Public Health Nutrition: 14(7), 1157–1164 doi:10.1017/S1368980010003678

The global availability of n-3 fatty acids

Stefka Petrova[1], Plamen Dimitrov[1], Walter C Willett[2] and Hannia Campos[2,*]
[1]National Center for Public Health Protection, Sofia, Bulgaria: [2]Department of Nutrition, Harvard School of Public Health, Harvard University, Room 201, 665 Huntington Avenue, Boston, MA 02115, USA

Submitted 13 April 2010: Accepted 23 November 2010: First published online 31 March 2011

Abstract

Objectives: To assess the validity of FAO data on the availability of fish and vegetable oils as an indicator of national *n*-3 fatty acid (FA) intake and to estimate the worldwide population living in countries with low *n*-3 FA intake.
Design: Levels of the essential FA α-linolenic acid (ALA) and DHA, measured by GC in adipose tissue from participants in the present study and from published studies in eleven other countries, were used to validate ALA and fish availability estimated from FAO food balance sheets. On the basis of the validated FAO data for ALA and fish availability, we estimated the global prevalence of low *n*-3 FA availability.
Setting: Rural and urban areas of Bulgaria.
Subjects: Fifty men and fifty-eight women.
Results: Adipose tissue ALA and DHA levels (0·34% and 0·11% of total FA, respectively) in Bulgaria were lower than those of the eleven other countries with available data. A strong positive correlation was found between adipose tissue DHA and fish availability ($r = 0{\cdot}88$) and between adipose tissue ALA and ALA availability ($r = 0{\cdot}92$). Approximately half of the world's population lived in middle- and low-income countries with limited access to *n*-3 FA (fish < 400 g/week and ALA < 4% of total vegetable oils), with the largest proportion being in South-East Asia (53·6%), followed by Africa (27·1%) and Eastern Europe (8·5%). Of this half, 33% lived in countries such as Bulgaria where *n*-3 FA was almost unavailable (fish < 200 g/week and ALA < 2% of total vegetable oils).
Conclusions: Very low availability of *n*-3 FA is extensive worldwide.

Keywords
Essential fatty acids
Food availability
Nutrient deficiency

n-3 Fatty acids (FA), also known as omega-3 FA, are a family of PUFA that have their last double bond in the third position from the methyl end of the FA molecule. α-Linolenic acid (ALA), an essential 18-carbon *n*-3 FA, is found mainly in vegetable oils such as soyabean, rapeseed and flaxseed. The longest chain *n*-3 FA EPA and DHA are found mainly in fish, but they can also be obtained through metabolic conversion from ALA[1,2]. *n*-3 FA are likely to exert multiple health benefits (recently reviewed by Riediger *et al.*[3]). Numerous clinical, epidemiological and experimental studies show that they are likely to reduce risk of CVD[4] and could be implicated in the prevention of other diseases including some cancers[3]. *n*-3 FA also play an important role in brain structure and function and low levels have been associated with mood disorders[5]. In addition, optimal levels of *n*-3 FA are required for normal fetal and postnatal development[6,7]. Improved visual acuity, psychomotor development and cognitive function have been observed with *n*-3 FA supplementation[6–8].

WHO[9] recommends intake of one to two fish meals per week (~400–1000 mg EPA + DHA)[10], but intake is likely to be insufficient in many regions of the world[11]. A study that evaluated long-chain *n*-3 FA availability in thirty-eight countries using FAO food balance sheets found marginal availability for most countries, with Bulgaria, Romania and Hungary having the lowest availability[11]. Similar analyses and WHO recommendations for ALA are not available, but countries with low availability of both ALA and long-chain FA would likely be the most vulnerable to the diseases described above and would benefit the most from increased *n*-3 FA intake.

The present study was designed to confirm the low availability of *n*-3 FA in Bulgaria[11,12] by measuring levels of *n*-3 FA in adipose tissue, which provides an excellent biomarker of *n*-3 intake[13]. We then used these and published measurements of adipose FA from other countries to validate the calculated national availability of fish and ALA in vegetable oils using food balance sheets from the FAO. Because the validity of calculated availability was high, we used the FAO data from 168 countries to estimate the world wide prevalence of low access to foods containing *n*-3 FA.

Subjects and methods

A total of fifty men and fifty-eight women living in urban or rural areas of Bulgaria participated in the present study. Subjects were randomly selected from population lists

*Corresponding author: Email hcampos@hsph.harvard.edu

available at health-care units of the centralized government health-care system. All subjects aged 25–65 years were eligible to participate. General health practitioners contacted potential participants by telephone. Of those contacted, 82 % agreed to participate. Data collected included age, height, weight, blood pressure, smoking habits and dietary intake using one 24 h recall. A subcutaneous adipose tissue aspiration was collected from the upper buttock with a 16-gauge needle and disposable syringe following methods previously used in over 3600 participants from a case–control study in Costa Rica[14,15]. Samples were immediately placed in a cooler with ice packs at 4°C and immediately transported to the laboratory. Approximately 2 mg of adipose tissue was stored in Wheaton brosilicate glass vials with solid Teflon caps containing approximately 1 ml hexane:isopropanol. Samples were stored at −80°C, and within 2 weeks they were transported over dry ice to the Harvard School of Public Health for analysis. FA in adipose tissue was quantified by GLC as described previously[13]. Peak retention times and area percentages of total FA were identified by injecting known standards (NuCheck Prep, Elysium, MN, USA), and analysed with Agilent Technologies ChemStation A.08·03 software (Santa Clara, CA, USA). The SAS statistical software package version 9·1 (SAS Institute Inc., Cary, NC, USA) was used for data analysis, and all participants gave informed consent on documents approved by the Human Subjects Committee of the Harvard School of Public Health (Boston, MA, USA) and the Center for Public Health Protection (Sofia, Bulgaria).

Data from FAO food balance sheets for 2003[16] were used to estimate fish in g/person per d, ALA as a percentage of total vegetable oil and type of oil as a percentage of total vegetable oil for 168 countries with available data. The fish and seafood category that includes freshwater fish, demersal and pelagic fish, other marine fish, crustaceans, cephalopods, molluscs and others was used. Total vegetable oil (g/person per d) was calculated as the sum of the following categories: soyabean oil, rape + mustard seed oil, groundnut oil, sunflower oil, cottonseed oil, palm kernel oil, palm oil, coconut oil, sesame seed oil, olive oil, ricebran oil, maize germ oil and other oil crops. ALA was calculated as the sum of soyabean oil (g/person per d) × 0·07 and rape + mustard seed oil (g/person per d) × 0·09 divided by total vegetable oil[17]. The International Database from the US Census Bureau[18] was used to estimate the population of each country with available fish and vegetable oil data. ALA and fish availability data from FAO food balance sheets were validated using published adipose tissue ALA and DHA data from nine countries that participated in the European Multicenter Case–Control Study on Antioxidants, Myocardial Infarction and Cancer (EURAMIC)[19] (Finland, Germany, Israel, Netherlands, Norway, Russia, Spain, Switzerland and the UK), as well as from Costa Rica[15], USA[20] and Bulgaria (the present study). The FA analyses for USA, Costa Rica and Bulgaria were conducted in the same laboratory and the methodology was comparable to that used in the EURAMIC study. For the present validation study, we used FAO data from the year in which the samples were collected. The world health report of WHO was used to estimate CVD mortality data[21].

For data presentation in Figs 2 and 3, countries were divided into two groups on the basis of their ranking for combined fish and ALA availability. The first group (low *n*-3) included countries with very low fish and very low ALA (fish < 200 g/week and ALA < 2 % of total vegetable fat) and those with low fish and low ALA (fish 200–400 g/week and/or ALA 2–4 % of total vegetable fat). The second group (high *n*-3) included countries with low fish and high ALA (fish < 400 g/week and ALA > 4 % of total vegetable fat), countries with high fish and low ALA (fish > 400 g/week and ALA < 4 % of total vegetable fat) and those with both high fish and high ALA (fish > 400 g/week and ALA > 4 % of total vegetable fat). The FAO fish availability cut-off point of 400 g/week was selected to represent mean population intake levels of approximately one portion per week or the lower limit for international recommendations to prevent *n*-3 FA deficiency (one to two fish meals per week)[10]. To estimate approximate intake based on FAO availability, we used national fish intake data from the Environmental Protection Agency in the USA[22], where the average fish intake of 107 g/week (∼ 1·3 portions of 84 g) corresponds to FAO fish availability of 406 g/week. The ALA availability cut-off point of 4 % of total vegetable oils was selected to represent mean population intakes of approximately 1·4 g/d or the lower limit for international recommendations (1·4–3·0 g/d)[23]. To estimate approximate ALA intakes based on FAO availability we used data from the Costa Rica Heart Study, in which FAO ALA availability of 4·03 % corresponds to a mean daily ALA intake of 1·3 g/8368 kJ (2000 kcal) or 3·3 % of total vegetable oil[15].

In addition to the groups described above, countries were grouped into nine regions for data presentation in Table 2: Eastern Europe including central, northern and southern regions; Europe (Western region); Central Asia; South-East Asia; the Middle East; Africa; Oceania; Latin America including the Caribbean; and North America. Estimates for CVD mortality, type of oil and fish were weighted by the population.

Results

Table 1 shows the general characteristics, dietary intake and adipose tissue FA of the Bulgarian participants. The average age and BMI were 46 years and 29·4 kg/m^2 for men and 42 years and 26·7 kg/m^2 for women, respectively. All participants reported using sunflower oil for cooking, except one who used olive oil. Total fat provided 36 % of energy (13 % SFA, 11 % MUFA and 12 % PUFA). ALA levels of adipose tissue were 0·34 % of total

Table 1 General characteristics, dietary intake and adipose tissue fatty acids of Bulgarian men and women

	Men (*n* 50)		Women (*n* 58)	
Parameters	Mean	SD	Mean	SD
Age (years)	46	13	42	11
BMI (kg/m^2)	29·4	4·9	26·7	5·8
Blood pressure (mmHg)				
Systolic	130	13	121	13
Diastolic	88	10	80	10
Smoking (%)*	47		53	
Daily dietary intake				
Energy (kJ)	562	130	410	112
Protein (%E)	16	5	15	4
Carbohydrate (%E)	43	11	47	10
Total fat (%E)	36	9	36	10
Saturated fat (%E)	13	5	13	5
Monounsaturated fat (%E)	11	3	11	3
Polyunsaturated fat (%E)	12	5	12	6
Cholesterol (mg/4184 kJ)	158	113	118	92
Adipose tissue fatty acids (% total)				
SFA				
12 : 0	0·06	0·07	0·10	0·12
14 : 0	1·26	0·51	1·32	0·56
15 : 0	0·18	0·07	0·19	0·06
16 : 0	18·6	2·00	16·9	1·85
17 : 0	0·18	0·04	0·16	0·04
18 : 0	3·09	0·90	2·73	0·66
MUFA				
18 : 1*n*-9	40·8	2·22	40·8	2·38
18 : 1*n*-7	1·65	0·35	1·52	0·26
PUFA				
n-6				
18 : 2*n*-6	25·2	3·66	27·3	3·31
18 : 3*n*-6	0·09	0·03	0·09	0·02
20 : 3*n*-6	0·36	0·10	0·35	0·06
20 : 4*n*-6	0·60	0·14	0·55	0·15
n-3				
18 : 3*n*-3	0·34	0·07	0·34	0·14
20 : 5*n*-3	0·03	0·02	0·02	0·01
22 : 5*n*-3	0·14	0·04	0·12	0·03
22 : 6*n*-3	0·12	0·05	0·10	0·04
Trans fatty acids				
16 : 1*n*-7*t*	0·12	0·04	0·13	0·04
18 : 1*t*†	0·87	0·33	0·88	0·29
18 : 2*tt*,*ct*,*tc*‡	0·29	0·05	0·29	0·07
18 : 2*n*-7*ct*§	0·29	0·09	0·31	0·08

%E, percentage of energy.
*Smoking one or more cigarettes per day.
†Sum of 18 : 1 *trans* (*n*-7*t*, *n*-9*t* and *n*-11*t*).
‡Sum of 18 : 2 *trans* (*n*-6*tt*, *n*-6*ct* and *n*-6*tc*).
§Conjugated linoleic acid 9*c*-11*t*.

FA in men and women, whereas EPA and DHA levels were 0·14 % and 0·12 % of total FA in men and 0·12 % and 0·10 % of total FA in women, respectively.

Figure 1(a) shows the association between ALA availability as a percentage of total vegetable oil and adipose tissue ALA in twelve countries. A strong correlation was observed between FAO ALA estimates and corresponding adipose tissue levels ($r = 0·92$). Bulgaria had the lowest ALA availability (1·1 % of total vegetable oil) and the lowest ALA in adipose tissue (0·34 % of total FA). Norway, the USA, Israel and Finland had the highest ALA availability and ALA in adipose tissue. Figure 1(b) shows the association between adipose tissue DHA and fish availability (in g/person per week) in twelve countries. Fish availability estimates from FAO were strongly related to adipose tissue DHA ($r = 0·88$). Bulgaria had the lowest fish availability (57 g/person per week) and DHA levels in adipose tissue (0·11 % of total FA). The highest fish availability and DHA levels in adipose tissue were found in Norway.

Figure 2(a) shows fish and ALA availability for countries in the high *n*-3 group. Large differences in *n*-3 FA availability were observed among the countries. The smallest group (0·46 billion people) consisted of countries with high fish but low ALA availability. Mediterranean countries, some densely populated countries such as Malaysia, Thailand and the Philippines, as well as small islands, were found in this group. A large proportion of the population, including China, the USA and Japan, lived in countries with both high fish and ALA availability (1·9 billion people). Within these two high fish groups, fish availability ranged from 406 g/week in the USA to 1742 g/week in Samoa, but most of the population within these two groups lived in countries with fish availability between 400 and 800 g/week. Approximately 0·9 billion people lived in countries with low fish and high ALA availability, including Brazil, Mexico and Bangladesh. The highest ALA availability (>7 %) was found in Poland, the Czech Republic, Latvia and Cuba, whereas the lowest was found in Costa Rica. Figure 2(b) shows countries in the low *n*-3 group. Approximately 3·1 billion people lived in these countries, the most populated being India, Indonesia, Pakistan, Nigeria and Russia. Countries with the lowest fish and ALA availability, representing a total of 1·05 billion people, are shown in the grey shaded area.

Figure 3 illustrates the worldwide distribution of *n*-3 FA availability and Table 2 shows the type of oil as a percentage of total vegetable oil, fish availability and CVD mortality by geographical region and low *n*-3 or high *n*-3 groups. A large proportion of the population with very low (marked in black) or low (marked in hatched dark grey) fish and ALA availability (low *n*-3) lived in South-East Asia (53·6 %), Africa (27·1 %) and Eastern Europe (8·5 %). Within this group, palm oil was the main type of oil available in South-East Asia (48·2 %) and Africa (40·8 %), whereas sunflower oil was the predominant oil type available in Eastern Europe (82·8 %). Fish availability was 150 g/week in South-East Asia, 127 g/week in Africa and 277 g/week in Eastern Europe. ALA was <2 % for all. Most of the population in the high *n*-3 group lived in South-East Asia (57 %), Latin America (13·4 %) and Europe (11·2 %), but the sources of *n*-3 (vegetable oil *v*. fish) varied between these regions. Availability of both fish and ALA was high in South-East Asia (524 g/week and 4·9 %, respectively). In contrast, Latin America had low fish availability (207 g/week) and high ALA availability (5·3 %), whereas Europe had high fish (523 g/week) and low ALA availability (3·8 %). The main type of oil available was soyabean oil in South-East Asia (41·7 %) and Latin America (62·9 %), whereas similar proportions of

https://doi.org/10.1017/S1368980010003678 Published online by Cambridge University Press

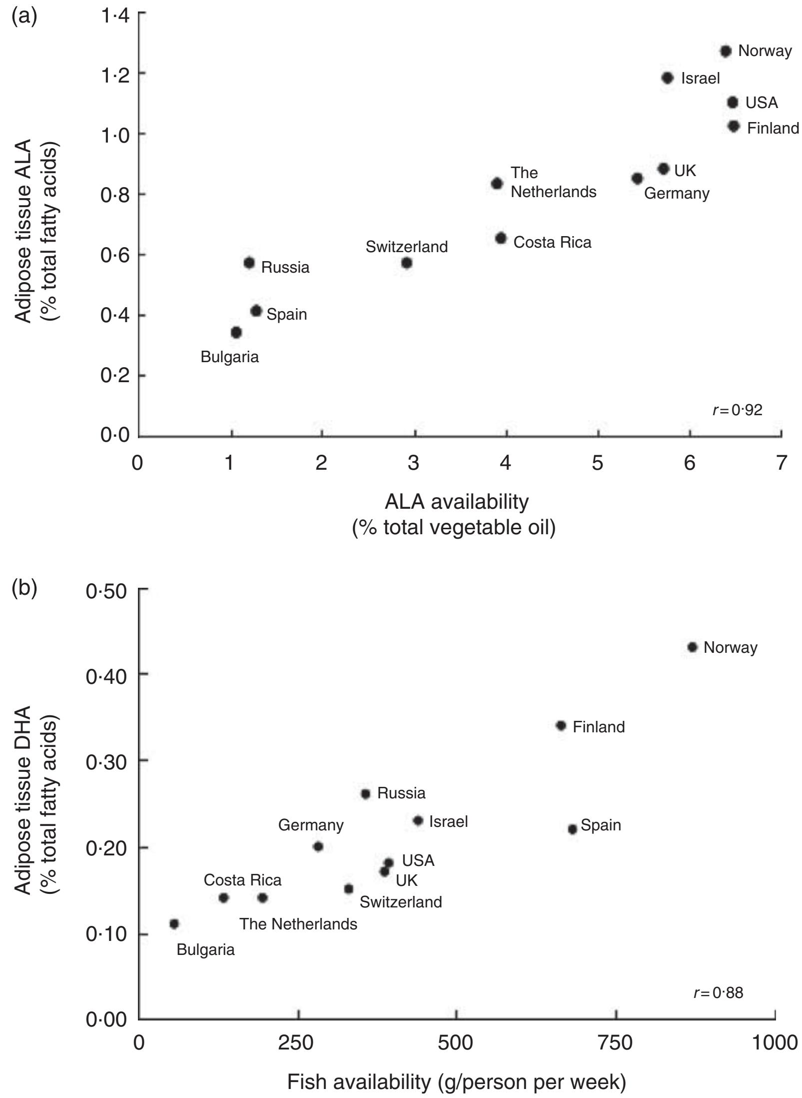

Fig. 1 Correlation between (a) adipose tissue α-linolenic acid (ALA; % total fatty acids) and ALA availability (% total vegetable oil); and (b) adipose tissue DHA and fish availability (in g/person per week). Availability data were obtained from FAO food balance sheets in twelve countries with available adipose tissue ALA and DHA. Previously published average adipose tissue data were used for Finland, Germany, Israel, the Netherlands, Norway, Russia, Spain, Switzerland and the UK[19], as well as for Costa Rica[15] and the USA[20]

soyabean (21·1 %), rapeseed (20·9 %) and sunflower (21·3 %) oils were available in Europe.

Discussion

We estimated ALA and fish availability in 168 countries using validated data from FAO food balance sheets. Fish and ALA availability in Bulgaria was among the lowest in the world, a finding consistent with the low ALA and DHA levels in adipose tissue. Approximately 3·1 billion people lived in countries with low fish and ALA availability, and 33 % of these lived in countries such as Bulgaria where fish and ALA were almost unavailable. This large segment of the world's population is likely to have serious consequences because of *n*-3 FA insufficiency.

Most of the population with low fish and ALA availability lives in middle- and low-income countries in South-East Asia (53·6 %), followed by Africa (27·1 %) and Eastern Europe (8·5 %). Average fish availability in these regions ranged between 29 and 277 g/week, and the main oils available were palm oil in South-East Asia and Africa and sunflower oil in Eastern Europe. None of these oils contain ALA, but the levels of other FA vary substantially. For example, sunflower oil is high in linoleic acid (69 %) and low in SFA (12 %), whereas the opposite is observed in palm oil (10 % and 50 %, respectively). Consistent with these data, Bulgarian participants almost exclusively used sunflower oil, and the content of linoleic acid in adipose tissue was considerably higher (25 % of total FA) than in other populations in which palm oil was highly used, such as Costa Rica (16 % of total FA)[13].

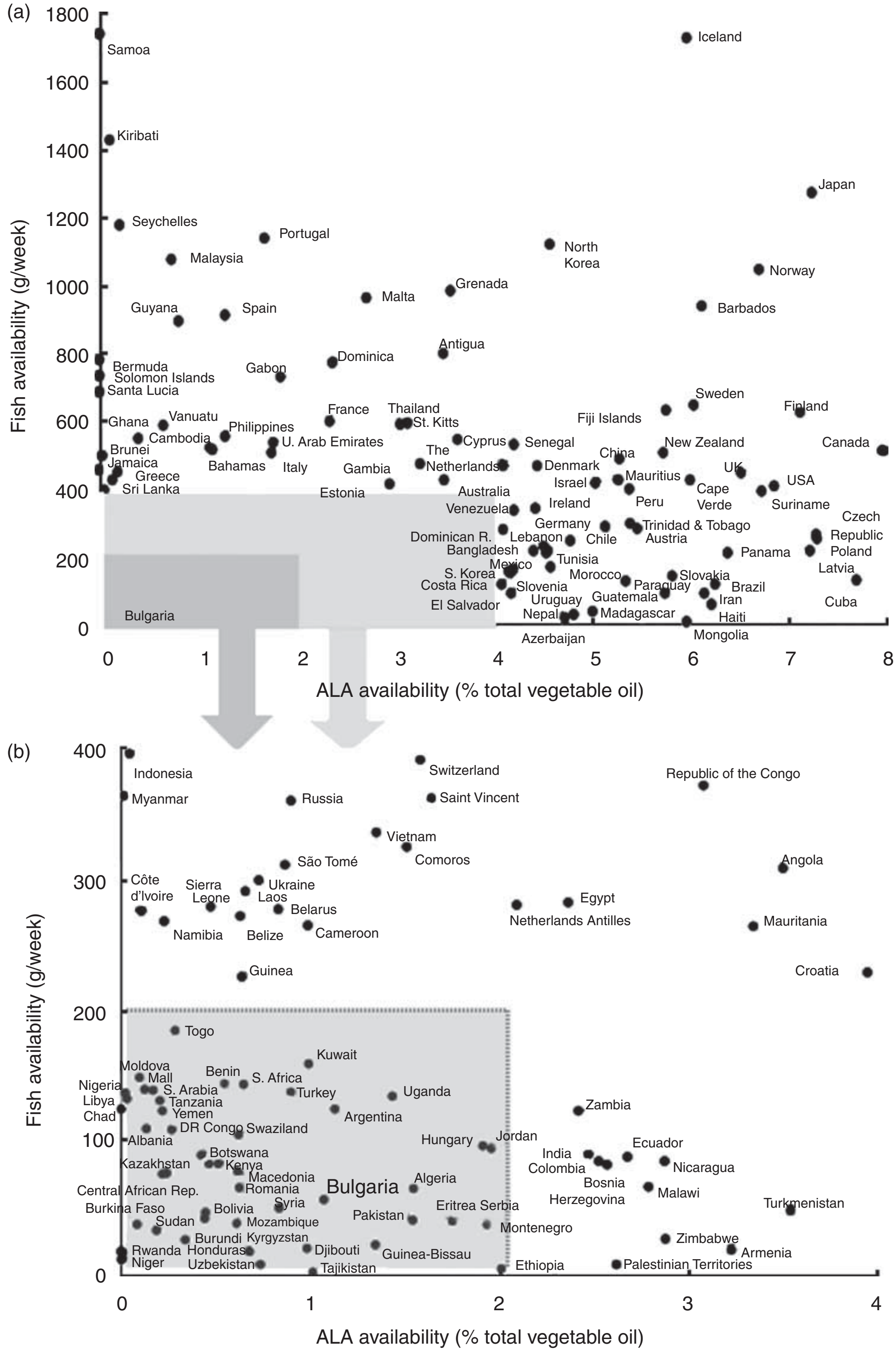

Fig. 2 Fish (g/week) and α-linolenic acid (ALA; % total vegetable oil) availability for 168 countries as estimated from FAO food balance sheets: (a) countries in the high *n*-3 group (fish availability > 400 g/week and/or ALA availability > 4 % total vegetable oil); (b) countries in the low-*n*-3 group (fish availability < 400 g/week and ALA availability < 4 % total vegetable oil)

Our finding that Bulgaria and forty-six other countries have almost no access to *n*-3 FA is of great concern. *n*-3 FA are required to achieve optimal pregnancy outcomes and infant development[8,24,25]. Assuming the estimates of intake described in the methods section, fish availability in Bulgaria (57 g/week) would correspond to an average intake of less than one portion per month, and ALA availability (1·1 % of total vegetable oils) would correspond to an intake of <0·5 g/d. These intakes are consistent with our finding showing that Bulgaria had the lowest ALA and DHA adipose tissue levels compared with twelve other countries. Therefore, it is likely that most of the population in Bulgaria

https://doi.org/10.1017/S1368980010003678 Published online by Cambridge University Press

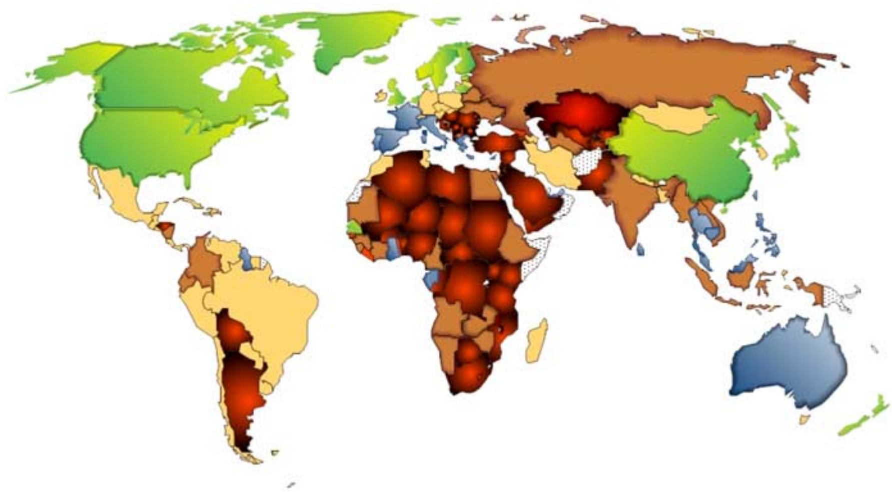

Fig. 3 (colour online) Availability of n-3 fatty acids worldwide: very low fish and very low α-linolenic acid (ALA; ■; fish < 200 g/week and ALA < 2 % of total vegetable oil); low fish and low ALA (■; fish 200–400 g/week and/or ALA 2–4 % of total vegetable oil); low fish and high ALA (■; fish < 400 g/week and ALA > 4 % of total vegetable oil); high fish and low ALA (■; fish > 400 g/week and ALA < 4 % of total vegetable oil); high fish and high ALA (■; fish > 400 g/week and ALA > 4 % of total vegetable oil). Availability was estimated from FAO food balance sheets

and other countries with comparable availability do not consume any of the major sources of n-3 FA. The detectable levels of DHA and ALA in adipose tissue in Bulgarians are likely to reflect other sources that provide small amounts of n-3 FA, such as diary products, meat, green leafy vegetables and walnuts. These food sources were not considered in the estimates of ALA intake in the present study, but our data suggest it is unlikely that these sources are enough to meet current recommendations.

The inadequate availability of n-3 FA could also be an important determinant of chronic disease, including mental, neurological and immunological disorders, cancer and CVD[3]. Clinical trials show that long-chain n-3 FA reduce CVD, and numerous epidemiological studies have found that higher intakes of n-3 FA are associated with lower risk of CVD and, specifically, sudden cardiac death[4,15]. In the present study, Central Asia, the region with the lowest ALA and fish availability, had the highest CVD mortality. In addition, CVD mortality in South-East Asian and Eastern European countries with high n-3 availability was approximately 50 % lower than in countries with low n-3 availability within the same region. The average adipose tissue ALA in Bulgaria is comparable to the levels found among those with the highest risk of myocardial infarction (MI) in Costa Rica[15]. Not surprisingly, regions with the lowest CVD mortality (North America, Europe and Oceania) had high n-3 availability. These observations should be interpreted with caution as the design of the present study precludes establishment of any causal links.

Adipose tissue ALA and DHA levels accessible from twelve countries including the present study were used to validate the FAO food data balance sheets. The observed strong linear relationship between ALA and fish availability estimated from FAO food balance sheets in each country, as well as adipose tissue ALA and DHA levels, indicates that estimates of n-3 availability in the present study are usually reliable indicators of intake. The validation analysis incorporated countries representing the worldwide range of fish and ALA availability. It included Norway, a country in which availability of fish and ALA is among the highest in the world, and Bulgaria, a country with one of the lowest availabilities. The validation study also included countries with high fish but low ALA availability, such as Spain, as well as those with relatively high ALA but low fish, such as Costa Rica. Yet, the twelve countries with available adipose tissue used in the validation study may not represent the quality of FAO data from all countries, and it is possible that more variation would be observed if more countries were included. For example, discrepancies between food availability and individual intake range between 0 % and 50 % within European countries. However, regardless of the uncertainties in estimating n-3 FA availability and how they relate to intake, it is clear from these results that there are marked differences in the availability of these FA worldwide and thus it is likely that a large proportion of the world population is not getting enough to meet minimum requirements.

Despite the inadequate availability of n-3 FA observed in the present study, WHO recommendations to increase fish intake are likely to be unsustainable, as fish stocks are rapidly declining and many are likely to collapse in 40 years if present trends continue[26–28]. Therefore, ALA could play an important role in meeting the n-3 requirements worldwide. For example, with regard to CVD, ecological data from Central and Eastern Europe, where

Table 2 CVD mortality and population-weighted average availability of vegetable oils and fish by regions with low or high n-3 availability

Region	Population (millions)	CVD mortality/100 000	Type of oil (% total vegetable oil)									ALA	Fish, seafood (g/week)
			Soyabean	Rapeseed*	Sunflower	Palm†	Cottonseed	Groundnut	Maize	Olive	Other		
	n	*n*	%	%	%	%	%	%	%	%	%	%	
Low *n*-3													
Eastern Europe‡	264·6	623	10·3	1·6	82·8	0·8	0·0	0·1	2·7	0·6	1·1	1·0	277
Central Asia	59·8	693	10·4	0·4	24·2	0·0	59·5	0·0	0·9	0·0	0·0	0·9	29
South-East Asia	1669·2	413	13·2	8·5	4·2	48·2	4·8	11·6	0·3	0·0	8·4	1·9	150
Middle East	157·8	482	9·5	0·3	16·8	37·7	10·9	1·6	7·3	9·8	7·1	0·8	115
Africa	843·6	442	9·7	1·4	11·2	40·8	6·5	15·5	3·0	1·0	10·7	0·9	127
Latin America§	121·3	242	22·3	0·1	35·1	34·5	2·4	0·6	3·4	0·5	1·3	1·8	94
High *n*-3													
Eastern Europe‡	62·9	335	27·0	47·6	11·8	8·7	0·4	0·5	0·4	0·9	3·0	6·9	291
South-East Asia	1926·0	291	41·7	15·5	3·1	23·4	3·6	7·7	1·5	0·2	2·7	4·9	524
Middle East	95·4	449	66·8	3·1	14·6	2·0	3·9	0·2	4·0	1·4	3·9	5·7	134
Africa	102·5	413	44·8	0·9	4·4	21·3	0·4	13·7	0·8	9·3	4·4	3·7	313
Latin America§	451·4	264	62·9	2·9	7·7	14·4	4·7	0·5	3·4	1·5	1·4	5·3	207
North America	337·3	183	76·2	8·8	0·5	1·2	2·6	1·3	5·4	2·7	1·2	7·0	415
Europe‖	378·5	177	21·1	20·9	21·3	9·2	0·3	2·7	2·8	18·2	5·6	3·8	523
Oceania	27·4	165	13·4	27·2	8·9	27·9	10·7	0·7	1·3	7·8	2·2	3·8	464

*Includes mustard seed oil.
†Includes, coconut and palm kernel oil.
‡North, central and south-eastern regions.
§Includes the Caribbean.
‖Western region.

fish intake is very low, show a strong linear correlation between the observed decrease in CVD mortality between 1990 and 2002 and increased ALA availability[12]. Countries that had the largest increases in ALA had the largest declines in CVD mortality. Bulgaria, the country with the smallest reduction in CVD mortality, did not increase ALA. Studies in Costa Rica and India, where intake of n-3 FA is low, show that a higher intake of ALA from vegetable oils (soyabean in Costa Rica and mustard seed in India) was associated with a 59 % and 79 % reduction in MI[15,29].

A limitation of the present study is that it relied exclusively on FAO availability data on vegetable oils and fish and did not incorporate modest sources of n-3 FA such as green leafy vegetables, dairy and meat products, walnuts and eggs. However, it is unlikely that these sources will provide considerable amounts to the overall population, as shown for Bulgaria. In addition, the present study did not take into account the fact that many countries, such as Iran, partially hydrogenate much of their soyabean oil, a process that destroys a large proportion of ALA[30]. Thus, ALA availability may have been overestimated in some countries. The present study also did not take the use of n-3 supplements into consideration. It is possible that the use of n-3 supplements has increased along with the use of other dietary supplements[31,32]. It is unlikely that these changes have occurred in low- and middle-income countries as supplement use is associated with higher income, education and health concerns[33,34]. Thus, it is unlikely that the lack of information on n-3 supplements would have affected the results of our study because these regions already have the highest n-3 availability. It should also be considered that the present study reported average intake for each country, but intake varies widely within a country. For example, in the USA, the average fish intake is 107 g/week, but 10 % of the population consumes more than 394 g/week and many consume far less than 100 g/week[22]. Finally, although the main purpose of the present study was to examine the world availability of n-3 FA, we provided information on CVD mortality by region according to n-3 availability. It is clear that many factors such as higher socio-economic status, better accessibility to health care and overall quality of the diet affect CVD mortality and the observations presented could be just attributed to chance.

In summary, about half of the world's population lives in countries where adequate sources of n-3 FA are not available. Increasing n-3 FA intake in these populations is likely to have numerous health benefits. Alternative sources of n-3 from fish will be required to meet this worldwide need.

Acknowledgements

The present research received no specific grant from any funding agency in the public, commercial or not-for-profit

sectors. There is no conflict of interest to declare. All authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All authors have participated sufficiently in the work to take public responsibility for the whole manuscript. H.C. conceptualized and designed the study, acquired the data, obtained funding and wrote the manuscript; S.P. and P.D. directed the study and helped to obtain data and funding. All authors contributed to the interpretation of results and provided critical revision of the manuscript for important intellectual content.

References

1. Goyens PL, Spilker ME, Zock PL *et al.* (2006) Conversion of alpha-linolenic acid in humans is influenced by the absolute amounts of alpha-linolenic acid and linoleic acid in the diet and not by their ratio. *Am J Clin Nutr* **84**, 44–53.
2. Burdge G (2004) Alpha-linolenic acid metabolism in men and women: nutritional and biological implications. *Curr Opin Clin Nutr Metab Care* **7**, 137–144.
3. Riediger ND, Othman RA, Suh M *et al.* (2009) A systemic review of the roles of *n*-3 fatty acids in health and disease. *J Am Diet Assoc* **109**, 668–679.
4. Mozaffarian D (2008) Fish and *n*-3 fatty acids for the prevention of fatal coronary heart disease and sudden cardiac death. *Am J Clin Nutr* **87**, issue 6, 1991S–1996S.
5. Ross BM, Seguin J & Sieswerda LE (2007) Omega-3 fatty acids as treatments for mental illness: which disorder and which fatty acid? *Lipids Health Dis* **6**, 21.
6. Uauy R & Dangour AD (2006) Nutrition in brain development and aging: role of essential fatty acids. *Nutr Rev* **64**, 5 Pt 2, S24–S33.
7. Carlson SE (2009) Docosahexaenoic acid supplementation in pregnancy and lactation. *Am J Clin Nutr* **89**, issue 2, 678S–684S.
8. Cheatham CL, Colombo J & Carlson SE (2006) *n*-3 Fatty acids and cognitive and visual acuity development: methodologic and conceptual considerations. *Am J Clin Nutr* **83**, Suppl. 6, 1458S–1466S.
9. World Health Organization (1971) *IHD Registers: Report of the 5th Working Group*. Copenhagen: WHO.
10. World Health Organization (2003) *Diet, Nutrition, and the Prevention of Chronic Diseases. Joint WHO/FAO Expert Consultation*. *WHO Technical Report Series* no. 916. Geneva: WHO.
11. Hibbeln JR, Nieminen LR, Blasbalg TL *et al.* (2006) Healthy intakes of *n*-3 and *n*-6 fatty acids: estimations considering worldwide diversity. *Am J Clin Nutr* **83**, Suppl. 6, 1483S–1493S.
12. Zatonski W, Campos H & Willett W (2008) Rapid declines in coronary heart disease mortality in Eastern Europe are associated with increased consumption of oils rich in alpha-linolenic acid. *Eur J Epidemiol* **23**, 3–10.
13. Baylin A, Kabagambe EK, Siles X *et al.* (2002) Adipose tissue biomarkers of fatty acid intake. *Am J Clin Nutr* **76**, 750–757.
14. Beynen AC & Katan MB (1985) Rapid sampling and long-term storage of subcutaneous adipose-tissue biopsies for determination of fatty acid composition. *Am J Clin Nutr* **42**, 317–322.
15. Campos H, Baylin A & Willett WC (2008) Alpha-linolenic acid and risk of nonfatal acute myocardial infarction. *Circulation* **118**, 339–345.
16. Food and Agriculture Organization of the United Nations (2008) FAOSTAT food balance sheets. http://faostat.fao.org (accessed November 2008).
17. US Department of Agriculture, Agricultural Research Service (2009) USDA National Nutrient Database for Standard Reference, Release 23. Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/ndl
18. US Census Bureau, Population Division (2010) International Data Base 2010. http://www.census.gov/ipc/www/idb/ (accessed March 2010).
19. Guallar E, Aro A, Jimenez FJ *et al.* (1999) Omega-3 fatty acids in adipose tissue and risk of myocardial infarction: the EURAMIC study. *Arterioscler Thromb Vasc Biol* **19**, 1111–1118.
20. Knutsen SF, Fraser GE, Beeson WL *et al.* (2003) Comparison of adipose tissue fatty acids with dietary fatty acids as measured by 24-hour recall and food frequency questionnaire in Black and White Adventists: the Adventist Health Study. *Ann Epidemiol* **13**, 119–127.
21. World Health Organization, Health Statistics and Health Information Systems (2009) Mortality and Burden of Disease Statistics. Disease and Injury Country Estimates 2009. http://www.who.int/healthinfo/statistics/mortality/en/index.html (accessed July 2009).
22. United States Environmental Protection Agency (2002) Estimated per capita fish consumption in the United States. http://www.epa.gov/waterscience/fish/files/consumption_report.pdf (accessed August 2009).
23. Gebauer SK, Psota TL, Harris WS *et al.* (2006) *n*-3 Fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. *Am J Clin Nutr* **83**, Suppl. 6, 1526S–1535S.
24. Judge MP, Harel O & Lammi-Keefe CJ (2007) Maternal consumption of a docosahexaenoic acid-containing functional food during pregnancy: benefit for infant performance on problem-solving but not on recognition memory tasks at age 9 mo. *Am J Clin Nutr* **85**, 1572–1577.
25. Hibbeln JR, Davis JM, Steer C *et al.* (2007) Maternal seafood consumption in pregnancy and neurodevelopmental outcomes in childhood (ALSPAC study): an observational cohort study. *Lancet* **369**, 578–585.
26. Brunner EJ, Jones PJ, Friel S *et al.* (2009) Fish, human health and marine ecosystem health: policies in collision. *Int J Epidemiol* **38**, 93–100.
27. Myers RA & Worm B (2003) Rapid worldwide depletion of predatory fish communities. *Nature* **423**, 280–283.
28. Jenkins DJ, Sievenpiper JL, Pauly D *et al.* (2009) Are dietary recommendations for the use of fish oils sustainable? *CMAJ* **180**, 633–637.
29. Rastogi T, Reddy KS, Vaz M *et al.* (2004) Diet and risk of ischemic heart disease in India. *Am J Clin Nutr* **79**, 582–592.
30. Mozaffarian D, Abdollahi M, Campos H *et al.* (2007) Consumption of trans fats and estimated effects on coronary heart disease in Iran. *Eur J Clin Nutr* **61**, 1004–1010.
31. Bailey RL, Gahche JJ, Lentino CV *et al.* (2011) Dietary supplement use in the United States, 2003–2006. *J Nutr* **141**, 261–266.
32. Briefel RR & Johnson CL (2004) Secular trends in dietary intake in the United States. *Annu Rev Nutr* **24**, 401–431.
33. Block G, Jensen CD, Norkus EP *et al.* (2007) Usage patterns, health, and nutritional status of long-term multiple dietary supplement users: a cross-sectional study. *Nutr J* **6**, 30.
34. Marques-Vidal P, Pecoud A, Hayoz D *et al.* (2009) Prevalence and characteristics of vitamin or dietary supplement users in Lausanne, Switzerland: the CoLaus study. *Eur J Clin Nutr* **63**, 273–281.