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Dietary Intakes of Arachidonic Acid and Docosahexaenoic Acid in Early Life – With a Special Focus on Complementary Feeding in Developing Countries

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Keywords
Docosahexaenoic acid · Arachidonic acid · Complementary feeding · Infants and children · Developing countries

Abstract
Background: In developing countries, dietary intakes of arachidonic acid (ARA) and docosahexaenoic acid (DHA) in early life are lower than current recommended levels. This review specifically focusses on the contribution that complementary feeding makes to ARA and DHA intakes in medium- to low-income countries. The aims of the review are (1) to determine the availability of ARA and DHA food sources in developing countries, (2) to estimate the contribution of complementary feeding to dietary intakes of ARA and DHA in infants aged 6–36 months, and (3) to relate the dietary ARA and DHA intake data to key socioeconomic and health indicators. ***Summary:*** The primary dietary data was collected by the Food and Agriculture Organisation (FAO) using Food Balance Sheets, and fatty acid composition was based on the Australian food composition tables. There is evidence of wide variation in per capita dietary intake for both DHA and ARA food sources, with low intakes of meat and seafood products being highly prevalent in most low-income countries. In children aged 6–36 months, the supply of ARA and DHA from the longer duration of breastfeeding in low-income countries is counterbalanced by the exceptionally low provision of ARA and DHA from complementary foods. The lowest tertile for ARA intake is associated with higher percentages of childhood stunting, birth rate, infant mortality, and longer duration of breast feeding. ***Key Message:*** In developing countries, intakes of DHA and ARA from complementary foods are low, and public health organisations need to adopt pragmatic strategies that will ensure that there is a nutritional safety net for the most vulnerable infants.

Introduction

During the last 3 decades, there has been considerable interest in the roles of long chain polyunsaturated fatty acids (LCPUFAs) in infant growth and development [1–6]. The seminal work of Manuel Martinez [7] showing the rapid accretion of docosahexaenoic acid (DHA) and arachidonic acid (ARA) by the infant brain during the first 1,000 days of life underlined the potential importance of these fatty acids during this critical period of growth and development. The subsequent evidence that infants who received breast milk, which contains both DHA and ARA, had higher concentrations of DHA in their red blood cell membrane and in the cerebral cortex compared to infants receiving infant formula (IF) devoid of these fatty acids, was the key driver for clinical intervention studies [8, 9].

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There is now a wealth of information on the roles of ARA and DHA from cellular, animal and human studies and it is evident that in early life, adequate supplies of both ARA and DHA are critical for normal growth and development [4, 5]. However, much of the available research data has been generated in high-income countries and there is currently limited information on dietary intakes of ARA and DHA by infants and young children living in medium- to low-income countries. In many of these countries, the diet is predominantly plant based and therefore, local diets may be low in food sources for ARA and DHA, which include meat, poultry and eggs for ARA and fish and other seafood products for DHA [10–12].

Recommendations on dietary intakes of ARA and DHA in early life are few and predominantly relate to findings obtained in high-income countries. The European Food Standard Authority (EFSA) has recommended a DHA level of 0.3% total fatty acid in IF for infants aged 0–12 months [13], and an intake of a minimum of 100 mg DHA/day for older infants and young children [14, 15]. The Food and Agricultural Organisation of the United Nations (FAO) recommended that during the period of 0–6 months a daily requirement of 0.1–0.18% energy for DHA (equivalent to a mean intake of 102 mg/day); for 6–24 months, a DHA intake of 10–12 mg/kg body weight; 2–4 years, DHA and EPA intake of 100–150 mg/day; increasing to DHA and EPA of 200–250 mg at age 6–10 years [16].

There are few explicit dietary recommendations for ARA; an expert group recommended 140 mg ARA/day during the first months of life [17], and for young children, the Belgian Health Council recommended that the ARA content of the diet should be 0.10–0.25% energy (approximately 102–258 mg/day), and DHA 0.10–0.40% energy (approximately 102–413 mg/day) [18].

The limited dietary recommendations for ARA reflect a previous understanding that ARA insufficiency was unlikely as it was plentiful in the diet and moreover, there was also endogenous synthesis of both ARA and DHA from their precursor fatty acids, linoleic acid and alpha-linolenic acid respectively. The opinion of EFSA in 2014 was that "there is no necessity to add ARA to IF even in the presence of DHA" [15]. Several more recent publications have challenged this statement and provided evidence that endogenous synthesis is low, especially in early life [5, 19–21], and levels of ARA (and DHA) are low in complementary foods especially in low-income countries [10–12]. With this evidence, it is reasonable to conclude that if an infant receives an IF or follow on formula without ARA and DHA, and is introduced to complementary foods that have low content of these fatty acids, the infant will have a very different fatty acid status from an infant who has received breast milk, which always contains DHA and ARA and receives complementary foods that have adequate levels of ARA and DHA.

This research group recently published data on per capita dietary intakes of DHA and ARA in developing countries [22] and as an extension of that study estimated the DHA and ARA intakes by infants and young children aged 6–36 months and living in developing countries [23]. In upper middle-income countries, the median daily intake of ARA for infants and young children aged 6–36 months was 68 mg/day (with a range of 38–137 mg/day), which was similar to the median ARA intake of 62 mg/day (range 50–92 mg/day) in low-income countries. For DHA, the median intake in upper middle income was 43 mg/day (range 14–371 mg/day) and in low-income countries 50 mg/day (range 28–121 mg/day). The similar levels for upper-, middle- and low-income countries were related to the variation in duration of breast feeding across the gross national income (GNI) groups, with the supply of ARA and DHA from breast milk being significantly longer in the low-income groups. This compensated for extremely low intakes of ARA and DHA from complementary foods in low-income countries, which was 8.9 mg/day (range 1–22 mg/day) for ARA and 9.6 (range 0.7–65 mg/day) for DHA [22, 23].

These findings indicate that dietary intakes of DHA and ARA in early life are generally lower than current recommended levels and the provision of ARA and DHA from breast milk and complementary foods varied with the economic status of the country. It is evident that maintaining a continuum of DHA and ARA during the early life period in developing countries is challenging but by enabling an optimum supply from both breast milk (or supplemented IF) and complementary foods during this period, an adequate ARA and DHA intake should be achievable.

Aim

The aims of this study, which focuses on developing countries, are (1) to determine the availability of ARA and DHA food sources in these countries, (2) to estimate the contribution of complementary feeding to dietary intakes of ARA and DHA in infants aged 6–36 months, and (3) to relate the dietary ARA and DHA intake data to key socioeconomic and health indicators.

Methodology

The methodology for the extraction of dietary data across developed and developing countries and the subsequent analyses have previously been described [22, 23]. In summary, the original dietary data was extracted from Food Balance Sheets that had been collected by the FAO Statistics Division [24–26]. Fatty acid composition was based on the Australian food composition tables 2009–2011 (NUTTAB) [27], and this analysis provided median per capita intake estimates for DHA and ARA in 175 countries worldwide, of which 128 are recognised as developing nations [22]. The food analysis focused on the predominant sources of ARA – meat, eggs and milk, and for DHA – fish and seafood products.

For the estimate of ARA and DHA intake by infants and young children aged 6–36 months, the contributions from breast milk consumption were calculated using previous published data on volume of breast milk intake [28], the DHA and ARA composition of breast milk [29], energy requirements for children 6–36 months of age [30], and the duration of breast feeding within individual countries [31].

Estimates of complementary food consumption during the age range of 6–36 months were based on the per capita data and proportionately reduced to represent normal energy intake during the age range of 6–36 months. The energy intakes per capita for developed and developing countries have been previously reported [32], and for children at 6–36 months of age an energy requirement of 930 kcal/day, which was considered by the FAO to meet requirements for normal growth, was the accepted benchmark [33]. The ARA and DHA intakes at ages 3–7 years were similarly calculated using FAO estimates of energy intakes at these ages. As these adjustments in energy intake resulted in a proportionate reduction in DHA and ARA intake, the % energy for DHA and ARA was not altered from the overall population levels.

The relationship of the economic status of the country to dietary intake was assessed using the World Bank Atlas method, which classifies countries by their per capita GNI [34]. Accordingly, the countries were grouped as "high income" if per capita income was greater than US$12,276 (GNI 1), "upper-middle" if income was US$3,976–12,276 (GNI 2), "lower-middle" if income was US$1,006–3,975 (GNI 3) and "low" if income was less than US$1,005 per capita (GNI 4).

The ARA and DHA intake data from 6 to 36 months was related to the previously published health indicators birth rate [35], infant mortality [36], and percentage of stunting [37].

The data is predominantly presented as a descriptive analysis and was analysed using IBM SPSS Statistics 22. Since key data, especially data relating to DHA intake did not have a normal distribution, the relevant data is presented as the median and the range, and differences in median intakes across categories are measured using non-parametric tests. The Kruskal–Wallis H test is used to determine if there are statistically significant differences in distribution of key outcome variables between 3 or more variable groups.

Results

The estimated per capita dietary intake of DHA and ARA food sources for 8 regions, including 134 medium- to low-income countries, are shown in Table 1. The data demonstrates that there is wide variation in dietary intake for both DHA and ARA food sources. In relation to fish and seafood products, which are the predominant sources of dietary DHA, intakes vary from 5.7 g/day in Central Asia to 80.8 g/day in East Asia. Dietary sources of ARA include eggs of which the highest intake was in South America and the lowest in Sub-Saharan Africa. Pork intake is unrecordable in South Asia and highest in East Asia and this reflects social and religious cultures. In relation to bovine meat, the highest and lowest intakes were again South America and Sub-Saharan Africa respectively.

The variation in per capita poultry meat and seafood intakes in the lowest income countries is shown in Figures 1 and 2 and the per capita intake of ARA and DHA by food sources in 28 low-income countries are shown in Table 2. In all, except 2 countries, the per capita intake of poultry meat is less than 20 g/day. All except 4 countries have less than 40 g/day fish/seafood intakes. In the lowest-income countries, the per capita median intake of ARA and DHA by food sources is 39 and 41 mg/day, respectively, with low intakes of meat and seafood products being highly prevalent in these countries (Table 2). The variation in per capita intake of ARA and DHA across low-income countries is shown in Figures 3 and 4. All but 2 countries have intakes of ARA less than 100 mg/day intake and two-thirds of the countries have per capita intakes of less than 50 mg/day. All but 4 countries have per capita intakes of DHA that are less than 100 mg/day.

The estimated contributions of breast milk and complementary feeding to median intakes of DHA and ARA in young children aged 6–36 months and their relation to GNI of the country are shown in Table 3 and the estimated ARA and DHA intakes in children aged 3–7 years by GNI are shown in Table 4. There is considerable variation between breast and complementary feeding practices with a significantly longer breastfeeding period in low-income countries. The longer supply of ARA and DHA from breast milk in these countries is counterbalanced by the exceptionally low supply of ARA and DHA from complementary foods.

Figure 5 demonstrates a direct positive correlation between the median duration of breastfeeding and percentage of stunting within the 76 developing countries and Table 5 shows the relationship of ARA intake to key health indicators. The lowest tertile for ARA intake is significantly associated with a higher percent of childhood stunting, higher birth rate, higher infant mortality, and longer duration of breast feeding. The intake of ARA significantly correlates with DHA intake.

Table 1. Estimated per capita dietary intake of DHA and ARA food sources (g/day) in medium- to low-income countries

Region	Fish/seafood	Eggs	Bovine meat	Mutton/goat	Poultry meat	Pig meat	Offals
North Africa							
n	6	6	6	6	6	6	6
Median	30.4	14.3	14.2	12.7	30.5	0.1	4.0
Range	10–48	1–24	12–31	4–18	1–47	0–27	3–5
Sub-Sahara Africa							
n	41	41	41	41	41	41	41
Median	17.7	2.9	13.5	4.3	8.7	3.7	4.2
Range	0.5–81	0–17	2–49	0.5–30	0.5–95	0–59	0.5–18
East Asia							
n	24	24	24	24	24	24	24
Median	80.8	14.0	14.5	1.5	38.1	34.6	6.1
Range	7–169	0–51	2–83	0–20	4–156	7–150	1–72
South Asia							
n	7	7	7	7	7	7	7
Median	18.5	6.6	13.9	3.3	10.2	0	1.8
Range	5–384	3–23	3–21	0.3–8	2–65	0–3	0–5
Western Asia							
n	10	10	10	10	10	10	10
Median	18.3	16.0	16.8	11.5	64.4	0.1	4.4
Range	7–59	5–29	6–64	4–39	20–181	0–6	1–16
Central Asia							
n	10	10	10	10	10	9	10
Median	5.7	15.6	31.4	10.5	25.1	14.0	7.1
Minimum	0–41	2–40	6–58	0.3–21	3–57	1–88	4–17
Caribbean and Central America							
n	24	24	24	24	24	24	24
Median	33.7	17.3	24.3	3.0	83.6	25.1	4.6
Range	3–150	0–42	6–90	0–64	10–165	1–62	0.5–13
South America							
n	12	12	12	12	12	12	12
Median	14.7	18.1	45.8	1.4	55.3	20.3	7.9
Range	1–51	3–46	10–132	0–122	4–105	0.4–59	4–26

n, number of countries.

Discussion

In previous publications, national estimated intakes of per capita ARA and DHA and intakes by infants and young children in the age range of 6–36 months have been reported [22, 23]. This paper specifically focusses on the contribution that complementary feeding during early life makes to ARA and DHA intakes in medium- to low-income countries, and to place this data in the context of key socioeconomic and health indicators.

It has previously been reported that the LCPUFA content of weaning foods is low compared to breast milk and that this is particularly evident in low-income countries where the staple foods are cereals, legumes and roots, which have a limited LCPUFA content [10–12]. However, even in high-income countries, the dietary intake of DHA and ARA from complementary foods can be low; in Germany, infants at the age of 6 months were reported to receive 47 and 72 mg/day of DHA and ARA, respectively, at 6 months and this fell to 28 and 24 mg/day at 9 months, respectively [38]. This change reflected the decrease in the intake of breast milk during this time. Data from Belgium showed that intakes of DHA at 2.5–3 and 4.6–5 years were 43 and 49 mg/day, respectively, and for ARA the intake was 17 and 18 mg/day, respectively [18].

In developing countries, it is common practice for infants to be weaned on to foods that are prepared for the whole family and therefore, the diet that infants receive during this important period of growth and development will reflect the nutritional content of the local adult diet.

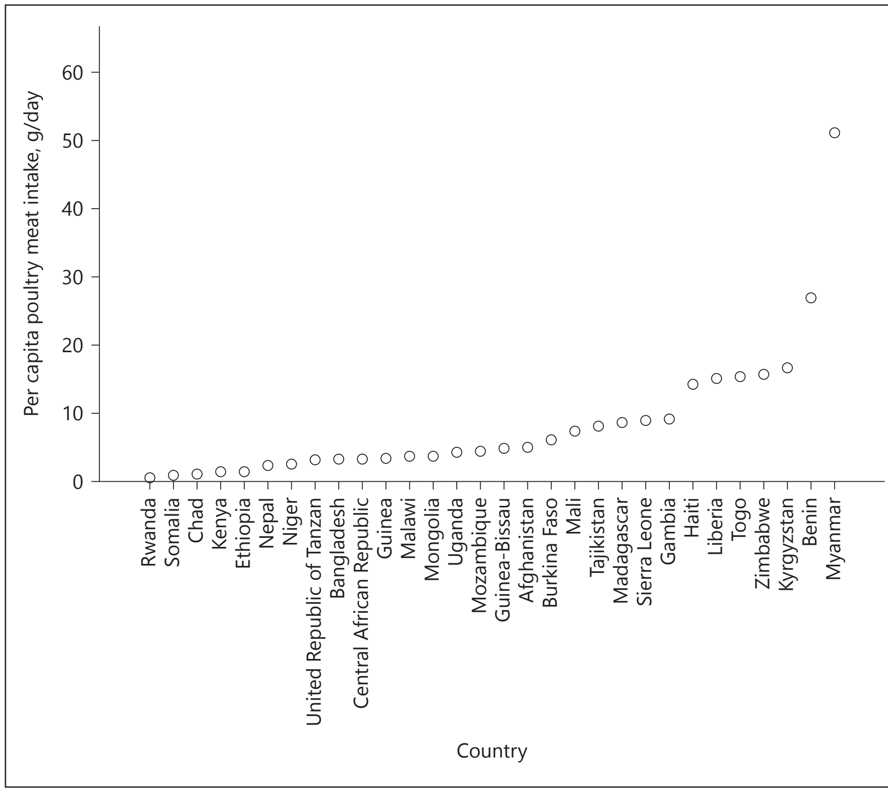

Fig. 1. Per capita intake of poultry meat (g/day) in low-income countries.

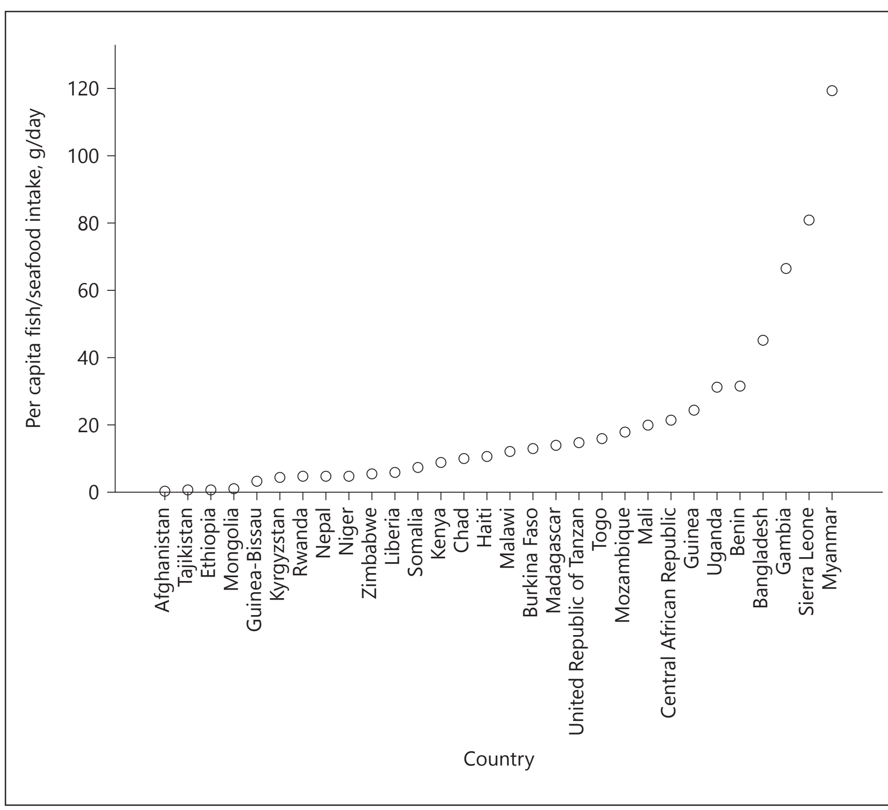

Fig. 2. Per capita intake of fish and sea food (g/day) in low-income countries.

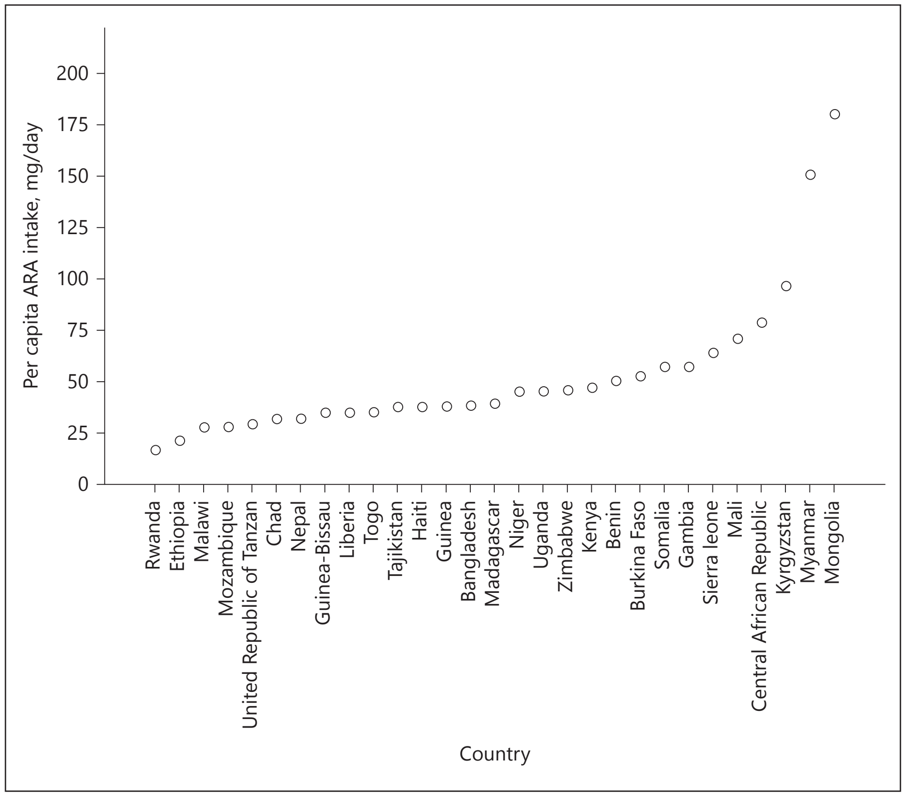

Fig. 3. Per capita ARA intake (mg/day) in low-income countries.

Table 2. Per capita intake of ARA and DHA by food sources in 28 low-income countries

	Eggs	Fish	Bovine	Mutton	Poultry	Pig meat	Meat other	Offals	Milk	Total
ARA intake, mg/day										
Median	4.3	5.6	6.0	3.2	3.3	1.1	1.3	5.0	1.4	39.1
Range	0.8–26	0–60	0.7–25	1–97	0.3–36	0–16	0–13	1–34	0.1–10	17–180
DHA intake, mg/day										
Median	4.8	34.6	0.6	0.4	0.5	0.2	0.2	2.7	0	41.3
Range	0.1–3	0–369	0.1–3	0.1–12	0.1–5	0–3	0–2	0.8–18	0	6–383

Prentice and Paul [12] report that in Gambia, which has access to a short coastline and inland fresh water, the fatty acid dietary profiles changed considerably following the cessation of breastfeeding with dietary ARA intakes falling from 17 mg/kg body weight during the first 6 months of life to 1 mg/kg body weight at 24 months and the reduction in dietary DHA intake during the same period was 21 mg/kg body weight falling to 1 mg/kg body weight.

Fat intake in early life in the Gambia, and similar developing countries, is provided almost entirely by breast milk [10, 12]. After the age of 6 months, the introduction of cereals and groundnut-based foods that contain little fat lead to replacement of some of the breast feeds. By the age of 2 years, the percentage of energy from fat in the infant diet will have fallen from more than 50% at 3 months to 15% at 2 years of age [12]. In this study, there is clear evidence that there is a direct relationship between ARA and DHA intake from complementary foods and GNI of the country. In the poorest countries, the intake of ARA and DHA from complementary foods is almost negligible, for example, in Nepal, Bangladesh, Ethiopia, and Rwanda. The high birth rate in these countries [35] will further increase the prevalence of the low-intake status and the potential for adverse health consequences. The low-income group in this study includes 25 coun-

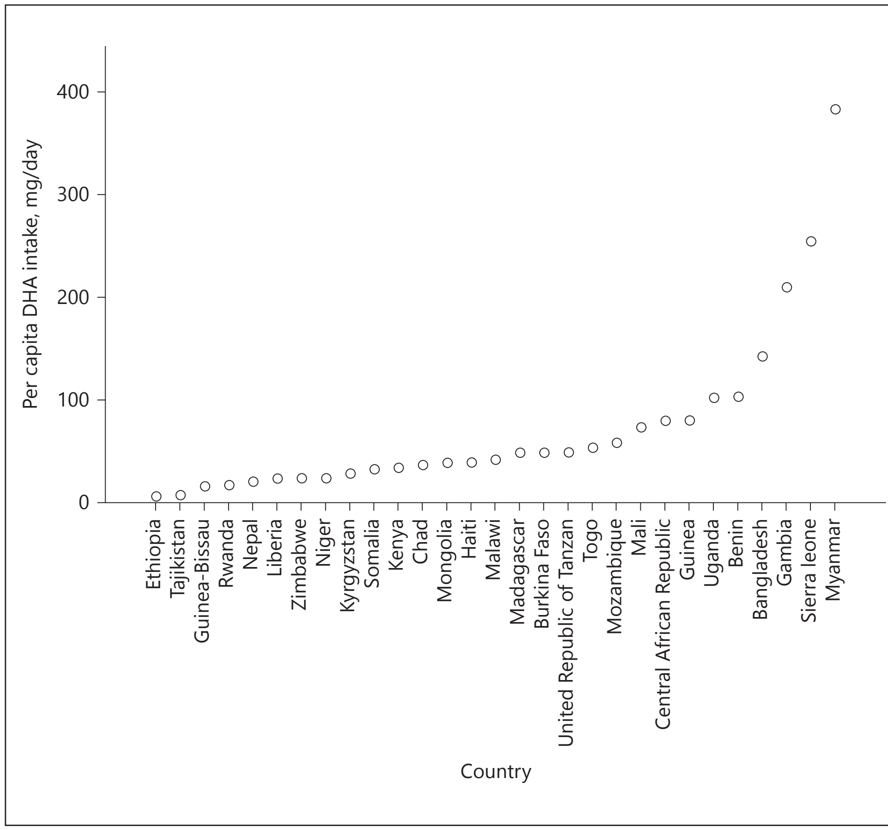

Fig. 4. Per capita DHA intake (mg/day) in low-income countries.

Table 3. Estimated contributions of breast milk and complementary feeding to median intakes of DHA and ARA (mg/day) in young children aged 6–36 months and their relation to GNI

GNI	Intake DHA from breast milk	Intake DHA from complementary food	Intake ARA from breast milk	Intake ARA from complementary food
Middle upper				
n	18	17	18	17
Median	17.3	23.7	26.7	34.6
Range	2.0–38	10–175	3–59	21–67
Middle lower				
n	34	34	34	34
Median	24.0	16.5	36.9857	19.1
Range	2–37	3–80	3–56	5–61
Low income				
n	25	25	25	25
Median	29.4	9.6	45.2	8.9
Range	22–55	0.7–65	34–84	1–23
Total				
n	77	76	77	76
Median	25.6	14.6	39.4	17.9
Range	2–55	0.7–175	3–84	1–67

n, number of countries.

Table 4. Estimated ARA and DHA intakes (mg/day) in children aged 3–7 years by GNI of the country

GNI	ARA intake 3 years	ARA intake 4 years	ARA intake 5 years	ARA intake 6 years	ARA intake 7 years	DHA intake 3 years	DHA intake 4 years	DHA intake 5 years	DHA intake 6 years	DHA intake 7 years
High income										
n	41	41	41	41	41	41	41	41	41	41
Median	77.0	83.1	88.4	95.1	102.8	63.6	68.7	731	78.6	85.0
Range	30–119	32–129	34–137	37–147	40–159	21–230	23–249	25–265	27–285	29–308
Upper middle income										
n	48	48	48	48	48	48	48	48	48	48
Median	66.0	71.3	75.8	81.6	88.2	42.5	45.9	48.8	52.6	56.8
Range	28–123	30–133	31–141	35–152	37–164	11–542	12–585	13–622	14–670	15–724
Lower middle income										
n	52	52	52	52	52	52	52	52	52	52
Median	39.7	42.9	45.6	49.1	53.0	50.5	54.5	58.0	62.4	67.4
Range	15–135	16–149	17–155	18–167	19–180	5–255	6–275	7–293	7–315	8–341
Low income										
n	28	28	28	28	28	28	28	28	28	28
Median	21.5	23.2	24.7	26.6	28.7	22.0	23.8	25.3	27.2	29.4
Range	9–96	10–104	11–111	12–119	13–129	3–189	4–204	4–217	4–234	5–252
Total										
n	169	169	169	169	169	169	169	169	169	169
Median	57.7	62.3	66.3	71.3	77.1	48.1	52.0	55.3	59.5	64.3
Range	9–135	10–149	11–155	12–167	13–180	3–542	4–585	4–622	4–670	5–724

n, number of countries.

tries, a total population of 644 million, and an average birth rate of 34 births per 1,000 population. It is estimated that in countries that fall within this category of GNI, approximately 22 million infants will be born each year.

The estimates for dietary intake of ARA and DHA from 3 to 7 years old children were based on the per capita dietary intakes for the individual countries [22], energy requirements of the children at the different ages [33], and the assumption that infants and young children, especially those living in low-income countries will be consuming the family diet. The estimated childhood intakes of DHA and ARA were generally low during the age range of 3–7 years, and this data corresponded closely with the economic status of the country.

With few exceptions, the per capita dietary intake data shows that the intake of ARA food sources including beef, poultry and eggs is minimal in low-income countries. A clear exception is Myanmar (formerly Burma), which has reported intakes that are more aligned to those found in high-income countries [39]. Although cereals, especially rice, remain the most important source of food energy (50%) in Myanmar, their contribution to overall dietary energy supply has decreased and products from animal origin have markedly changed with meat, milk and eggs increasing by 446% between 1991 and 2011 [39].

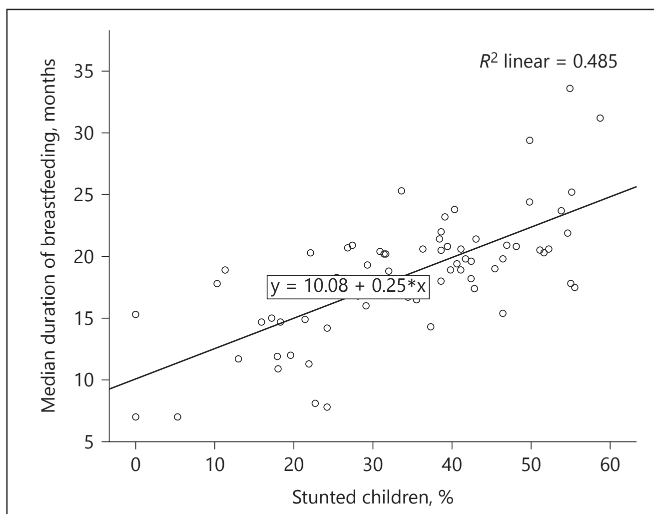

Fig. 5. Relationship of median duration of breastfeeding to percent of children with stunting in 73 developing countries.

Stunting is an irreversible outcome of inadequate nutrition and repeated bouts of infection during early life, and globally 162 million children under the age of 5 years may be affected [37]. In addition to marked growth retardation, the condition is associated with significant cogni-

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Table 5. Relationship of estimated ARA intake from complementary foods to population, birth rate, infant mortality rate, percent stunted, median duration of breastfeeding and intake of DHA from complementary foods in developing countries

ARA intake from complementary food, mg/day	Population, millions	Birth rate*, 1	Infant mortality rate*, 2	Percent of childhood stunting*	Duration of breastfeeding*, months	DHA intake from complementary food, mg/day*
Tertile 1 (1.1–12.4)						
n	25	25	24	24	25	25
Median	19.9	34.4	51.2	42.6	20.9	9.3
Range	2.1–1,275	19.6–45.5	23.5–102	30.9–58.7	17.0–33.6	0.7–35.8
Tertile 2 (12.5–23.3)						
n	26	26	26	26	26	26
Median	12.2	26.7	42.7	33.6	18.9	18.5
Range	0.19–244	15.9–42.1	8.8–90.6	17.2–55.5	15.0–21.4	3.9–64.9
Tertile 3 (23.4–66.7)						
n	25	25	25	25	25	25
Median	16.0	18.5	22.3	22.7	14.7	26.1
Range	0.34–204	11.2–34.9	9.6–71.5	5.3–52.2	7.0–25.3	5.6–174

Kruskal–Wallis H test. * $p < 0.001$. *n*, number of countries.
[1] Birth rate: the number of live births per thousand of population per year.
[2] Infant mortality: the number of deaths of children under one year of age per 1,000 live births occurring during the same year.

tive impairment. In this study of medium- to low-income countries, it is noted that the per capita intake of DHA and especially ARA is inversely related to the percentage of stunting in the country. Moreover, the median duration of breastfeeding was also directly related to the percentage of stunting of children. It is likely that this latter association represents reverse causality with breastfeeding duration being longer in the poorest countries because of the lack of available nutritious complementary foods and it is the deficiency of complementary feeding that is the critical factor in the development of stunting. This study has focussed on ARA and DHA, but there are clearly many other nutrients that are not meeting adequate levels for these children. Animal foods are not only important sources of energy, protein and fats, including ARA and DHA but also provide crucial supplies of vitamin A, vitamin B-12, riboflavin, calcium, iron, and zinc; sub-optimal intakes of these nutrients may lead to anaemia, night blindness, poor growth, rickets and impaired cognitive performance [40]. Therefore, in addition to the specific effects that low intakes of ARA and DHA may have on growth and development, ARA and DHA status may also reflect a wider deficiency of nutrients of animal source that collectively impact on a range of health outcomes. Clearly a balanced diet of grains, vegetables, fruit, dairy, fish and meats should be the ultimate objective.

International recommendations for ARA and DHA in early life have been underpinned by evidence from studies undertaken in high-income countries, and this data does not represent the contrasting geographical, economic, social, and cultural conditions that exist in most medium- to low-income countries. The evidence from this current analysis supports a previous opinion that plant-based complementary foods by themselves are insufficient to meet the needs for DHA and ARA and meat, poultry, eggs, and fish need to be more prevalent in complementary food diets [22]. It is important that public health strategies are aimed at providing a safety net for the most vulnerable infants. With so few ARA and DHA randomised controlled intervention studies involving infants from medium- to low-income countries, intakes achieved by an infant compliant with the WHO guidance on breast and complementary feeding [11, 28], may currently provide the best evidence for recommendations on dietary requirements of ARA and DHA during early life.

It is concluded that estimates of DHA and ARA intakes in developing countries worldwide indicate that many infants and young children are receiving low intakes of these metabolically important polyunsaturated fatty acids. Unfortunately, for the foreseeable future, there will continue to be nutritional, social, and economic factors that prevent many infants and young children from receiving an optimum feeding pattern of breast milk and complementary foods, and public health organisations need to adopt pragmatic strategies that will ensure that there is a nutritional safety net for the most vulnerable infants. This paper focussed on the importance of ARA and DHA, and identified global dietary deficiencies that are potentially reversible through improvements in provision of appropriate food sources and supplemented nutritional products [41].

Disclosure Statement

Prof. Stewart Forsyth undertakes consultancy work for DSM Nutritional Products. Sheila Gautier and Dr. Norman Salem Jr. are employees of DSM Nutritional Products. DSM Nutritional Products produces a wide range of nutritional ingredients including arachidonic acid and DHA.

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