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Short communication

Very low inadequate dietary intakes of essential n-3 polyunsaturated fatty acids (PUFA) in pregnant and lactating French women: The INCA2 survey

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SUMMARY

Background: The French National survey INCA2 pointed out that the majority of the French population (children, adolescents, adults and elderly) ingest low quantities of n-3 polyunsaturated fatty acid (PUFA) in the form of both precursor (alpha-linolenic acid, ALA) and long-chain (mainly docosahexaenoic acid, DHA). However, we don't know whether such inadequate n-3 PUFA consumption is also found again in pregnant and lactating women.

Methods: Dietary lipid and PUFA intakes were determined from 28 pregnant and 21 lactating French women by using the most recent set of national robust data on food (National Survey INCA2 performed in 2006 and 2007), and compared with that of 742 women of childbearing age.

Results: Main results showed that mean daily intakes of n-3 PUFA were very low in this French woman population because no pregnant and lactating women met recommended dietary intakes (RDIs). Moreover, some of them ingested quantities 4 times (ALA) to 10 times (DHA) lower than RDIs. Very similar dietary intakes were observed in women of childbearing age.

Conclusion: French pregnant and lactating women did not change their dietary habits to favor ALA and n-3 long-chain PUFA consumption via rich-ALA vegetable oils and fish and oily fish consumption, and have low n-3 PUFA dietary consumption typical of French women of childbearing age. Such PUFA intakes could have adverse impact on long-chain n-3 PUFA incorporation in brain membranes of fetus and infants, but also on cognitive and visual development of infants during the first years of life.

1. Introduction

Polyunsaturated fatty acids (PUFA) are crucial dietary fatty acids for human health. They play many vital functions in the body as components and modulators of the architecture and function of cellular membranes, endogenous mediators of cell signaling and gene expression, and precursors of several enzymatic cascades of lipid mediators and metabolites formed by autooxidation [1–4]. PUFA are derived from two metabolically distinct and non-interconvertible families, the n-6 and n-3 series. Linoleic acid (LA, 18:2n-6) is the n-6 metabolic precursor to the longer-chain arachidonic acid (AA, 20:4n-6) synthetized by a conversion pathway. AA is a ubiquitous PUFA found in all phospholipid tissues of mammals and the precursor of eicosanoids controlling reproduction, immune functions, aggregation, …. [5]. Alpha-linolenic acid (ALA, 18:3n-3) is the n-3 metabolic precursor of longer-chain eicosapentaenoic (EPA, 20:5n-3) and docosahexaenoic acids (DHA, 22:6n-3), which are implicated in brain and retina structure and function, and also in the control of inflammation, diabetes, obesity and cardiovascular diseases by the production notably of lipid mediators [1,6,7]. While it is well known that LA exerts also proper biological activities (physical properties of membrane, cutaneous physiology, cholesterol metabolism, ….), the question still remains for ALA as evidenced in Δ6-desaturase knock-out mouse model [8]. Lastly, in contrast to longer-chain PUFA, LA and ALA are true essential dietary fatty acids because they cannot be synthesized by the human body. The French Agency for Food, Environmental and Occupational Health & Safety (ANSES), as international and other national organizations, has proposed recommended dietary intakes (RDIs) for LA, ALA and DHA for the general adult population, and also for specific populations such as pregnant and lactating women [9].

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Indeed, the perinatal period of growth and development requires higher dietary supplies of energy and of n-6 and n-3 PUFA in both maternal and infant diets than in adult life. A low dietary intake of LA impaired growth and caused skin scaliness and hair loss both in the growing rat and the formula-fed infant [10]. More specifically for n-3 PUFA, it has been shown that the accretion of DHA in human brain phospholipids occurs primarily during the fetal brain growth spurt (i.e. the last trimester of pregnancy) and during the early postnatal period of development (first two years of life) [1,11]. DHA is selectively and actively transported from the maternal circulation to the fetus across the placenta during pregnancy, then into breast milk lipids during lactation as for all PUFA [12,13]. Several observational studies have reported positive associations between visual and cognitive development in breastfed infants and DHA concentrations in their mothers' milk (reviewed in [14]). In contrast, it has been reported in animal models that a low maternal dietary intake of n-3 PUFA (ALA and DHA) during pregnancy and lactation induces in the young significant decrease in brain DHA content and alterations in behavioral performances of learning and visual functions which partly persist in adulthood [1]. Similar alterations have been reported in visual acuity in 4-mo-old infants fed with infant formulas low in n-3 PUFA [15]. More recently, an increased risk of lower visual acuity was also reported in 2-mo-old infants whose mothers ingested very low amounts of DHA during the last trimester of pregnancy [16]. The French RDIs for women during pregnancy and lactation recommend a total energy intake of 2050 kcal/d for pregnant women from the 3rd trimester of pregnancy and 2250 kcal/d for lactating women (**Table 1**) [9]. The RDI values for total lipids and PUFA are the same as those recommended for the general adult population and adult woman (in % of total energy intake excluding alcohol (% EIEA): total lipids, 35 to 40%; LA, 4%; ALA, 1%). It is also admitted that half of these LA and ALA RDIs (i.e. 2 and 0.8% EIEA, respectively) are adequate to satisfy n-6 and n-3 PUFA human requirements for growth and brain development and to prevent the biochemical and physiological symptoms of PUFA deficiency [17,18]. As in adult woman, a RDI is also proposed for DHA (250 mg/d) for optimal infant brain and visual development and considering that the conversion of ALA to DHA is low in Human and consequently in pregnant and lactating women (**Table 1**) [9,19,20]. Recommendations reported by the Perinatal Lipid Intake Working Group (PNWG) and the International Society for the Study of Fatty Acids and Lipids (ISSFAL) were similar, notably for the DHA intake (≥ 200 mg/d) [21]. But that formulated by the European Food Safety Authority (EFSA) were somewhat different with RDIs of 0.5% for ALA and 100–200 mg/d for DHA (reviewed in [22]).

Most of current human adult diets in the Western industrialized societies are generally low in n-3 PUFA and mainly as long-chain (EPA, DHA) [22,23]. In France, data from one of the last National Survey INCA2 conducted in 2006–2007 on more than 4000 subjects aged from 3 to 79 years, reported that at least 85% of the adult population didn't meet recommendations of long-chain n-3 PUFA intake, but also of the essential precursor ALA [24]. This underlined a global pattern of imbalance between n-6 and n-3 PUFA which has been found again in children, adolescent and elderly populations [25,26]. Again very similar low ALA and long-chain n-3 PUFA dietary intakes were reported in the latest French National Survey INCA3 performed in 2014–2015 [27], suggesting no improvement in n-3 PUFA intakes of the French population but also that INCA2 data are still relevant. In Western populations, limited information is available on PUFA intakes of pregnant and lactating women. In Canadian women, Innis and Elias [28] reported that 84% of pregnant women at 28–35 wk gestation consumed low amount of DHA, but that their ALA intake was somewhat adequate. In Europe, a recent review also pointed out that only the DHA intake in pregnant and lactating was above the EFSA recommendations [22]. Since no data are available in France for pregnant and lactating women, no data in the INCA3 survey and only one French study with incomplete data for pregnant women [29], the aim of the present study was to explore the daily dietary intakes of fatty acids, especially main PUFA, in a small group of pregnant and lactating French women specifically issued from the INCA2 Survey. Moreover for a better estimation, intakes were calculated by using the most recent set of nutritional content of food consumed (the French Information Center on Food Quality Ciqual, 2013 [30]). Thus, intakes were recorded from 28 pregnant and 21 lactating women from different regions of France using a 7-d dietary record and by using a long list of food items (n = 1305). They were compared with that of women of childbearing age also issued for the same survey and assessed from 742 women.

Table 1
ANSES French recommended dietary intakes (RDIs) for total fat and polyunsaturated fatty acid (PUFA) for pregnant (third trimester) and lactating women[1].

	RDIs[2] (and adequate intakes for linoleic and alpha-linolenic acids)[3]	
	Pregnant women (third trimester)	Lactating women
Energy kcal (kJ)	2050 (8600)	2250 (9400)
Total fat	35–40%	35–40%
LA (18:2n-6)	4% (2%)[3]	4% (2%)[3]
ALA (18:3n-3)	1% (0.8%)[3]	1% (0.8%)[3]
LA/ALA	< 5	<5
DHA (22:6n-3)	250 mg/d	250 mg/d
EPA (20:5n-3) + DHA (22:6n-3)	500 mg/d	500 mg/d

LA, linoleic acid; ALA, alpha-linolenic acid; AA, EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid

[1] ANSES, French Agency for Food, Environmental and Occupational Health & Safety [9].

[2] ANSES RDIs are expressed as % EIEA (% of total energy intake excluding alcohol) for total fat, LA and ALA, and as mg/d for DHA and EPA + DHA.

[3] Adequate intakes of essential precursor PUFA (LA, ALA) recommended to satisfy n-6 and n-3 PUFA requirement during the perinatal period of human development.

2. Material and methods

Following the same methodology as in Tressou et al. [24], INCA2 data was combined to the ANSES Ciqual 2013 composition database (https://pro.anses.fr/TableCIQUAL/) to compute dietary intakes of all fatty acids for 28 pregnant women aged from 21 to 39 years old (mean age: 30.8 years; from the second to the third trimester of pregnancy) and 21 breastfeeding women aged from 23 to 45 years old (mean age: 32.9 years) issued from the INCA2 population. For comparison, fatty acid intakes were also assessed in 742 women of childbearing age from INCA2 (from 18 to 44 years old, mean age 32.8 years). As in Tressou et al. [24] and as recommended by ANSES, results are balanced using the weights provided in the INCA2 database to get results that are representative of the French population, except for the pregnant and lactating women groups, which are too small. Calculations are performed with the survey package of the R software for other women of childbearing age. Daily intakes were expressed as a mean percentage of % EIEA, and in g/d for total fat, LA and ALA, and in mg/d for DHA and EPA + DHA. They were compared to the current ANSES RDIs, and the number of pregnant and lactating women meeting these RDIs and also ingesting adequate levels of essential fatty acids (LA, ALA) for healthy development were calculated [9]. Data of daily PUFA intakes were also reported in the form of boxplots to display the distribution of results and to compare them with the RDIs. Lastly, the contributions of main key food categories to total fat and PUFA dietary intakes were analyzed.

Table 2
Mean daily dietary intake of total fat and main polyunsaturated fatty acids (PUFA) of French pregnant and lactating women (INCA2–Ciqual)[1].

	Mean daily intakes		Number of women meeting French RDIs[2] (number meeting adequate intakes)[3]
Pregnant women (n = 28)	kcal	kJ	
Energy	1875 ± 264 (1011–2877)	7866 ± 1105 (4241–12,070)	
		g/d	
Total fat	% EIEA	77.1 ± 22.5 (36.0–118.4)	8/28
LA (18:2n-6)	37.0 ± 5.2 (28.4–47.1)	8.3 ± 4.1 (2.3–17.2)	11/28 (26/28)[3]
ALA (18:3n-3)	4.0 ± 2.2 (1.8–9.0)	0.9 ± 0.4 (0.3–1.7)	0/28 (1/28)[3]
LA/ALA	0.4 ± 0.1 (0.3–0.7)	–	0/28
	10.2 ± 5.4 (4.5–26.5)	mg/d	
AA (20:4n-6)		83 ± 21 (42–126)	–
DHA (22:6n-3)	–	90 ± 77 (7–252)	1/28
EPA + DHA	–	155 ± 98 (22–415)	0/28
Lactating women (n = 21)	kcal	kJ	
Energy	1911 ± 605 (963–2772)	8017 ± 2538 (4040–11,629)	
		g/d	
Total fat	% EIEA	84.1 ± 30.0 (41.5–136.4)	6/21
LA (18:2n-6)	39.6 ± 5.5 (30.2–47.8)	7.7 ± 5.1 (2.8–19.4)	5/21 (19/21)[3]
ALA (18:3n-3)	3.4 ± 1.4 (1.8–6.8)	0.8 ± 0.5 (0.4–2.1)	0/21 (0/21)[3]
LA/ALA	0.4 ± 0.1 (0.2–0.7)	–	0/21
	9.4 ± 2.9 (5.0–14.7)	mg/d	
AA (20:4n-6)		84 ± 42 (42–168)	–
DHA (22:6n-3)	–	103 ± 66 (10–217)	0/21
EPA + DHA	–	185 ± 113 (22–390)	0/21

% EIEA, % of total energy intake excluding alcohol; LA, linoleic acid; ALA, alpha-linolenic acid; AA, arachidonic acid ; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.

[1] Mean ± SD and 2.5th–97.5th percentile in parentheses.

[2] Number of pregnant and lactating women meeting French recommended dietary intakes (RDIs) [9]

[3] Number of pregnant and lactating women ingesting adequate levels of essential fatty acids (LA, ALA) [9]

3. Results

3.1. Total fat and PUFA dietary intakes

Table 2 reports the mean ± SD daily intakes (2.5th–-97.5th percentiles) of total fat and main n-6 and n-3 PUFA of pregnant and lactating French women. To compare the median and interquartile values with the RDIs and the daily intakes of women of childbearing age, daily intakes for LA, ALA, DHA and EPA + DHA are also presented as boxplots (**Figs. 1–4**). Globally, mean energy dietary intakes were below ANSES recommendations [9], i.e. respectively 2050 and 2250 kcal/d for pregnant and lactating women, ranging from 1875 kcal/d (pregnancy) to 1911 kcal/d (lactation). The mean total fat daily intakes were in the range of recommended values (RDI of 35–40% EIEA), but about 60% of pregnant and lactating women consumed not enough (down to 28%) or too much (up to 48%) total fat. Mean daily intake of LA was ranging from 3.4 to 4.0% EIEA, which seemed close to the ANSES RDI value (4% EIEA). Twenty-five to fifty percent of pregnant and lactating women ingested less than this RDI value, respectively, but on the contrary the majority ingested adequate levels of LA for healthy growth and development of fetus during pregnancy and newborn infant during breastfeeding (2% EIEA). This was well illustrated by the LA boxplot which showed that almost no women ingested less than 2% LA and that 25% (lactating) to 40% (pregnant) ingested more than 4% LA (Fig. 1). Data collected for women of childbearing age pointed out similar total fat and LA dietary daily intakes (Fig. 1) for a lower energy intake (1750 kcal/d). Lastly, the mean intakes of AA for pregnant and lactating women were 83 ± 21 mg/d and 84 ± 42 mg/d, respectively.

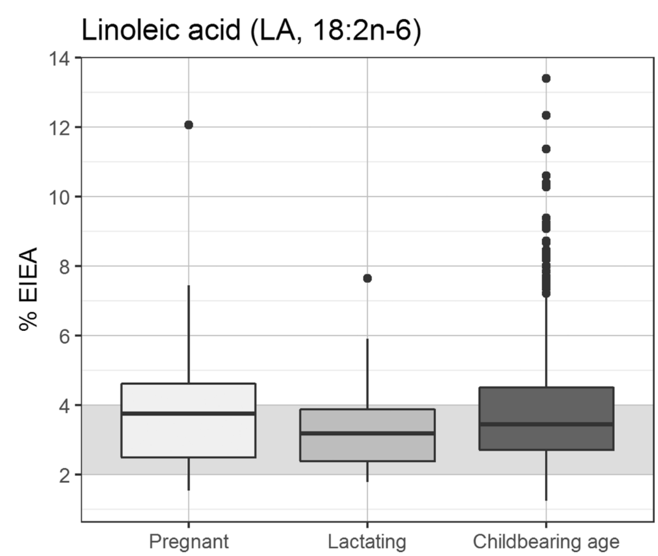

Fig. 1. Daily dietary intakes of linoleic acid of pregnant and lactating French women. Comparison with data of women of childbearing age (INCA2–Ciqual). The upper part of the gray area corresponds to the value of the recommended dietary intake (RDI: 4% of total energy intake excluding alcohol (EIEA)) and the lower one to the adequate intakes (2% EIEA) (reported in Table 1). Sizes of pregnant and lactating women and of women of childbearing age: 28, 21 and 742, respectively.

As regards to the precursor and long-chain n-3 PUFA, the situation was at the opposite of LA since their dietary daily intakes were not adequate in the two groups of women studied and even very low (Table 2 and Figs. 2–4). First, mean ALA daily intake was only 0.4% EIEA in both groups; no pregnant and lactating woman reached the RDI and adequate intake levels, respectively 1% and 0.8% EIEA, and some of them ingested no more than 0.2–0.3% EIEA. This low dietary intake of ALA translated into an unbalanced n-6/n-3 dietary ratio with a mean LA to ALA ratio two times higher than ANSES recommendation (about 10 *vs* < 5), and upper values of 20 for pregnant women. Secondly, mean long-chain n-3 PUFA daily dietary intakes in pregnant and lactating women were ranging from 90 to 103 mg for DHA (RDI: 250 mg) and from 155 to 185 mg for EPA + DHA (RDI: 500 mg) (Table 2). Thus no pregnant and lactating women met ANSES RDIs for these long-chain n-3 PUFA and some of them ingested no more than 10 mg/d of DHA. Boxplots for DHA and EPA + DHA intakes clearly confirmed such low consumption of long-chain n-3 PUFA in pregnant and lactating women

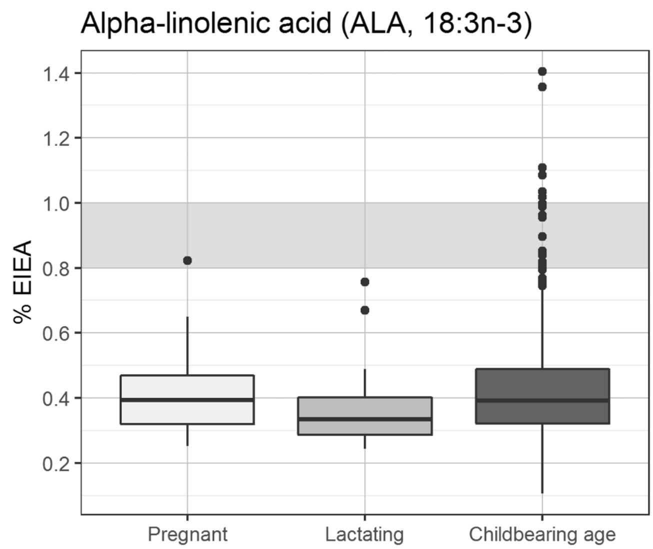

Fig. 2. Daily dietary intakes of alpha-linolenic acid of pregnant and lactating French women. Comparison with data of women of childbearing age (INCA2–Ciqual).
See footnotes in Fig. 1

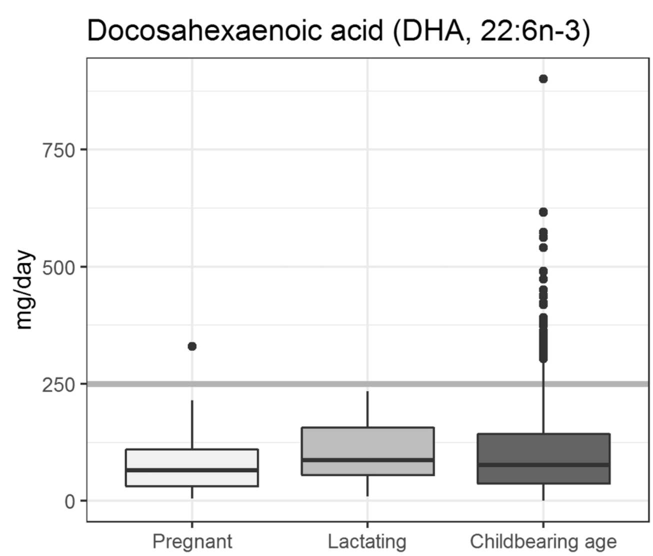

Fig. 3. Daily dietary intakes of long-chain n-3 PUFA docosahexaenoic acid of pregnant and lactating French women. Comparison with data of women of childbearing age (INCA2–Ciqual).
The horizontal gray bar corresponds to the value of the recommended dietary intake (RDI: 250 mg/d) (reported in Table 1). Sizes of pregnant and lactating women and of women of childbearing age: 28, 21 and 742, respectively.

which is found again in the overall French population of women of childbearing age (Figs. 3 and 4).

3.2. Food categories contributions

The 5 major food categories contributing to total fats and PUFA intakes in French pregnant and lactating women are reported in Table 3. The two major contributors to total fat intake were vegetable oils and butter, although lactating women consumed significantly more fats from butter than vegetable oils, but also substantial amounts of fats from cheese and mixed dishes. As regards to PUFA precursors, vegetable oils were the main dietary source for LA whereas pastries-cakes, condiments-sauces and vegetable oils were the main dietary contributors for ALA. Lastly, the main dietary contributor of DHA was fish,

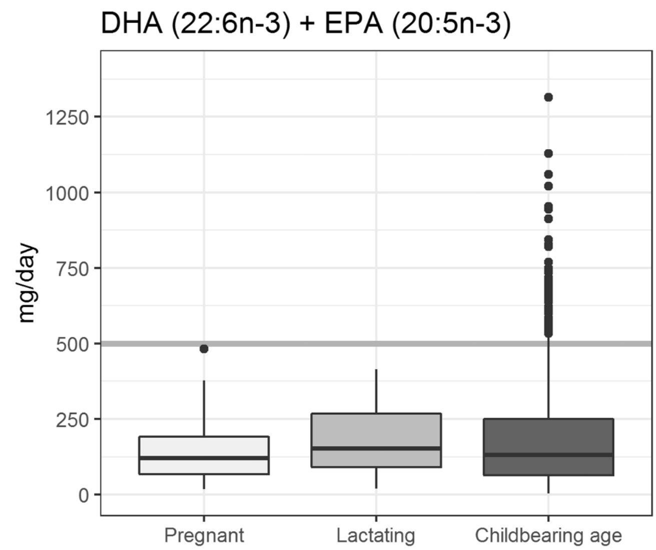

Fig. 4. Daily dietary intakes of total long-chain n-3 PUFA (eicosapentaenoic + docosahexaenoic acids) of pregnant and lactating French women. Comparison with data of women of childbearing age (INCA2–Ciqual).
The horizontal gray bar corresponds to the value of the recommended dietary intake (RDI: 500 mg/d) (reported in Table 1). Sizes of pregnant and lactating women and of women of childbearing age: 28, 21 and 742, respectively.

but pregnant women ingested less DHA from fish and also from shellfish. Compared to women of childbearing age, pregnant women have excluded cheese from their total fat intake and shellfish from their DHA intake, and have limited the consumption of DHA from fish. In contrast, lactating women have mainly increased their total fat intake from butter.

4. Discussion

In the present study, we calculated the daily intakes of main PUFA of pregnant and lactating French women using the data issued from the French National Survey INCA2 performed in 2006 and 2007 with a 7-d food questionnaire that contained 1305 food items for which the fat and fatty acid content was available. The data presented here support a global pattern of inadequate n-3 PUFA intake in pregnant and lactating French women similar to that reported in the general population of adult women and men, children and adolescents, and elderly from the same National Survey INCA2 [24–26] but also from the last INCA3 Survey conducted in 2014–2015 [27]. Indeed, the n-3 PUFA mean intake was low both for ALA and long-chain fatty acids (mainly DHA), and far below the French RDIs i.e. half less than 0.8% EIEA for ALA and 250 mg/d for DHA. Moreover, some pregnant women consumed very low quantities of DHA that are below the amount accumulated daily in fetal tissues during the last trimester of pregnancy [31], and probably for lactating women the amount that might be daily consumed by breast-fed infants to achieve DHA accumulation in their tissues [32]. These women consumed also low amounts of ALA with a high LA/ALA ratio which could considerably limit the rate of DHA biosynthesis from ALA. Therefore, such low n-3 PUFA status during pregnancy and lactation is of public health concern because these periods of active DHA accretion in the developing brain of fetus and newborn infants are particularly critical for ensuring optimal development of infant brain and visual systems.

In our study, mean total fat intakes in pregnant and lactating women were between 37.0 and 39.6% EIEA, respectively, which globally met the French recommendations (total fat 35–40% EIEA) [9]. This corresponded to a mean daily intake of 77 g/d (pregnant) and 84 g/d (lactating) which are also close to total fat RDIs (respectively 80 and 85 g/d), although total energy intakes were not fully optimal. They

Table 3
Main food groups contributing to total fat and main polyunsaturated fatty acids (PUFA) intakes in French pregnant and lactating women – Comparisons with women of childbearing age (INCA2–Ciqual).

	Main food group contributors (g/d or mg/d)
Pregnant women (*n* = 28)	
Total fat	Total (77.1 g/d), vegetable oils (11.3 g/d), butter (7.6 g/d), meat products (5.3 g/d), pastries and cakes (5.2 g/d), delicatessen (5.2 g/d)
LA (18:2n-6)	Total (8.3 g/d), vegetable oils (2.1 g/d), condiments and sauces (1.3 g/d), mixed dishes (0.5 g/d), bread and breadmaking (0.5 g/d), pastries and cakes (0.5 g/d)
ALA (18:3n-3)	Total (0.9 g/d), pastries and cakes (54 mg/d), condiments and sauces (49 mg/d), oils (42 mg/d), vegetables (excluding potatoes) (28 mg/d), mixed dishes (24 mg/d)
DHA (22:6n-3)	Total (90 mg/d), fish (39 mg/d), eggs and egg-products (11 mg/d), poultry and game (8 mg/d), pastries and cakes (6 mg/d), delicatessen (5 mg/d)
Lactating women (*n* = 21)	
Total fat	Total (84.1 g/d), butter (12.5 g/d), vegetable oils (9.3 g/d), cheese (7.7 g/d), mixed dishes (7.4 g/d), meat products (6.4 g/d)
LA (18:2n-6)	Total (7.7 g/d), vegetable oils (1.9 g/d), mixed dishes (0.8 g/d), condiments and sauces (0.6 g/d), meat products (0.5 g/d), delicatessen (0.5 g/d)
ALA (18:3n-3)	Total (0.8 g/d), pastries and cakes (87 mg/d), vegetable oils (82 mg/d), mixed dishes (77 mg/d), butter (65 mg/d), condiments and sauces (53 mg/d)
DHA (22:6n-3)	Total (103 mg/d), fish (51 mg/d), poultry and game (14 mg/d), eggs and egg-products (10 mg/d), mixed dishes (5 mg/d), shellfish (5 mg/d)
Women of childbearing age (*n* = 742)	
Total fat	Total (74.8 g/d), vegetable oils (8.1 g/d), butter (6.7 g/d), cheese (5.9 g/d), pastries and cakes (4.9 g/d), delicatessen (4.6 g/d)
LA (18:2n-6)	Total (7.6 g/d), vegetable oils (1.6 g/d), condiments and sauces (1.1 g/d), mixed dishes (0.5 g/d), pastries and cakes (0.5 g/d), bread and breadmaking (0.4 g/d)
ALA (18:3n-3)	Total (0.8 g/d), pastries and cakes (107 mg/d), condiments and sauces (89 mg/d), vegetable oils (70 mg/d), mixed dishes (49 mg/d), vegetables (excluding potatoes) (41 mg/d)
DHA (22:6n-3)	Total (112 mg/d), Fish (54 mg/d), eggs and egg-products (11 mg/d), poultry and game (8 mg/d), pastries and cakes (4 mg/d), shellfish (4 mg/d)

LA, linoleic acid; ALA, alpha-linolenic acid; DHA, docosahexaenoic acid

were in accordance with total fat data reported for pregnant women [16,33,34] and for lactating women [33,34] living in Canada and in Chile, but were lower than in some European countries in which it was reported excessive total fat intakes in pregnant women at 30 wk of gestation exceeding 130 g/d [35]. Compared to French women of childbearing age, French pregnant and lactating women consumed more total fat but with a similar pattern of main food group contributors, except for pregnant women who specifically removed cheese and mostly non-cooked pressed cheese from their diet to limit the risk of listeriosis [36]. Moreover, our results showed that about 30% of women in each of the 2 groups studied had very low total lipid intake less than 50 g/d, suggesting that these women could be more probably exposed to low consumption of fat-soluble vitamins and PUFA (mainly n-3 PUFA) by limiting drastically their consumption of foods rich in fats and PUFA such as vegetable oils and condiments/sauces. Anyway, the major contributors to total fat intakes in pregnant and lactating women diets were vegetable oils and butter, but lactating women increased their dietary intake of total fats mainly via the consumption of dairy fats (butter and cheese).

As regards to n-6 PUFA and its essential fatty acid LA, we reported that mean daily intakes of our women population range from 3.4% (lactating) to 4.0% (pregnant) EIEA, i.e., a level intake just below the RDI value of 4% EIEA for both pregnant and lactating women. Whether the data distribution analysis showed that only 25–50% of the study population met the LA intake recommendation, the majority (>96%) have a healthy adequate intake of 2% EIEA to ensure optimal growth and development of the fetus during pregnancy and the newborn infant during breastfeeding (reviewed in [37]). Although slightly lower, level intakes found are quite similar with published data in pregnant and lactating women living from several Western countries (Canada, USA, Denmark) [28,33,38,39]. In contrast, they are significantly lower than levels reported in Chile and some European countries (Germany, Hungary, Spain) in which LA intakes, due to specific consumption of vegetable oil rich in n-6 PUFA, could approach or even exceed 10% energy, i.e., 5 times the healthy adequate intake [34,35]. Such high LA intakes could induce an unbalanced LA/ALA ratio in the diet (>10) unfavorable to n-3 long-chain PUFA metabolism, i.e. by inhibition of DHA synthesis by increased competition at the level of desaturase and elongase enzymes, and also possibly by modifying the half-live of DHA [40]. Finally, results of our study show that the daily LA intake of the INCA2 French population of pregnant and lactating is adequate for health for optimal growth and development, but remains not completely satisfactory for the prevention of cardiovascular heart diseases.

In contrast, the present data on n-3 PUFA daily intakes clearly pointed out that the French population of pregnant and lactating women does not meet the French RDIs for both ALA and long-chain n-3 PUFA (DHA, but also EPA + DHA), similarly as previously reported in the same INCA2 survey population of children, adolescent and elderly [25,26]. Indeed, the mean ALA intake was 0.4% EIEA, and close to 100% of the women population do not reach the RDI and adequate intake values for this PUFA (1% and 0.8% EIEA, respectively). Moreover, about 75% (pregnant) and almost 100% (lactating) could be considered at risk of n-3 PUFA deficiency since they ingest less than the minimal intake of 0.5% EIEA for optimal tissue levels of n-3 PUFA and to prevent biochemical and physiological symptoms of deficiency in the brain and retina during their active development [17,18]. Such low ALA consumption has been found again in an incomplete study conducted in 2001 on 61 pregnant women living in the South-West of France (0.4% energy) [29], but also in a very recent large prospective study conducted on 250 lactating women in the Metropolitan France (0.3% energy) [41]. It was also reported from the ALA content analysis of human breast milk measured from 1990 to 2005 [42]. Level of ALA consumption in French pregnant and lactating women was well below than that reported in women living in other Western countries, daily ALA intakes being generally higher than 0.5% energy in Europe (reviewed in [22,38]), and, expressed in g/d, ranging from 1.0–1.6 g/d in Canada and USA [28,33,39] up to 2.0 g/d for Danish lactating women [38] and 2.8 g/d for Chilean pregnant and lactating women [34] (vs 0.8–0.9 g/d in the present study). Similarly as the French population of women of childbearing age, our results clearly show that the French population of pregnant and lactating women also ingests insufficient amount of ALA because very falling short of recommendations, and finally did not favor their consumption of vegetable oils rich in ALA such as rapeseed oil as recommended by the National Nutrition-Health Program [36]. Indeed, the contribution of vegetable oils to ALA intake (5–10%) in our women populations was in agreement with the low consumption in the general French population of vegetable oils rich in ALA such as rapeseed oil [43]. Nevertheless, the essentiality of ALA in France was first recognized as early as the 1990s since (i) many experimental works conducted by Bourre et al. have showed that a maternal diet deficient in ALA during all the period of development alters the content of brain DHA and several neurophysiological parameters in the rat and that the ALA requirement was estimated at 0.4% of the total dietary energy [44], (ii) at the same time ALA French RDIs have been already proposed for the Human, and (iii) very low consumption of ALA was also noticed in French lactating women via nutritional biomarker tissues such as human breast milk [45,46]. These different points show that, nowadays in France, pregnant and lactating women did not receive enough information about n-3 PUFA and infant brain development, and that health authorities and medical practitioners (gynecologists pediatricians and midwives) have not yet considered all these data.

Such low ALA intakes in the French pregnant and lactating women population induced a high LA/ALA mean ratio of about 10 (RDI < 5), against 5.4– 8.5 in other countries around the world [28,33,34,38]. One-third of this specific population had a ratio included between 10 and 20 associated to low ALA intake. Such ALA-driven PUFA imbalance could induce, by competition between LA and ALA for the desaturation and elongation enzymes, a disequilibrium of PUFA metabolism against n-3 long-chain and namely DHA synthesis. Moreover, it was concluded from stable isotope tracer studies that less than 0.5% of dietary ALA is converted to DHA in adult humans [47]. While ALA conversion rate seems to be greater in women compared with men [48], it could suggested that no more than a few dozen mg of DHA are daily synthesized from dietary ALA ingested by French pregnant and lactating women. This is of nutritional importance during pregnancy and lactation because (i) fetus during the last trimester of pregnancy and newborn infant during the first 6 mon of life accumulate high amounts of DHA in brain membranes [31,32], and (ii) pregnant and lactating women have low consumption of DHA in our French population. Indeed, mean DHA intakes were between 90 mg/d (pregnant) and 103 mg/d (lactating), and 100% of the studied population did not meet the RDI level (250 mg/day) due to the low frequency of fish and oily fish consumption. Moreover, 25% of pregnant and lactating women ingested respectively less than 70 mg/d and 85 mg/d, a quantity which is barely equivalent to the one daily accumulated for example in the fetus during the last trimester of pregnancy [31] and not enough compensated by the DHA produced by the ALA conversion. Such low DHA consumption was also found again in the population of women of childbearing age, suggesting that pregnant and lactating women did not modify their dietary habits to favor fish and oily fish consumption. On the contrary, data of the present study pointed out that pregnant women have slightly decreased their DHA dietary intake by limiting oily fish and shellfish consumption because of the risk of contamination with heavy metals (oily fish) and of listeriosis (raw fish and shellfish). Similar low DHA consumptions were found again in the very recent prospective study conducted in French lactating women (70 mg/d) [41]. Across all Western countries around the world studied, mean daily DHA intakes were also generally lower, but less markedly, than current recommendations both in Europe (reviewed in [22]) and in Canada and USA [28,33,39]. In contrast in Nordic countries considered as large consumers of fish and seafood, DHA intakes reached RDI value with about 300 mg DHA daily consumed by Danish lactating women [38]. Similar high DHA intakes has been also notified in some European countries due to specific pattern of fish consumption [35], but also in France but specifically in women of childbearing age living in coastal cities (400–500 mg/d) [49]. Since fish consumption is the major contributor to DHA consumption (43–49% in this study), similar trends of low intakes were observed for EPA + DHA with an inadequate total n-3 long-chain intake in 100% of pregnant and lactating women, mostly below the RDI level to prevent the risk of cardiovascular heart disease. Once again as described for ALA, our results clearly show that the French population of pregnant and lactating women ingests insufficient amount of DHA and EPA + DHA and ate less than two servings/week of fish with a serving/week of oily fish, as recommended by the National Nutrition-Health Program [36].

In conclusion, data reported from this INCA2 survey pointed out that our population of French pregnant and lactating women ingest low inadequate quantities of both ALA and n-3 long-chain PUFA because of low consumption of vegetable oils rich in ALA and fish and sea foods rich in EPA + DHA. Due to the specific low ALA intake in the French general population, this nutritional situation appears different to what is observed in other Western countries and is at the origin of a non-balanced LA/ALA ratio of 10 and more. Such PUFA imbalance in the maternal diet against n-3 PUFA during perinatal life, i.e. from the beginning of the third trimester of pregnancy up to 2 y of age in human, could alter DHA accretion and function of the developing brain and retina in infant [1,50]. For example, clinical data showed an increased risk of lower visual acuity in 2-mon-old infants and of lower language development in 18-mon-old infants whose mothers consumed during the last trimester of pregnancy diets with very low amounts of DHA [16,51]. Moreover, low maternal DHA intake might also cause increase in early preterm birth and the risk of asthma in children [52,53]. However new large human studies must be conducted to validate that such low maternal n-3 PUFA intake has deleterious and measurable impacts on the health of mothers and their infants because today extremely limited epidemiological and clinical data are available. Furthermore due the low sample of women in our study, it would be important to validate by a large sample study whether such low n-3 PUFA intake is representative and generalizable to the French general population of pregnant and lactating women. A very recent cross-sectional study conducted during the year 2014 on 250 breastfeeding women living in France supports our data with an ALA intake of 0.3% EIEA and a DHA intake of 70 mg/d [41]. Therefore, new public health programs might be developed in France to increase ALA and DHA intake in these populations of women, and even in women of childbearing, by encouraging pregnant and lactating women to consume more vegetable oils and margarines rich in ALA, and fish and oily fish rich in long-chain n-3 PUFA. Very recent positive data on the temporal variations of ALA and DHA in breast milk in France reported significant, but still insufficient, elevation of their contents between 2007 and 2014 [54].

Author contributions

BB, JT, PG, NS, and SP conceptualized the study. PG wrote the manuscript. JT processed the statistical analysis. All authors read and approved the final version.

Conflict of interest statement

JT and SP reported grants from Terres Univia during the conduct of the study. BB, PG, and NS have no conflicts of interest to declare

Ethical standards

The French INCA2 dietary survey was approved by the French Data Protection Authority (Commission Nationale de l' Informatique et des Libertés n°2003 × 727AU) and the French National Council for Statistical Information (Conseil National de l' Information Statistique).

Publication of the data

Only Mean daily PUFA intakes and main food groups contributors in French lactating women were presented on November 21th 2017 at the

"Journée du Groupe Lipides et Nutrition" entitled "Perinatal consumption of dietary lipids: consequences for child health", and were partly published as a published lecture in a special issue in OCL Journal (2018) https://www.ocl-journal.org/articles/ocl/pdf/2018/03/ocl180028s.pdf

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References

[1] JM. Alessandri, P. Guesnet, S. Vancassel, et al., Polyunsaturated fatty acids in the central nervous system: evolution of concepts and nutritional implications throughout life, Reprod. Nutr. Dev 44 (2004) 509-38.
[2] F. Echeverría, M. Ortiz, R. Valenzuela, L.A. Videla, Long-chain polyunsaturated fatty acids regulation of PPARs, signaling: relationship to tissue development and aging, Prostaglandins Leukot. Essent. Fatty Acids 114 (2016) 28-34.
[3] R.S. Chapkin, D.N. McMurray, L.A. Davidson, B.S. Patil, Y.Y. Fan, J.R. Lupton, Bioactive dietary long-chain fatty acids: emerging mechanisms of action, Br. J. Nutr. 100 (2008) 1152- 1157.
[4] J.M. Galano, Y.Y. Lee, C. Oger, C. Vigor, J. Vercauteren, T. Durand, M. Giera, J.C. Lee, Isoprostanes, neuroprostanes and phytoprostanes: an overview of 25years of research in chemistry and biology, Prog. Lipid Res 68 (2017) 83-108.
[5] M.A. Crawford, Y. Wang, S. Forsyth, J.T. Brenna, The European food safety authority recommendation for polyunsaturated fatty acid composition of infant formula overrules breast milk, puts infants at risk, and should be revised, Prostaglandins Leukot. Essent. Fatty Acids 102-103 (2015) 1–3.
[6] D. Swanson, R. Block, S.A. Mousa, Omega-3 fatty acids EPA and DHA: health benefits throughout life, Adv. Nutr. 3 (2012) 1–7.
[7] R.K. McNamara, R.H. Asch, D.M. Lindquist, R. Krikorian, Role of polyunsaturated fatty acids in human brain structure and function across the lifespan: an update on neuroimaging findings, Prostaglandins Leukot. Essent. Fatty Acids S0952-3278 (2017) 30219-8.
[8] J.M. Monk, D.M. Liddle, D.J. Cohen, et al., The delta 6 desaturase knock out mouse reveals that immunomodulatory effects of essential n-6 and n-3 polyunsaturated fatty acids are both independent of and dependent upon conversion, J. Nutr. Biochem. 32 (2016) 29-38.
[9] French Agency for Food, Environmental and Occupational Health & Safety (ANSES), Actualisation des apports nutritionnels conseillés pour les acides gras, Rapport d'expertise collective https://www.anses.fr/fr/system/files/NUT2006sa0359Ra.pdf, (2011) Accessed May 2018.
[10] R.T. Holman, Biological activities of and requirements for polyunsaturated acids, in: progress in chemistry of fats and other lipids, vol.9, Edited by R.T. Holman, 1971, pp.275–348.
[11] C. Joffre, A. Nadjar, M. Lebbadi, F. Calon, S. Laye, n-3 LCPUFA improves cognition: the young, the old and the sick, Prostaglandins Leukot. Essent. Fatty Acids 91 (2014) 1–20.
[12] M.A. Crawford, A.G. Hassam, P.A. Stevens, Essential fatty acid requirements in pregnancy and lactation with special reference to brain development, Prog. Lipid Res. 20 (1981) 31–40.
[13] R.G. Jensen, The lipids in human milk, Prog. Lipid Res. 35 (1996) 53–92.
[14] S.M. Innis, Impact of maternal diet on human milk composition and neurological development of infants, Am. J. Clin. Nutr 99 (2014) 734S–741S.
[15] R. Uauy, D.R. Hoffman, P. Peirano, D.G. Birch, E.E. Birch, Essential fatty acids in visual and brain development, Lipids 36 (2001) 885–895.
[16] S.M. Innis, R.W. Friesen, Essential n-3 fatty acids in pregnant women and early visual acuity maturation in term infants, Am. J. Clin. Nutr. 87 (2008) 548–557.
[17] European Food Safety Authority (EFSA), Scientific opinion on dietary reference values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol, EFSA J 8 (2010) 1461–1568.
[18] P. Guesnet, S.M. Lallemand, J.M. Alessandri, M. Jouin, S.C. Cunnane, α-Linolenate reduces the dietary requirement for linoleate in the growing rat, Prostaglandins Leukot. Essent. Fatty Acids 85 (2011) 353–360.
[19] J.T. Brenna, N. Jr Salem, A.J. Sinclair, S.C. Cunnane, alpha-Linolenic acid supplementation and conversion to n-3 long-chain polyunsaturated fatty acids in humans, Prostaglandins Leukot. Essent. Fatty Acids. 80 (2009) 85–91.
[20] R.A. Gibson, B. Muhlhausler, M. Makrides, Conversion of linoleic acid and alpha-linolenic acid to long-chain polyunsaturated fatty acids (LCPUFAs), with a focus on pregnancy, lactation and the first 2 years of life, Matern. Child Nutr. 7 (Suppl 2) (2011) 17–26.
[21] B. Koletzko, I. Cetin, J.T. Brenna, et al., Dietary fat intakes for pregnant and lactating women, Br. J. Nutr 98 (2007) 873–877.
[22] I. Sioen, L. van Lieshout, A. Eilander, et al., 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, Ann. Nutr. Metab 70 (2017) 39–50.
[23] B.J. Meyer, Are we consuming enough long chain omega-3 polyunsaturated fatty acids for optimal health? Prostaglandins Leukot. Essent Fatty Acids 85 (2011) 275–280.
[24] J. Tressou, P. Moulin, B. Vergès, C. Le Guillou, N. Simon, S. Pasteau, Fatty acid dietary intake in the general French population: are the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) national recommendations met? Br. J. Nutr. 116 (2016) 1966–1973.
[25] P. Guesnet, J. Tressou, B. Buaud, N. Simon, S. Pasteau, Inadequate daily intakes of n-3 polyunsaturated fatty acids (PUFA) in the general French population of children (3-10 years) and adolescents (11-17 years): the INCA2 survey, Eur. J. Nutr. Apr 23 (2018), https://doi.org/10.1007/s00394-018-1694-1.
[26] B. Buaud, J. Tressou, P. Guesnet, N. Simon, S. Pasteau, Inadequacy of n-3 polyunsaturated fatty acid dietary intakes in the general French population of elderly (65 to 79 years old): the INCA2 survey, J. Aging Res. Clin. Pract. 7 (2018) 69–74.
[27] French Agency for Food, Environmental and Occupational Health & Safety (ANSES), Étude individuelle nationale des consommations alimentaires 3 (INCA3) Avis de l'Anses, Rapport d'expertise collective https://www.anses.fr/fr/system/files/NUT2014SA0234Ra.pdf, (2017) Accessed October 2018.
[28] S.M. Innis, S.L. Elias, Intakes of essential n-6 and n-3 polyunsaturated fatty acids among pregnant Canadian women, Am. J. Clin. Nutr 77 (2003) 473–478.
[29] N. Combe, C. Boué, Linoleic and alpha-linolenic acids supplied by food in a population group in Aquitaine, OCL 8 (2001) 118–121.
[30] French Agency for Food, Environmental and Occupational Health & Safety (ANSES) Ciqual 2013 database, CIQUAL Accessed Oct https://pro.anses.fr/Table, (2016) CIQUAL Accessed Oct.
[31] M.T. Clandinin, J.E. Chappell, T. Heim, P.R. Swyer, G.W. Chance, Fatty acid utilization in perinatal de novo synthesis of tissues, Early Hum. Dev 5 (1981) 355–366.
[32] SC. Cunnane, V. Francescutti, J.T. Brenna, M.A. Crawford, Breast-fed infants achieve a higher rate of brain and whole body docosahexaenoate accumulation than formula-fed infants not consuming dietary docosahexaenoate, Lipids 35 (2000) 105–111.
[33] X. Jia, M. Pakseresht, N. Wattar, J. Wildgrube, S. Sontag, M. Andrews, F.B. Subhan, L. McCargar, C.J. Field, APrON study team, women who take n-3 long-chain polyunsaturated fatty acid supplements during pregnancy and lactation meet the recommended intake, Appl. Physiol. Nutr. Metab 40 (2015) 474–481.
[34] C. Barrera, R. Valenzuela, R. Chamorro, K. Bascuñán, J. Sandoval, N. Sabag, F. Valenzuela, M.P. Valencia, C. Puigrredon, A. Valenzuela, The impact of maternal diet during pregnancy and lactation on the fatty acid composition of erythrocytes and breast milk of Chilean women, Nutrients 10 (2018), https://doi.org/10.3390/nu10070839 Accessed Jul 2018.
[35] C. Franke, S. Verwied-Jorky, C. Campoy, M. Trak-Fellermeier, T. Decsi, V. Dolz, B. Koletzko, Dietary intake of natural sources of docosahexaenoic acid and folate in pregnant women of three European cohorts, Ann. Nutr. Metab. 53 (2008) 167–174.
[36] French Agency for Food, Environmental and Occupational Health & Safety (ANSES), Le guide nutrition avant et après la grossesse. Livret d'accompagnement destiné aux professionnels de santé. Groupe de travail « Guides alimentaires du Programme national nutrition-santé» (2007) inpes.santepubliquefrance.fr/CFESBases/catalogue/pdf/1060.pdf Accessed March 2018.
[37] S.C. Cunnane, Problems with essential fatty acids: time for a new paradigm? Prog. Lipid Res 42 (2003) 544–568.
[38] L. Lauritzen, L.B. Halkjaer, T.B. Mikkelsen, S.F. Olsen, K.F. Michaelsen, L. Loland, H. Bisgaard, Fatty acid composition of human milk in atopic Danish mothers, Am. J. Clin. Nutr 84 (2006) 190–196.
[39] S.M. Donahue, S.L. Rifas-Shiman, S.F. Olsen, D.R. Gold, M.W. Gillman, E. Oken, Associations of maternal prenatal dietary intake of n-3 and n-6 fatty acids with maternal and umbilical cord blood levels, Prostaglandins Leukot. Essent. Fatty Acids 80 (2009) 289–296.
[40] A.F. Domenichiello, A.P. Kitson, C.T. Chen, M.O. Trépanier, P.M. Stavro, R.P. Bazinet, The effect of linoleic acid on the whole body synthesis rates of polyunsaturated fatty acids from α-linolenic acid and linoleic acid in free-living rats, J. Nutr. Biochem. 30 (2016) 167–176.
[41] P. Hébel, A. Francou, L.D Van Egroo, C. Rougé, P. Mares, Alimentation lipidique en période périnatale: conséquences pour la santé de l'enfant, OCL https://www.ocl-journal.org/articles/ocl/pdf/2018/03/ocl180014s.pdf, (2018) Accessed Jul 2018..
[42] G. Ailhaud, F. Massiera, P. Weill, P. Legrand, J-M. Alessandri, P. Guesnet, Temporal changes in dietary fats: role of n-6 polyunsaturated fatty acids in excessive adipose tissue development and relationship to obesity, Prog. Lipid Res. 45 (2006) 203–236.
[43] Agency for Food, Environmental and Occupational Health & Safety (ANSES), Apports en acides gras de la population vivant en France et comparaison aux apports nutritionnels conseillés définis en 2010 https://www.anses, (2015) .fr/fr/syste m/files /NUT20 14sa0 117Ra.pdf. Accessed Jul 2018.
[44] J-M. Bourre, M. Francois, A. Youyou, O. Dumont, M. Piciotti, G. Pascal, G. Durand, The effects of dietary alpha-linolenic acid on the composition of nerve membranes, enzymatic activity, amplitude of electrophysiological parameters, resistance to poisons and performance of learning tasks in rats, J. Nutr. 119 (1989) 1880–1892.
[45] P. Guesnet, J-M. Antoine, J-B. Rochette de Lempdes, A. Galent, G. Durand, Polyunsaturated fatty acid composition of human milk in France: changes during the course of lactation and regional differences, Eur. J. Clin. Nutr. 47 (1993) 700–710.
[46] P. Guesnet, J-M. Alessandri, C. Couet, G. Durand, Variability in linoleic acid (18:2n-6) content and 18:2n-6/18:3n-3 ratio in human breast milk in France, Annales de Pédiatrie 42 (1995) 282–288.
[47] M. Plourde, S.C. Cunnane, Extremely limited synthesis of long chain polyunsaturates in adults: implications for their dietary essentiality and use as supplements, Appl. Physiol. Nutr. Metab. 32 (2007) 619–634.
[48] G. Burdge, Alpha-linolenic acid metabolism in men and women: nutritional and

biological implications, Curr. Opin. Clin. Nutr. Metab. Care 7 (2004) 137–144.
[49] Agency for Food, Environmental and Occupational Health & Safety (ANSES), https://www.anses.fr/en/system/files/PASER-Ra-Calipso.pdf, (2006) Accessed June 2018.
[50] F. Echeverría, R. Valenzuela, M. Catalina Hernandez-Rodas, A. Valenzuela, Docosahexaenoic acid (DHA), a fundamental fatty acid for the brain: new dietary sources, Prostaglandins Leukot. Essent. Fatty Acids 124 (2017) 1–10.
[51] K.A. Mulder, D.J. King, S.M. Innis, Omega-3 fatty acid deficiency in infants before birth identified using a randomized trial of maternal DHA supplementation in pregnancy, PLoS One 9 (2014) e83764.
[52] L.N. Yelland, B.J. Gajewski, J. Colombo, R.A. Gibson, M. Makrides, S.E. Carlson, Predicting the effect of maternal docosahexaenoic acid (DHA) supplementation to reduce early preterm birth in Australia and the United States using results of within country randomized controlled trials, Prostaglandins Leukot. Essent. Fatty Acids 112 (2016) 44–49.
[53] E.A. Miles, P.C. Calder, Can early omega-3 fatty acid exposure reduce risk of childhood allergic disease? Nutrients 21 (2017) piiE784.
[54] C. Vaysse, N. Simon, J. Tressou, S. Pasteau, B. Buaud, P. Guesnet, L. Couedelo, Claude Billeaud, Niveau de consommation en acides gras polyinsaturés de la femme allaitante en France: étude de consommation INCA2 et évolution du contenu en acides gras essentiels du lait maternel de 1997 à 2014, OCL 25 https://www.ocl-journal.org/articles/ocl/pdf/2018/03/ocl180028s.pdf, (2018) Accessed May 2018.