly, 2 kinds of dietary reference values (DRVs) were derived for PUFAs, the AI, for example, set by EFSA and many European countries, and the acceptable macronutrient distribution range, set by FAO/WHO [19]. For LA, the FAO/WHO additionally set an estimated average requirement.

In general, the DRVs for different n-3 and n-6 PUFAs for Europe and European countries differ with regard to age group, type of fatty acid and unit of expression, which made it difficult to compare. In general, DRVs were reported for LA, ALA and EPA + DHA or DHA, while no recommendations were reported for DPA, and for ARA recommendations were only reported for infants 0–6 months of age. If guidelines were formulated for pregnant and breastfeeding women, they were focused on a specific increase in the intake of DHA. Recommendations for children >2 years of age were not age-specific and were often similar to those for adults. For elderly, no rec-

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Table 1. Current recommendations for PUFA intake in specific population groups according to different national and international authorities[a]

Region/country (authority)	Age/age group	Year	LA	ARA	Total n-3 PUFAs	ALA	EPA	DHA	EPA + DHA
Europe (EFSA) [18, 52]	Pregnant and lactating women	2010	4.0 E%	–	–	0.5 E%	–	100.0–200.0 mg/d[b]	250.0 mg/d
	0–6 mo	2013	4.0 E%	140.0 mg/d	–	0.5 E%	–	100.0 mg/d	–
	7–24 mo	2010	4.0 E%	–	–	0.5 E%	–	100.0 mg/d	–
	>2 y	2010	4.0 E%	–	–	0.5 E%	–	–	250.0 mg/d
	Elderly (= adults)	2010	4.0 E%	–	–	0.5 E%	–	–	250.0 mg/d
Worldwide (FAO/WHO) [19]	Pregnant and lactating women	2008	2.5–9.0 E% (ADMR) 2.0 E% (EAR) 2.0–3.0 E%	–	0.5–2.0 E% (AMDR)	>0.5 E% (L-AMDR)	–	200.0 mg/d (ANR)	300.0 mg/d (ANR)
	0–6 mo	2008	Human milk	0.2–0.3 E% human milk (U-AMDR)	–	0.2–0.3 E%	–	0.1–0.2 E% <0.8 E% (U-AMDR)	–
	6–24 mo	2008	3.0–4.5 E% <10.0 E% (U-ADMR)	–	–	0.4–0.6 E% <3.0 E% (U-AMDR)	–	–	10.0–12.0 mg/kg BW
	2–4 y	2008	3.0–4.5 E% <10.0 E% (U-AMDR)	–	0.5–2.0 E% (AMDR)	>0.5 E% (L-AMDR)	–	–	100.0–150.0 mg/d
	4–6 y	2008	2.5–9.0 E% (AMDR) 2.0 E% (EAR) 2.0–3.0 E%	–	0.5–2.0 E% (AMDR)	>0.5 E% (L-AMDR)	–	–	150.0–200.0 mg/d
	6–10 y	2008	2.5–9.0 E% (AMDR) 2 E% (EAR) 2.0–3.0 E%	–	0.5–2.0 E% (AMDR)	>0.5 E% (L-AMDR)	–	–	200.0–250.0 mg/d
	10–18 y	2008	2.5–9.0 E% (AMDR) 2.0 E% (EAR) 2.0–3.0 E%	–	0.5–2.0 E% (AMDR)	>0.5 E% (L-AMDR)	–	–	250.0–2,000.0 mg/d (AMDR)
	Elderly (= adults)	2008	2.5–9.0 E% (AMDR) 2.0 E% (EAR) 2.0–3.0 E%	–	0.5–2.0 E% (AMDR)	>0.5 E% (L-AMDR)	–	–	250.0–2,000.0 mg/d (AMDR)
Belgium (superior health council of Belgium)[c] [53]	0–6 mo	2009	4.4 g/d	–	–	0.5 g/d	–	–	–
	7–12 mo	2009	4.6 g/d	–	–	0.5 g/d	–	–	–
	1–18 y	2009	2.0–5.0 E%[d]	0.1–0.3 E%	–	0.5–1.5 E%	0.1–0.2 E%	0.1–0.4 E%	–
	Elderly (= adults)	2009	>2.0 E%	–	1.3–2.0 E%	>1.0 E%	–	–	0.3 E%

Table 1. (continued)

Region/country (authority)	Age/age group	Year	LA	ARA	Total n-3 PUFAs	ALA	EPA	DHA	EPA + DHA
Belgium (superior health council of Belgium) [53]	0–6 mo	2016	4.0 E%	–	–	1.0 E%	–	–	–
	7–12 mo	2016	4.0 E%	–	–	1.0 E%	–	100.0 mg/d	–
	1–3 yrs	2016	4.0 E%	–	–	1.0 E%	–	100.0 mg/d	–
	3–18 yrs	2016	4.0 E%	–	–	1.0 E%	–	–	250.0–500.0 mg/d
	Elderly (= adults)	2016	4.0 E%	–	–	1.0 E%	–	–	250.0–500.0 mg/d
France (ANSES) [4]	Pregnant women (2,050 kcal)	2011	4.0 E%	–	–	1.0 E%	–	250.0 mg/d	500.0 mg/d
	Lactating women (2,250 kcal)	2011	4.0 E%	–	–	1.0 E%	–	250.0 mg/d	500.0 mg/d
	0–6 mo	2011	2.7 E%	0.5% of total FA	–	0.5 E%	EPA < DHA	0.3% of total FA	–
	6–36 mo	2011	2.7 E%	–	–	0.5 E%	–	70.0 mg/d	–
	3–9 y	2011	4.0 E%	–	–	1.0 E%	–	125.0 mg/d	250.0 mg/d
	10–18 y	2011	4.0 E%	–	–	1.0 E%	–	250.0 mg/d	500.0 mg/d
	Elderly	2011	4.0 E%	–	–	1.0 E%	250.0 mg/d	250.0 mg/d	500.0 mg/d
Germany – Austria – Switzerland (D-A-CH)[c] [54]	Pregnant and lactating women	2013	2.5 E%	–	–	0.5 E%	–	–	–
	0–4 mo	2013	4.0 E%	–	–	0.5 E%	–	> 200.0 mg/d	–
	4–12 mo	2013	3.5 E%	–	–	0.5 E%	–	–	–
	1–4 y	2013	3.0 E%	–	–	0.5 E%	–	–	–
	4–19 y	2013	2.5 E%	–	–	0.5 E%	–	–	–
	Elderly	2013	2.5 E%	–	–	0.5 E%	–	–	–
Switzerland (Eidgenössische Ernährungskommission) [55]	Pregnant and lactating women	2013	–	–	–	–	–	> 200.0 mg/d	–
	Elderly (= adults)	2013	–	–	0.5–2.0 E%	–	–	–	500.0 mg/d
The Netherlands (Health Council of the Netherlands) [56]	0–5 mo	2001	0.6 g/kg BW	0.0 g/kg BW	0.1 g/kg BW	–	–	0.0 g/kg BW	–
	6 mo–18 y	2001	–	–	–	–	–	–	150.0–200.0 mg/d
	Elderly (= adults)	2001	2.0 E%	1.0 E%	–	–	–	–	450.0 mg/d[e]

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Table 1. (continued)

Region/country (authority)	Age/age group	Year	LA	ARA	Total n-3 PUFAs	ALA	EPA	DHA	EPA + DHA
Nordic countries[c] [57]	Pregnant and lactating women	2012	–	–	>1.0 E%	–	–	200.0 mg/d	–
	6–23 mo	2012	–	–	>1.0 E%	–	–	–	–
	>2 y	2012	2.5 E%[f]	–	–	>0.5 E%	–	–	–
Poland [58]	Pregnant and lactating women	2012	4.0 E%	–	–	0.5 E%	250.0 mg/d	100.0–200.0 mg/d	–
	1–2 y	2012	5.0 E%	–	–	1.0 E%	–	100.0 mg/d (<2 y)	–
	2–18 y	2012	4.0 E%	–	–	0.5 E%	–	–	250.0 mg/d
	Elderly (= adults)	2012	4.0 E%	–	–	0.5 E%	–	–	250.0 mg/d
Spain (AEP) [1]	6 mo–2 y	2006	3.0–4.5 E%	–	–	>0.5 E%	–	–	–
Spain (AECOSAN) [59]	>2 y	2014	–	–	–	2.0 g/d	–	<200.0 mg/d	–
	Elderly (= adults)	2014	–	–	–	2.0 g/d	–	<200.0 mg/d	–

Values are adequate intake unless otherwise noted.

y, year; mo, months; g/d, grams per day; mg/d, milligrams per day; E%, energy percentage; PUFAs, polyunsaturated fatty acids; – , no data available; LA, linoleic acid; ARA, arachidonic acid; n-3, omega-3 PUFA; ALA, α-linolenic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; ADMR, acceptable macronutrient distribution range; L-AMDR, lower acceptable macronutrient distribution range; U-AMDR, upper acceptable macronutrient distribution range; EAR, estimated average requirement; ANR, average nutrient requirement; BW, body weight.

[a] Total n-6 PUFAs is not included in this online supplemental table as there are only recommendations set for the adult population and this is not a target group in our review.

[b] In addition to the 250.0 mg of (EPA + DHA).

[c] Total n-6 PUFA has been set for adults: 4.0–8.0 E% (Belgium); 2.5–9.0 E% (Switzerland).

[d] DRI unit not mentioned.

[e] As 2 serving fish per week (Guidelines for healthy diet, 2006).

[f] Obtained by calculation (official recommendation is for total LA + ALA, and for ALA).

Table 2. Overview of European countries meeting n-3 and n-6 PUFA intake recommendations per population group if compared with the EFSA recommendations (percentage of countries with adequate intake)

	Studies, *n*	N countries	N subjects included	Evaluation against recommendations (percentage of countries with adequate intake)					
				total n-6 PUFAs	LA	ARA[a]	total n-3 PUFAs	ALA	EPA + DHA
Recommendations				4.0 E%[b]	4.0 E%	–	0.5 E%[b]	0.5 E%	RI: 250 + 100–200 mg/d DHA
Pregnant women	10	11	6,033	66 (2 out of 3)	75 (3 out of 4)	3 reported	100 (3 out of 3)	100 (4 out of 4)	33 (3 out of 9)
Lactating women	4	4	293	0 (0 out of 1)	0 (0 out of 3)	1 reported	100 (4 out of 4)	100 (2 out of 2)	50 (1 out of 2)
Recommendations				4.0 E%[b]	4.0 E%	–	0.5 E%[b]	0.5 E%	100.0 mg/d DHA[c]
Infants 6–12 mo	3	3	606	100 (2 out of 2)	100 (2 out of 2)	1 reported	100 (2 out of 2)	100 (2 out of 2)	0 (0 out of 2)
Children 1–3 y	6	6	1,797	66 (2 out of 3)	75 (3 out of 4)	1 reported	100 (4 out of 4)	75 (3 out of 4)	0 (0 out of 2)[c]
Recommendations				4.0 E%[b]	4.0 E%	–	0.5 E%[b]	0.5 E%	≥250.0 mg/d
Children 4–9 y	11	10	10,102	55 (5 out of 9)	66 (2 out of 3)	2 reported	78 (7 out of 9)	100 (3 out of 3)	0 (0 out of 3)
Adolescents 10–18 y	8	11	4,988	50 (1 out of 2)	44 (4 out of 9)	8 reported	100 (3 out of 3)	70 (7 out of 10)	20 (2 out of 10)
Elderly >65 y	11	9	9,091	66 (2 out of 3)	33 (2 out of 6)	4 reported	66 (2 out of 3)	50 (3 out of 6)	50 (3 out of 6)
Total of all population groups				61 (14 out of 23)	52 (16 out of 31)	20 reported	89 (25 out of 28)	77 (24 out of 31)	26 (9 out of 34)

y, year; mo, months; mg/d, milligrams per day; E%, energy percentage; EFSA, European Food Safety Authority; PUFAs, polyunsaturated fatty acids; LA, linoleic acid; ARA, arachidonic acid; n-6, omega-6 PUFA; n-3, omega-3 PUFA; ALA, α-linolenic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; RI, reference intake.

[a] No recommendation, only number of studies with intake data.

[b] Based on EFSA recommendations for LA and ALA.

[c] For children >2 y recommendation 250 mg EPA + DHA per day.

ommendations were derived, as no specific needs for any of the PUFAs were deemed evident.

Based on these outcomes, and as explained in the method section, the EFSA recommendations [18] have been selected to evaluate adequacy of fatty acid intake data in the current review. In the absence of EFSA recommendations for elderly, adult recommendations were used.

Evaluation of Intake of Total and Specific N-3 and N-6 PUFAs

Altogether 5,404 titles and abstracts were identified via electronic, bibliographic and additional expert searches, and 267 of them appeared to be potentially relevant. Finally, 49 studies fulfilled the inclusion criteria. For pregnant women, 10 different publications were included, reporting PUFA intake data in 11 different European countries. For lactating women, only 4 studies from 4 different countries were included, all with a limited sample size (14–63 women). For infants aged 6–12 months, only 3 studies from 3 different countries were found, of which the study in German infants reported intake data, when children were 6 and 9 months old [20]. For young children aged 1–3 years, 6 studies from 6 different countries were included. For older children aged 4–9 years, 11 studies from 10 countries were identified, of which some studies reported intake in multiple countries. For adolescents aged 10–19 years, 8 studies from 11 different countries reported data on individual PUFA intake. For elderly aged ≥65 years, 11 studies from 9 countries were included of which one study from Hungary [21] reported data in elderly aged ≥60 years. Details of intake data can be found in online supplementary Tables 1–7.

In general, intake data were reported for total n-6 PUFAs, LA, total n-3 PUFAs, ALA, EPA and DHA, whereas for DPA and ARA, very little intake data were found.

Table 2 gives an overview of available intake data and summarises the proportions of countries where current intake data were in line with the EFSA recommendations for each population group. Detailed information about the countries included in each population group can be found in the online supplementary Tables 1–7. Across all population groups, mean LA intake was below the recommendation of ≥4 E% in 48% of the countries, with low intake more likely in lactating women, adolescents and elderly, whereas mean ALA intake was below the recommendation of ≥0.5 E% in 23% of the countries (Table 2). Across all population groups, mean EPA and/or DHA intake was lower than the EFSA recommendation in 74% of the countries, and low intake was of concern in pregnant and lactating women and in infants, children and adolescents.

Evaluation of Major Dietary Contributors to PUFA Intake

Dietary Sources of Individual PUFAs

Data on the contribution of different food groups and supplements to the intake of various PUFAs were limited

to 3 studies, including a Belgian study in children aged 2.5–6.5 years [22], the HELENA study in adolescents aged 12.5–17.5 years [17] and a study in Dutch elderly aged ≥70 years [23]. In Belgian children, fats and oils were the major contributors to intakes of LA (23.6%) and ALA (33.1%), followed by cereal products with 17.6 and 13.5%, respectively [22]. Meat, poultry and eggs were the main contributors to ARA intake (72.0%), and fish and seafood were the main contributors to EPA (83.5%), DPA (57.8%) and DHA (75.7%) intake [22]. In adolescents in the multiple country HELENA study [17], the food group "meat, fish, eggs and meat alternatives" was the largest contributor to the intake of LA (31.7%), ALA (21.5), ARA (54.2%), EPA (92.3%), DPA (94.9%) and DHA (85.8%). In Dutch elderly, fats and oils were the main contributor to LA (39%) and ALA (36%) intake, whereas fish and shellfish (29%) and meat and meat products (28%) were the main contributors to EPA and DHA intake.

Individual PUFA Content of Human Milk

LA and ALA are the major PUFAs present in human milk. According to a review of 14 studies from 9 European countries [24, 25], the median (range) content of human milk is 11.0% wt/wt (6.9–16.4) for LA and 0.9% wt/wt (0.7–1.3) for ALA. A descriptive meta-analysis including 65 studies of 2,474 women worldwide indicated a mean ± SD concentration of DHA and ARA in human milk of 0.32 ± 0.22 and 0.47 ± 0.13% of total fatty acids, respectively [26]. European countries tended to report higher DHA levels [27], with the highest DHA concentrations in coastal regions such as Greece, Italy and Spain. Detailed information about PUFA content of human milk can be found in the online supplementary Table 8 [26]. DHA levels in human milk vary considerably among women and are strongly influenced by maternal diet, for example, fish and seafood intake [27–30], whereas ARA concentrations in human milk are less sensitive to maternal dietary ARA intake [26, 30].

Discussion

We provided an overview of the available data on recommendations, dietary intake and sources of total and individual n-3 and n-6 PUFAs in European pregnant women, lactating women, infants, young children, older children, adolescents and elderly.

Recommendations

Since the review of Aranceta and Pérez-Rodrigo [15] published in 2012, we found that some recommendations had not been updated (FAO/WHO, EFSA, The Netherlands, Spain), while others had (France, Nordic countries, Belgium). In addition, we identified new recommendations that were not published at the time of the earlier review (DACH countries – Germany, Austria, Switzerland, Poland; France and Spain for infants and children). Similar to FAO/WHO and EFSA, no specific dietary recommendations were formulated for elderly in Europe, despite the fact that some countries (e.g., France 2001) discussed the specific dietary needs of the elderly [31].

For ARA, recommendations are limited to infants aged 0–6 months and were based on human milk content. However, the functional effect of increased ARA intake in this age group, and in other age groups, is still much discussed [32, 33]. The role of preformed DHA in visual development and brain growth and functioning in foetal life and early infancy has been demonstrated and translated into specific recommendations for pregnant and lactating women and infants. After the age of 2 years, based largely on their preventive effect on CVD and beneficial effects for neurodevelopment, recommendations have been formulated for EPA + DHA, since these PUFAs are often consumed in combination, for instance in seafood and supplements. In contrast to recommendations in European countries and EFSA, some authorities, such as those of Australia and New Zealand [34] have set an AI based on the concept of essentiality, that is, on the median intake for children and adults in a population without apparent essential fatty acid deficiency, resulting in generally lower recommended intakes. While no recommendations for DPA were formulated in Europe, the health authority from Australia and New Zealand included DPA in its recommendations, that is, the recommended intake for long chain n-3 PUFAs including EPA + DPA + DHA.

Germany and The Netherlands recently reviewed their intake recommendations, but did not set any reference value for fatty acids, and rather formulated food-based dietary guidelines [35, 36]. Moreover, 2 important authorities, the US Institute of Medicine and the WHO Nutrition Guidance Expert Advisory Group intend to update their PUFA intake recommendations [37]. In 2014, the US and Canadian governments collaboratively indicated that nutrient reference values for n-3 PUFAs needed to be updated with priority, based on public health and/or policy importance. The committee is considering the incorporation of chronic disease endpoints into the setting of dietary reference intake values [38].

Intake Data

In summary, we found that the current information on PUFA intake, with especially individual long chain PUFAs in specific age groups being at risk for an inadequate PUFA intake across Europe is limited, and identified many gaps in the current knowledge. Our findings show that EFSA recommendations for intake of LA, ALA and EPA + DHA were not met in almost half, a quarter and 3-quarters of the countries, respectively. This is in line with findings of earlier studies that have evaluated intakes of these fatty acids in children, adolescents and adults worldwide [12, 13].

The lowest number of available studies was found for lactating women and infants. However, these population groups are of particular interest as PUFA intake is very important for rapid brain growth and development during infancy. In addition, our findings indicate that there is a lack of data on ARA and DPA intakes. The scarcity of data on ARA and DPA intakes limits the assessment of intake adequacy, especially for at-risk population groups. A potential explanation is that information on individual PUFAs in the European food composition tables is often missing. Therefore, it may be necessary to combine information from different food composition tables to make a complete estimation of the individual PUFA intake. In future, it would be relevant that ARA and DPA are also included in food composition analyses.

Furthermore, large heterogeneity between studies with regard to methodologies and data presentation, made it difficult to compare the available intake data across countries. First, studies used different methods for dietary assessments (e.g., 24 h recall, food frequency questionnaires, dietary record). Some of these methods assess intake over a short term (1–3 days), which may not capture the intake of foods that are not consumed on a daily basis (e.g., fish and seafood) and consequently underestimate the intake of EPA and DHA. However, when dietary assessments of the study population cover all weekdays and seasons, the estimation of mean intakes on the population level will be reasonable [39]. In a limited number of identified studies, statistical methods were applied to correct this between-day variability. However, even when diets were evaluated over a longer period, foods may have been grouped together (e.g., n-3 PUFA-rich fish and fish less rich in n-3 PUFAs), which may reduce the specificity of intake data. Second, some studies took the use of food supplements into consideration [40–42] or even selected participants based on very high seafood consumption (a survey in French coastal populations) [43], while others specifically excluded fish oil supplement users [44–46] and some studies just did not report whether or not supplements were taken into consideration. Also, in some countries the use of food supplements in general (not specifically, n-3 PUFA supplements) by pregnant and lactating women is quite common (e.g., in the study of Rodriguez-Bernal, 55.8% of the women report the use of multivitamin supplements) [42], which may explain the large variation in PUFA intake. Unfortunately, no data could be found on the average use of n-3 PUFA supplements by European pregnant women, which indicated the need to collect data on supplement use in addition to dietary intake in future studies. Third, different metrics were used to represent the intake data: some studies reported the median, while others used the arithmetic or geometric mean, sometimes in combination with the standard deviation or with a percentile range. This shows a need to harmonise the way data on PUFA intake is presented; for example, in case of skewed distributions (e.g., EPA and DHA intakes) medians should be reported. The studies included in our review mainly reported data in means and only a few reported medians. Moreover, comparing the mean PUFA intake of a population with PUFA recommendation does not allow to determine the percentage of the population not meeting the PUFA recommendation. To do so, the distribution of the intake in the population has to be known. Fourth, different units to express the intake data were used: intake of fatty acids can be expressed in (m)g/day, E% or % of total fat. As it was not always possible to convert intake to a common unit based on the available information in the publication, comparisons between different studies and evaluation of EFSA recommendations were not possible for some data.

This review also showed that information on food and food groups contributing to the intake of different PUFAs, and in which amount they contribute, is largely lacking and if available, food groups did often report data for individual PUFAs and were not comparable between studies.

Strengths and Limitations

This study has some important strengths. First, the overview provided is based on the application of a systematic and standardised approach to screen the literature and identify the studies to be included. Second, data extraction from the selected studies was conducted in a harmonised way to obtain useful data for comparison. However, some limitations also need to be mentioned. First, most of the available studies were not based on a random sampling procedure or on a national representative sample. Second, the EFSA recommendations for LA and ALA intakes were used to evaluate if intake of total n-6 PUFAs

and total n-3 PUFAs was adequate, which may have led to an overestimation of countries with sufficient total n-6 and n-3 PUFA intakes. While the approximation is small for n-6 PUFAs (LA contributes on an average to ~99% of total n-6 PUFA intake), it is higher for n-3 PUFAs (ALA contributes on an average to ~80% of n-3 PUFA intake).

Recommendations for Future Research

Given the limited data available on individual n-3 and n-6 PUFA intakes in specific population groups in Europe, our key recommendation is that the EU should develop harmonised data collection systems that will provide a robust and reliable database on the intake of individual PUFAs. This would be needed to establish evidence-based guidelines for public health programs aiming to improve fatty acid intake and for monitoring and evaluating the effectiveness of these programs. Moreover, greater national commitment to and consistency in the provision of intake data is required to allow reasonable comparative analyses between different countries. Future more detailed intake data should be used to re-evaluate the current recommendations for the general population and specific population groups, including those with different pathologies and genetic polymorphisms. This would particularly be relevant for ARA and DPA for which extremely limited data are available. While studies in infants have suggested the role of ARA in combination with DHA on physical growth and cognitive development [47–50], more recent data indicate that ARA and its derivatives may also play key roles in cardiovascular, inflammatory and immune functions, which have not yet been adequately investigated [34]. Similarly, the potential role of DPA in cardiovascular disease, immune function and psychiatric and cognitive health needs further investigation [51].

Conclusion

The available data indicate that mean intake of EPA and DHA and to a lesser extent of LA and ALA may be suboptimal compared to EFSA recommendations for a significant part of specific population groups in Europe. More nationally representative surveys, including subsamples of specific population groups and data on relevant individual PUFAs are required to clarify the need for specific public health measures to optimise PUFA intake in Europe. Also, recommendations for nutrient requirements should be developed for the elderly population and recommendations for intake of total n-6 and n-3 PUFAs in all population groups.

Disclosure Statement

Dr. Catarina Petisca is an employee of Bunge Europe, Dr. Mathilde Fleith is an employee of Nestlé Research Centre, Dr. Ans Eilander is an employee of Unilever Research and Development, Dr. Simone Eussen is an employee of Danone Nutricia Research, Prof. Stewart Forsyth is a consultant for DSM Nutritional Products Ltd. and Prof. Philip C. Calder is an advisor to Pronova BioPharma (part of BASF), Danone Research Centre for Specialized Nutrition, DSM, Cargill, and Smartfish.

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