Fish intake and serum fatty acid profiles from freshwater fish1–3

Aline Philibert, Claire Vanier, Nadia Abdelouahab, Hing Man Chan, and Donna Mergler

ABSTRACT

Background: Although high mercury concentrations in fish diets raise an alarm, fish can also be a healthy choice because it is the primary source of n−3 fatty acids (FAs). However, little information is available on the contribution of freshwater fish to serum FA concentrations.

Objective: This study examined the FA pathway from fish to serum in 243 moderate consumers of freshwater fish.

Design: A food-frequency questionnaire was used to determine the intakes of freshwater fish caught locally and not sold in markets and of fish purchased in markets (5 ± SD: 58 ± 63 g/d). Locally caught freshwater fish accounted for an average of 45% of total fish intake. Fish were categorized as lean or fatty on the basis of the eicosapentaenoic acid + docosahexaenoic acid content estimated from published data. Serum FA concentrations were determined by gas chromatography.

Results: The results showed no relation between total fish intake or estimated n−3 FA intake from all fish and serum n−3 FA concentrations. Only fatty fish intake, particularly salmonid, and estimated EPA + DHA intake from fatty fish were significantly associated with serum EPA + DHA (R² = 0.41 and 0.40, respectively). No relation was observed between the quantity of locally caught fish (g/d) consumed or the estimated FA intake from locally caught fish and serum n−3 FAs. Age, sex, and lipid metabolism medication were associated with serum n−3 FA concentrations. Neither blood selenium nor blood mercury was associated with serum FAs.

Conclusion: The relation between fatty fish consumption and serum n−3 FAs cannot be generalized to all fish intakes. Am J Clin Nutr 2006;84:1299–307.

KEY WORDS Fatty acids, n−3 fatty acids, n−6 fatty acids, EPA, DHA, serum fatty acids, fish consumption, food-frequency questionnaire, freshwater fish, fatty fish

INTRODUCTION

Fish consumption poses a particular dilemma for cardiovascular health because it is the vehicle for both mercury, which has been shown to be cardiotoxic, and beneficial fatty acids (FAs), which may be cardioprotective (1–5). In addition to being a good source of proteins and other minerals, fish are practically the only natural source of two n−3 FAs: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These n−3 FAs may be beneficial in treating medical conditions such as arrhythmias, atherosclerosis, endothelial dysfunction, and high blood pressure (6–9).

Although the association between fish intake or FA intake from fish and serum FA concentrations appears well established (10–16), it has primarily been reported for marine fish, many of which have a high FA content (9, 17–19), or in studies in which there was no clear distinction between marine and freshwater fish intake (11, 13, 16, 20). Furthermore, most studies that have examined the relation between fish intake and serum FAs have been conducted in persons with a high fish consumption (10–12, 14, 19), often from indigenous communities (16, 21–23). For the general population or recreational freshwater sport fishers, whose traditional culture is not based on a fish diet and who generally consume moderate amounts of fish, the relation between fish consumption and serum n−3 FAs remains unclear (24).

The serum concentration of FAs may be influenced by essential nutrients and environmental pollutants. Of the many possible toxic mechanisms, mercury is known to promote lipid peroxidation, either by inhibiting sulfhydryl-dependent enzymes (glutathione peroxidase) and NADP-NAD–dependent metabolic reactions or by preventing the capture of free radicals and enhancing the supply of hydrogen peroxide (25, 26). It has been suggested that selenium, a component of glutathione peroxidase, prevents the oxidation of lipids (27, 28).

The present study is part of the Canadian Collaborative Mercury Research Network (COMERN), which adopted an ecosystem approach to identify mercury pathways in the Canadian environment and to assess the potential risks and benefits associated with fish consumption (30). The objectives were to examine, in persons from lakeside communities, 1) the association between fish consumption, including both locally caught freshwater fish not sold in markets (local catch) and fish purchased in markets (market fish), or estimated n−3 FA intakes from fish, and serum FA profiles, taking into account sociodemographic and anthropometric variables, lifestyle, and medication use, and 2) the possible influence of blood selenium and methyl mercury on these relations. It was hypothesized that there would be a relation between total fish consumption or estimated n−3 FAs

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from fish and serum n—3 FA concentrations, a positive association between blood selenium and serum n—3 FAs, and a negative association between n—3 FAs and blood methyl mercury.

**SUBJECTS AND METHODS**

The study used a cross-sectional design and targeted fish eaters of local catch from lakeside communities in 2 regions of Québec, Canada: Lake St Pierre (LSP), a fluvial lake of the St Lawrence River, and 3 lakes of the Abitibi region (Duparquet, Preissac, and Malartic). Participants were recruited in collaboration with regional environmental and fishers associations and were eligible if they were ≥18 y of age and reported eating fish from the local lakes. Interested participants were contacted by telephone. The study was carried out at central locations between March and April 2003 in LSP and between July and August 2003 for the 3 lakes in Abitibi. The participants included 130 persons from LSP and 129 from Abitibi. The study protocol was approved by the Ethics Committee of the Université du Québec à Montréal, and informed consent was obtained from each participant.

**Sociodemographic variables, anthropometric measurements, and disease status**

A self-administered questionnaire was used to obtain information on sociodemographic (age, sex, annual income, and education level) and lifestyle (alcohol intake, smoking habits, and recreational drug use) characteristics and on present and past occupational and recreational chemical and pesticide exposure. Questions on alcohol consumption were about intakes of beer, wine, and spirits during the week and on weekends (31). These data were then transformed into weekly ethanol intake (g/wk) based on the alcohol content of the beverages: beer (5%), wine (12%), and spirits (40%).

A series of questions on the history of diagnosed illness were included in the self-administered questionnaire. In addition, each participant was required to bring all of his or her current medication. A registered nurse recorded the information, which was then classified into the following categories: medication for heart disease, hypertension, diuretics, lipid metabolism regulators, and medication for diabetes, allergies, gastroenteritis, thyroid disorders, hormone replacement therapy, neuroleptics, nonsteroid and steroid antiinflammatory agents, antiasthmatics, and vitamin supplements.

Anthropometric measures (height, weight, and waist girth) were made by the nurse. Body mass index (BMI) was calculated as weight (in kg)/height2 (in m). Persons with a BMI > 30 were classified as obese (32).

**Fish intake and fatty acid intake**

An interviewer-administered food-frequency questionnaire, adapted from Legrand et al (33) and other studies (34, 35), focused on the fish diet throughout the year. Seasonal consumption (winter, spring, summer, and fall) of fish from catch and market sources was recorded. For fresh and frozen fish and seafood, participants were asked how many meals and how many portions/meal were consumed; portion sizes were adapted to 120 g for each fish category. For canned fish, the number of small cans was used and then converted to grams. Daily fish intake was then estimated (g/d) for each of the 42 fish categories recorded (12 freshwater and 30 marine). Note that a fish species, such as tuna, could be in several subcategories, including fresh, canned in water, and canned in oil. We focused on the 3-mo period of fish consumption before the interview, because serum FA concentrations reflect recent FA intakes (weeks to months after consumption) (36, 37). Fish consumption was categorized into catch and market. All catch were freshwater. Trout was either fished or from the market. All of the other market produce were marine fish.

The concentrations of polyunsaturated FAs (PUFAs), monounsaturated FAs (MUFRAs), and saturated FAs (SFAs) in the various fish and seafood categories consumed by the participants were estimated by using the Canadian File of Nutrients (38). When these values were unavailable, other references were used, including those of the US Department of Agriculture (39), the results of a study conducted in Lac Saint Pierre by Blanchet and Dewailly (40), and the results of a study by Hearn et al (41). When data for specific FAs were not available from the literature, the median for all fish species was used (missing data occurred in <3% when considering all FAs and affected only 2 species: canned cod and pollock). Data are expressed as mg FAs/100 g raw fish. Because fish tissue FA concentrations have been reported to vary according to cooking method (broiling, frying, baking, and buttering) and preparation time (42–44) and because we did not obtain detailed information on cooking methods, we used the values for raw fish to estimate FA intakes. Note that the raw and cooked values from the Canadian Nutrient File (38) are highly correlated (Spearman rho = 0.75 for n—3 FAs). The choice of raw values also allowed us to maintain the same conservative FA value for each species and to compare our results with other studies (10–16, 22, 23).

**Serum fatty acids**

For the FA analysis, blood samples were collected in 10-mL tubes and were centrifuged at 480 × g for 20 min. The serum was then removed (top layer) without disturbing the bottom layer of red blood cells with a transfer pipette, transferred to 7-mL “crewtop” storage tubes (no. 2–7341; Supelco, Bellefonte, PA) and frozen at −20 °C. All fatty acid analyses were performed at the Centre for Indigenous Peoples’ Nutrition and Environment of McGill University (Montreal, Canada). Total lipids were extracted from 500 μL serum as described by Folch et al (45) with chloroform:methanol (2:1, by vol), 0.02% butylated hydroxytoluene as an antioxidant, and 1.0 mg each of tridecanoic acid (C13:0) as an internal standard (0.5 mg/mL). FAs were then methylated with the use of the following reagents: boron fluoride–methanol reagent, benzene, and methanol at 100 °C for 45 min (46). After extraction in hexane, 10 μL (20 mg/mL) heptadecanoic acid (C17:0) as a surrogate standard was added and then fatty acid methyl esters (FAME) were separated on a Supelcowax-10 fused silica capillary column (30 m × 0.32 mm internal diameter, 0.25-μm film thickness) in a Star 3400 CX gas chromatograph (Varian, Palo Alto, CA) with a flame ionization detector and helium as a carrier gas. One microliter of sample was injected, and FAs were then identified by comparing their retention times with those of standards obtained from Nu-Chek Prep, Inc (Elysian, MN). FAMEs were quantified with the use of a Varian Saturn Workstation (version 5.4) by using a 4-point calibration curve. Serum FAs are expressed as mg/mL serum.

**Blood metal samples**

Blood samples for mercury and other metal analyses were obtained by venipuncture in 6-mL metal-free Vacutainer
Hemogard (Becton-Dickinson, San Jose, CA) blood collection tubes (no. 7863), which contained 0.05 mL of 15% EDTA K3. Samples were stored at 4°C and sent at the end of each day by bus to the Quebec Center of Toxicology of the Quebec Institute for Public Health. Total blood selenium concentrations were analyzed by using inductively coupled plasma mass spectrometry (ICP-MS) according to the method described by Labat et al (47). Total mercury and inorganic mercury were measured by cold vapor atomic absorption spectrometry, as described by Ebesad et al (48). The organic fraction of mercury in whole blood was estimated as the difference between total and inorganic mercury and is reported as methyl mercury. Detection limits were 7.9 μg/L for selenium and 0.2 μg/L for mercury. The Quebec Center of Toxicology of the Quebec Institute for Public Health is ISO 17025–accredited, and analytic performance for mercury analysis in the Interlaboratory Comparison Program for Metals in Biological Media was 36/36 for precision and 6/6 for reproducibility. The organic fraction of mercury is reported as methyl mercury.

**Statistical analyses**

For all data analyses, 2 of the 259 participants were excluded due to missing data for serum FA and one was eliminated due to extreme values in serum n–3 FA, which were 50-fold higher than the calculated medians among all participants. Because diabetes medication explained on average >50% of the total variance of serum n–3 FA and those taking diabetic medication had lower serum total n–3 FA concentrations compared with the others, participants taking diabetic medication (n = 13) were excluded in the analysis. The total number of participants for the present study was 243. Because EPA can be transformed into DHA through a chain of elongation and saturation, and because there is a simultaneous retroconversion of DHA into EPA (49, 50), we preferentially used the sum of both, ie, EPA + DHA.

A hierarchical cluster analysis was done by using the Ward’s distance to agglomerate fish categories and subcategories according to their EPA + DHA content. Because most variables were not normally distributed, nonparametric analyses were preferentially performed or variables were log transformed. When testing the association between 2 categorical variables, the chi-square test of Pearson was used. When testing continuous variables against categorical data, nonparametric analyses of variance (Wilcoxon’s rank-sum test and the Kruskal-Wallis test) were performed. Multiple regression models were used to infer the variations in serum FAs. Stepwise multiple regression analyses were used to determine the final variable selection of explanatory variables. Residual analysis was performed to examine assumptions of the multiple regression models. Statistical analyses were performed with JMP software package version 5.01 (SAS institute Inc, Cary, NC). The limit of significance was set at ≤0.05.

**RESULTS**

The hierarchical cluster analysis separated the fish into 2 groups according to their n–3 FA values (EPA + DHA). Fish with EPA + DHA values <0.5 g/100 g tissue were considered “lean fish,” whereas fish with higher values were considered “fatty fish” (Figure 1). The fish with the highest n–3 FA contents were 1) the marine fish (mackerel, herring, and salmon) and 2) the freshwater fish (trout, especially gray trout; lake whitefish, and bass). Lobster, scampi, and northern pike had the lowest EPA + DHA contents, followed by the local catch (walleye-pickerel and perch, <0.4 g/100 g).

The participants’ average daily total fish intake was 58 g/d (median: 43 g/d; range: 0.55–641 g/d); the fatty fish intake averaged 7.7 g/d (median: 4 g/d; range: 0–59 g/d). Fatty fish intake represented only 18% of total fish intake (0–95%), of which 95% was market fish; >75% of fatty fish intake was from salmonid (salmon) (79.05%) and trout (20.95%). Freshwater catch (median: 16 g/d; range: 0–600 g/d) accounted for >80% of lean fish intake and averaged 45% of total fish intake. Walleye pickerel, perch, and northern pike made up 70% of the freshwater catch intake.

The 243 participants were divided into quartiles of fish intake over the 3 mo preceding the interview (occasional consumers: <24 g/d; low consumers: 24–41 g/d; moderate consumers: 41–66 g/d; and high consumers: >66 g/d) (Table 1). Consumption of both freshwater catch and market fish increased with fish group consumer intake (Table 1). High-fish consumers ate proportionally less market fish than did the occasional fish group (P = 0.03); 73% of their total fish intake was freshwater catch, of which 89% was lean fish. Although both lean and fatty fish intake increased with fish intake category, the high-fish consumers ate only half as much fatty fish in terms of proportion (7.7%) as did the occasional or low-fish consumers (14.5%).

Anthropometric and sociodemographic characteristics and lifestyle factors were examined according to quartiles of fish intake (Table 1). The study group ranged in age from 18 to 74 y (median: 48 y) and 53% were men. The high-fish consumers tended to be older than the occasional and low-fish consumers. Although daily fish intake increased with age, the relation was not significant. Twenty-six percent of the participants were considered obese (BMI: >30). No relation was observed between fish intake and BMI. The average alcohol intake was 128 g/wk (median: 68 g/wk). No association was observed between daily fish intake category and alcohol intake. Sex varied within fish consumer categories. More men were moderate and high consumers, whereas occasional and low consumers were mainly women.

Mean estimated EPA + DHA and n–6 FA intakes from fish were 223 mg/d (median: 172 mg/d) and 95 mg/d (median: 59 mg/d), respectively (Table 2). EPA + DHA, the total sum of n–3 FAs, and n–6 FAs represented 22.5%, 24%, and 8%, respectively, of the total FA intake from fish. The average ratio of n–6 to n–3 FAs from fish intake was 0.32. Although fatty fish and salmonid made up 18% and 13.5%, respectively, of total fish intake, their respective estimated EPA + DHA intakes were 36% and 25% of the total estimated EPA + DHA intake. Although freshwater catch made up 45% of total fish intake, the EPA + DHA intake from freshwater fish constituted only 32% of the total estimated EPA + DHA intake.

EPA + DHA, total n–3 FA or n–6 FA intake from total fish or from fatty fish progressively increased from the lowest fish-consumer category (occasional) to the highest fish-consumer category. However, no difference in the n–6 to n–3 FA ratio or the proportion of EPA + DHA intake from fatty fish was observed between the fish-consumer categories. No association was found between the fasting condition of participants at the time of the blood sampling and their respective serum FA concentrations (data not shown).
Serum EPA + DHA and total n-3 FAs accounted for 2% and 3% of total serum FAs, respectively. Serum EPA + DHA, total n-3 FA, n-6 to n-3 FA ratio and blood selenium and methyl mercury for the fish-consumer categories (Table 3). Although blood methyl mercury concentrations increased as fish consumption increased, blood selenium concentrations remained similar between fish groups.

The results of the multiple regression models, with serum EPA + DHA concentrations as dependent variables and fish intake or estimated FA intake as predictor variables are provided in Table 4. Serum concentrations of EPA + DHA and the percentage of serum EPA + DHA (Table 4) and total serum n-3 FAs and DHA (data not shown here) were significantly and positively associated with salmonid intake or with fatty fish intake. Neither freshwater catch nor total lean fish entered into any of the inference models. The significant contribution of salmonid intake to serum EPA + DHA concentrations (partial $R^2 = 8.7\%, P < 0.001$) and the absence of association between total freshwater catch intake and serum EPA + DHA concentrations (partial $R^2 = 0.6\%, P = 0.51$) are illustrated in Figure 2.

Serum concentrations of EPA + DHA, the percentage of serum EPA + DHA, and total n-3 FAs were significantly and positively associated with their estimated intake from salmonids or from fatty fish. Estimated FA intakes from freshwater catch and total lean fish did not enter into any of the inference models. However, a relation between the percentage of serum EPA + DHA and its estimated intake from total fish consumption was
observed. Neither blood methyl mercury nor selenium were associated with any of the measures of serum n-3 FAs.

Age was positively associated with EPA, DHA, and the total sum of EPA + DHA. The serum n-3 FA concentration was positively correlated with serum oleic acid (18:1n-9) and was negatively correlated with the percentage of total serum SFAs (data not shown). The strong correlation between alcohol intake and serum 18:1n-9 prevented alcohol intake from entering into any of the inference models. No relation with BMI or sex was observed with serum EPA + DHA or total n-3 FAs, although the proportion of serum EPA + DHA in FAs was higher in women than in men.

DISCUSSION

The most striking finding of this study was the absence of a relation between total fish intake and concentrations of any type of n-3 FAs in serum. This result is even more surprising for EPA and DHA, whose primary source is fish. Although the subjects with the greatest fish consumption had the highest estimated

### TABLE 1

| Fish intake | <24 g/d | 24–41 g/d | 41–66 g/d | >66 g/d | P
|-------------|--------|----------|----------|--------|---
| Total fish (g/d) | 17.5 (0.55–93.7) | 32.1 (16.2–168) | 52.4 (24.0–79.5) | 97.5 (15.9–641) | <0.0001
| Catch (g/d) | 5.28 (0.89–6.6) | 11.8 (0.63–3.3) | 21.1 (0.56–2.7) | 56.7 (0.65–700) | <0.0001
| All marine produce (g/d) | 6.98 (0.3–1.16) | 19.9 (0.55–1.05) | 26.1 (0.61–3.6) | 36.4 (0.65–1.43) | <0.0001
| Total market (g/d) | 9.72 (0.3–1.16) | 22.4 (0.55–1.05) | 27.4 (0.29–0.69) | 39.5 (0.65–1.45) | <0.0001
| Salmonoids (g/d) | 0.99 (0.11–2.2) | 3.94 (0.3–6.6) | 3.95 (0.3–4.1) | 3.12 (0.5–7.2) | 0.005
| Lean fish (g/d) | 12.6 (0.55–0.92) | 25.9 (4.15–1.56) | 41.5 (10.5–64.6) | 83.3 (13.3–64.1) | <0.0001
| Fatty fish (g/d) | 2.47 (0.12–2.5) | 4.93 (0.24–2.9) | 5.43 (0.34–3.7) | 7.89 (0.59–2.9) | 0.002
| Subject characteristics | | | | | |
| Age (y) | 45 (18–70) | 49 (19–72) | 52 (18–74) | 50 (20–73) | 0.06
| BMI (kg/m²) | 26 (18.1–42.2) | 26 (18.2–41.4) | 26 (15.4–42.7) | 27 (18.5–46.4) | 0.46
| Alcohol intake (g/wk) | 52 (1372) | 85 (508) | 67 (511) | 78 (5704) | 0.93
| Sex, dummy variable | | | | | |
| Men | 26 (41.9) | 26 (42.6) | 35 (59.3) | 40 (66.7) | —
| Women | 36 (58.1) | 35 (57.4) | 24 (40.7) | 20 (33.7) | —

1 Significance of the nonparametric ANOVA, P ≤ 0.05 (Wilcoxon’s rank-sum and Kruskal-Wallis tests, chi-square αerr = 0.05).
2 All values are medians; range in parentheses.
3 All values are n; range in parentheses.
4 Significance of the Pearson test, P ≤ 0.05 (chi-square contingency table, αerr = 0.05).

### TABLE 2

| Fish intake | <24 g/d | 24–41 g/d | 41–66 g/d | >66 g/d | P
|-------------|--------|----------|----------|--------|---
| EPA (mg/d) | 24.9 (0.26–91.5) | 52.7 (19.2–212) | 72.6 (26.7–181) | 135 (17.4–455) | <0.0001
| DHA (mg/d) | 44.2 (1.22–223) | 81.8 (33.3–368) | 130 (61.1–260) | 240 (40.6–1012) | <0.0001
| EPA + DHA (mg/d) | 65.7 (1.48–314.7) | 131 (52.5–580) | 199 (89.3–341) | 367 (58–1468) | <0.0001
| EPA + DHA (%) | 0.23 (0.08–0.39) | 0.21 (0.13–0.43) | 0.22 (0.13–0.37) | 0.23 (0.13–0.42) | 0.05
| Total n-3 FAs (mg/d) | 70.3 (1.49–324) | 143 (55.2–608) | 209 (97.3–537) | 410 (60.6–1557) | <0.0001
| Total n-3 FAs (mg/d) | 71.7 (1.2–145) | 45.4 (13.8–520) | 59.1 (22.7–620) | 135 (12.8–650) | <0.0001
| Total n-3 FAs (%) | 0.27 (0.13–0.96) | 0.28 (0.17–1.63) | 0.28 (0.17–1.29) | 0.31 (0.17–1.12) | 0.31
| EPA + DHA from fatty fish (mg/d) | 24.1 (0.4–159) | 50.9 (0.5–322) | 61.9 (0.4–408) | 86.2 (0.6–754) | <0.0001
| EPA + DHA from fatty fish (%) | 0.36 (0.0–0.98) | 0.34 (0.0–0.95) | 0.34 (0.0–0.92) | 0.26 (0.0–0.86) | 0.47

1 All values are medians; range in parentheses. EPA, eicosapentaenoic acid (20:5n–3); DHA, docosahexaenoic acid (22:6n–3).
2 Significance of the nonparametric ANOVA, P ≤ 0.05 (Wilcoxon’s rank-sum and Kruskal-Wallis tests, chi-square αerr = 0.05).
3 Calculated from the total sum of serum FAs.
4 Calculated as α-linolenic acid (18:3n–3) + EPA + DHA.
5 Calculated as linoleic acid (18:2n–6) + arachidonic acid (20:4n–6).
6 Calculated as total n-6 FA/total n-3 FA.
intake of n−3 FAs, they had the lowest serum FA concentrations—similar to those of the occasional fish consumers. These results contrast with those of most observational studies (12–15), in which persons with the highest total fish or FA intakes also had the highest serum n−3 FA concentrations, but are similar to those of 3 other studies, which were conducted in Norway and in Japan (14, 20), and to those of the study by Godin et al (24) in Quebec, who reported no relation between fish consumption concentrations, is puzzling. The results of this study tend to support the hypothesis that EPA and DHA from different fish oils may be metabolized or incorporated into plasma in different manners (49, 50). In rats, it has been shown that fatty fish oil may be necessary for the assimilation of EPA, DHA, or both into the absorption by enzyme competition; however, in the present study, the ratio of n−6 to n−3 FAs was similar between fatty and

### TABLE 3

Description and comparison of serum fatty acids (FAs), blood selenium, and methyl mercury by fish-intake category

<table>
<thead>
<tr>
<th>Fish intake (g/d)</th>
<th>Serum FAs</th>
<th>Blood selenium (µg/L)</th>
<th>Blood methyl mercury (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 24 g/d</td>
<td>(n = 62)</td>
<td>0.03 (0–0.12)</td>
<td>203 (148–268)</td>
</tr>
<tr>
<td>24–41 g/d</td>
<td>(n = 59)</td>
<td>0.04 (0–0.14)</td>
<td>204 (142–296)</td>
</tr>
<tr>
<td>41–66 g/d</td>
<td>(n = 62)</td>
<td>0.04 (0–0.13)</td>
<td>208 (152–291)</td>
</tr>
<tr>
<td>&gt; 66 g/d</td>
<td>(n = 60)</td>
<td>0.03 (0–0.39)</td>
<td>215 (170–265)</td>
</tr>
</tbody>
</table>

1. All values are medians; range in parentheses. EPA, eicosapentaenoic acid (20:5n−3); DHA, docosahexaenoic acid (22:6n−3).
2. Calculated from the total sum of serum FAs.
3. Calculated as α-linolenic acid (18:3n−3) + EPA + DHA.
4. Calculated as total n−6 (linoleic acid (18:2n−6) + arachidonic acid (20:4n−6))/total n−3 FAs.
5. Oleic acid.
6. Calculated from the total sum of serum FAs.

### TABLE 4

Results of linear multiple regression analyses between adjusted serum eicosapentaenoic acid (EPA) + docosahexaenoic acid (DHA) and the percentage of EPA + DHA as response variables and the explanatory variables of fish intake and estimated EPA + DHA intake (n = 240)

<table>
<thead>
<tr>
<th>Fish intake</th>
<th>Median (range)</th>
<th>Serum EPA + DHA</th>
<th>Percentage of serum EPA + DHA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²</td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>Total fish</td>
<td>40.6 (0.5–641)</td>
<td>0.35</td>
<td>0.01</td>
</tr>
<tr>
<td>Total locally caught fish</td>
<td>15.8 (0–600)</td>
<td>0.35</td>
<td>−0.04</td>
</tr>
<tr>
<td>Total fatty fish</td>
<td>4.24 (0–59.2)</td>
<td>0.39</td>
<td>0.22</td>
</tr>
<tr>
<td>Total salmonid</td>
<td>6.04 (0–57.3)</td>
<td>0.41</td>
<td>0.25</td>
</tr>
<tr>
<td>Estimated EPA + DHA intake from</td>
<td>171 (1–1468)</td>
<td>0.36</td>
<td>0.10</td>
</tr>
<tr>
<td>Total fish</td>
<td>38.1 (0–78.5)</td>
<td>0.35</td>
<td>−0.07</td>
</tr>
<tr>
<td>Total fatty fish</td>
<td>49 (0–754)</td>
<td>0.39</td>
<td>0.21</td>
</tr>
<tr>
<td>Total salmonid</td>
<td>25.5 (0–712)</td>
<td>0.40</td>
<td>0.24</td>
</tr>
</tbody>
</table>

1. Significance of the general regression model (P ≤ 0.05).
2. Adjusted for lipid metabolism medication (dummy variable: yes or no), age, sex (dummy variable: male or female), serum 18:1n−9 (oleic acid), and the percentage of total saturated fatty acids in serum.
3. Adjusted for lipid metabolism medication (dummy variable: yes or no), age, sex (dummy variable: male or female) and the percentage of total saturated fatty acids in serum.
lean fish. The greater serum ratio of n–3 to n–6 FAs in occasional- and in high-fish consumers is an unlikely explanation for the differences in serum n–3 FAs observed for the low- and moderate-fish consumers. The use of FA content of raw fish to estimate FA intake may be a source of error in our analyses, but it is unlikely that lean fish are systematically differently prepared when compared with fatty fish. Thus, the absence of a relation between serum and estimated EPA + DHA intake from lean fish remains unclear.

Previous studies (28, 29) have reported an association between selenium and FA concentrations and have suggested that this could be explained by the structural role of selenium in the glutathione peroxidase enzyme, which prevents lipid peroxidation from free radicals. In the present study, the small range of blood selenium concentrations possibly explains the weak and nonsignificant association observed between blood selenium and serum EPA + DHA. Although blood methyl mercury concentrations increased as fish consumption increased, the concentrations were low and did not enter into any of the predictive models for any of the serum n–3 FA concentrations.

The positive relation between age and serum n–3 FA concentrations is consistent with the relations observed in other studies, such as those conducted in Australia (52), in Quebec (15), in sport fishers in Quebec (53), in Japan (19, 54), and in northern indigenous populations of Cree and Inuit (16, 22, 23). It is known that age modifies appetite, taste, basal metabolism, and physical activity (55). Similar to the finding by Lopes et al (56), sex in the present study contributed to the association between fish intake or FA intake and the percentage of serum EPA + DHA; the percentage of serum EPA + DHA was higher in women than in men. The absence of an association between fish intake and BMI is consistent with the results of Bonna et al (57) and Dewailly et al (15).

Using the ecosystem approach, adopted by COMERN, we were able to follow n–3 FAs from actual fish consumption (from catch and market sources) to serum concentrations of moderate fish consumers. These findings have important consequences with respect to the expected benefits of n–3 FA intakes from many locally caught freshwater fish in persons living near lakes and rivers. Our results indicate that no matter how many freshwater local catch are eaten in the communities studied, serum n–3 FA concentrations are not affected. This finding is in contrast with the findings concerning the consumption of salmonid, such as trout and the fatty marine fish salmon. These findings strongly suggest that the data obtained for marine fatty fish–eating populations cannot be generalized to all fish-eating populations and that more must be learned about the possible benefits of freshwater fish consumption in different areas of the world.

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AP merged the data collected from the field and the fatty acid concentrations in fish tissues available from the literature into a new data matrix, carried out an exhaustive review of the literature, performed and interpreted the statistical analyses, and wrote the article. CV coordinated the fieldwork, collected the fish-consumption data, set up a general database, and helped write the article (particularly the study design and results sections). NA participated in the field studies, was responsible for the laboratory manipulations in the field, categorized the medication, and provided essential input to the study design section. HMC provided all of the serum fatty acid concentrations data from his laboratory and provided helpful comments. DM was the principal investigator of the study and was involved in all aspects of the study and preparation of the manuscript. None of the authors declared any competing financial interests.

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