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 autoxidation [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 for 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 lactating woman from different regions of France using a 7-d dietary record and by using a long list of food items (= 1305). They were recorded in the form of boxplots to display the distribution of results and by using the most recent set of nutritional content of foods (the French Information Center on Food Quality, Cifip, 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

<table>
<thead>
<tr>
<th></th>
<th>Pregnant women (third trimester)</th>
<th>Lactating women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy kcal (kJ)</td>
<td>2050 (8600)</td>
<td>2250 (9400)</td>
</tr>
<tr>
<td>Total fat (%)</td>
<td>35–40%</td>
<td>35–40%</td>
</tr>
<tr>
<td>LA (18:2n-6) (%)</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>ALA (18:3n-3) (%)</td>
<td>1% (0.8%)</td>
<td>1% (0.8%)</td>
</tr>
<tr>
<td>LA/ALA</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>DHA (22:6n-3) mg/d</td>
<td>250 mg/d</td>
<td>250 mg/d</td>
</tr>
<tr>
<td>EPA (20:5n-3) + DHA (22:6n-3) mg/d</td>
<td>500 mg/d</td>
<td>500 mg/d</td>
</tr>
</tbody>
</table>

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.
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 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.

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 LA 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.

### Table 2

<table>
<thead>
<tr>
<th>Mean daily intakes</th>
<th>Number of women meeting French RDIs (number meeting adequate intakes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pregnant women (n = 28)</td>
<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>1875 ± 264 (1011–2877)</td>
</tr>
<tr>
<td>% EIEA</td>
<td>77.1 ± 22.5 (36.0–118.4)</td>
</tr>
<tr>
<td>LA (18:2n-6)</td>
<td>37.0 ± 5.2 (28.4–47.1)</td>
</tr>
<tr>
<td>ALA (18:3n-3)</td>
<td>4.0 ± 2.2 (1.8–9.0)</td>
</tr>
<tr>
<td>LA/ALA</td>
<td>0.4 ± 0.1 (0.3–0.7)</td>
</tr>
<tr>
<td>DHA (22:6n-3)</td>
<td>10.2 ± 5.4 (4.5–26.5)</td>
</tr>
<tr>
<td>EPA + DHA</td>
<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>1911 ± 605 (963–2772)</td>
</tr>
<tr>
<td>% EIEA</td>
<td>84.1 ± 30.0 (41.5–136.4)</td>
</tr>
<tr>
<td>LA (18:2n-6)</td>
<td>39.6 ± 5.5 (30.2–47.8)</td>
</tr>
<tr>
<td>ALA (18:3n-3)</td>
<td>3.4 ± 1.4 (1.8–6.8)</td>
</tr>
<tr>
<td>LA/ALA</td>
<td>0.4 ± 0.1 (0.2–0.7)</td>
</tr>
<tr>
<td>DHA (22:6n-3)</td>
<td>9.4 ± 2.9 (5.9–14.7)</td>
</tr>
<tr>
<td>EPA + DHA</td>
<td></td>
</tr>
<tr>
<td>Lactating women (n = 21)</td>
<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>2050 ± 605 (963–2772)</td>
</tr>
<tr>
<td>% EIEA</td>
<td>84.1 ± 30.0 (41.5–136.4)</td>
</tr>
<tr>
<td>LA (18:2n-6)</td>
<td>39.6 ± 5.5 (30.2–47.8)</td>
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<tr>
<td>ALA (18:3n-3)</td>
<td>3.4 ± 1.4 (1.8–6.8)</td>
</tr>
<tr>
<td>LA/ALA</td>
<td>0.4 ± 0.1 (0.2–0.7)</td>
</tr>
<tr>
<td>DHA (22:6n-3)</td>
<td>9.4 ± 2.9 (5.9–14.7)</td>
</tr>
<tr>
<td>EPA + DHA</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

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]
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, 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
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 (INCA2–Ciqual), the data distribution analysis showed that only 25–50% of the study women of childbearing age, our results clearly show 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 in human breast milk was found much lower 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 in 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

### 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).

<table>
<thead>
<tr>
<th>Main food groups contributors (g/d or mg/d)</th>
<th>Pregnant women (n = 28)</th>
<th>Lactating women (n = 21)</th>
<th>Women of childbearing age (n = 742)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fat</td>
<td>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)</td>
<td>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)</td>
<td>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)</td>
</tr>
<tr>
<td>LA (18:2n-6)</td>
<td>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)</td>
<td>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)</td>
<td>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)</td>
</tr>
<tr>
<td>ALA (18:3n-3)</td>
<td>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)</td>
<td>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)</td>
<td>Total (112 mg/d), Fish (54 mg/d), eggs and egg-products (11 mg/d), poultry and game (8 mg/d), pastries and cakes (6 mg/d), shellfish (4 mg/d)</td>
</tr>
<tr>
<td>DHA (22:6n-3)</td>
<td>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)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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-life 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 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 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 in 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 RDI’s 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 [46], it could suggest 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 month 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 years of age in humans, 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, 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% EEA 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
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