JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Human Exposure to Perfluorinated Chemicals through the Diet: Intake of Perfluorinated Compounds in Foods from the Catalan (Spain) Market

INGRID ERICSON,† ROSER MARTÍ-CID,‡ MARTÍ NADAL,‡ BERT VAN BAVEL,† GUNILLA LINDSTRÖM,† AND JOSÉ L. DOMINGO*,‡

Man-Technology-Environment (MTM) Research Center, Örebro University, Örebro 70182 Sweden, and Laboratory of Toxicology and Environmental Health, "Rovira i Virgili" University, San Lorenzo 21, 43201 Reus, Spain

The aim of this study was to determine the dietary intake of perfluorinated chemicals (PFCs) by the population of Tarragona County (Catalonia, Spain). PFC levels were determined in 36 composite samples of foodstuffs randomly purchased in various locations. Exposure to PFCs through the diet was estimated for various age/gender groups. Perfluorooctane sulfonate (PFOS), perfluorocarboxylate perfluorooctanoate (PFOA), and perfluoroheptanoic acid (PFHpA) were the only detected PFCs in foodstuffs. On average, for a standard adult man (70 kg of body weight), the dietary intake of PFOS was estimated to be 62.5 or 74.2 ng/day (assuming ND = 0 or ND = 1/2 LOD, respectively). Fish, followed by dairy products and meats, were the main contributors to PFOS intake. For an adult man, the intake of PFOS (1.07 ng/kg/day) and those of PFOA and PFHpA were lower than that recently reported for Canada (4.0 ng/kg/day), and considerably lower than that previously found in the United Kingdom, the only two countries where, to date, results concerning this issue have been reported. A correlation between dietary intake and blood levels of PFOS is suggested. However, the current results do not justify dietary intake as the main route of exposure governing blood concentrations of other PFCs.

KEYWORDS: Perfluorinated chemicals; foodstuffs; dietary intake; Catalonia (Spain)

INTRODUCTION

The perfluoroalkyl acids (PFAA) and their salts, such as perfluoroalkyl sulfonates, perfluoroalkyl carboxylates, and telomer alcohols, are chemicals that have wide consumer and industrial applications, including protective coatings for fabrics and carpets, paper coatings, insecticides, paints, cosmetics, and fire-fighting foams. In recent years, a number of studies have reported the ubiquitous distribution of perfluorinated compounds (PFCs) in humans and wildlife (*1–8*). Among the perfluoroalkyl sulfonates, perfluorooctane sulfonate (PFOS), followed by perfluorohexanesulfonate (PFHxS) and perfluorocarboxylate perfluorooctanoate (PFOA), have been the most extensively studied (*9*). These compounds are extremely persistent, bioaccumulative, and of toxicological concern (*10–13*).

Although accumulation and trends of PFCs are still largely unknown, it is well established that in contrast to the classical more lipophilic persistent organic pollutants (POPs) such as dioxins and furans, or polychlorinated biphenyls (PCBs), PFCs do not typically accumulate in lipids. In humans, exposure levels and pathways leading to the presence of PFCs can be better characterized by monitoring these chemicals in whole blood. PFCs have been detected in human blood worldwide, with increased levels observed in industrialized areas. In recent years, the concentrations of various PFCs in human blood have been determined in individuals from a number of regions and countries: the United States (*1, 14*), Sweden (*5, 6*), China (*15*), Catalonia (Spain) (*2*), Japan (*16*), and Germany (*17*) as well as Colombia, Brazil, Italy, Poland, Belgium, India, Malaysia, and Korea (*18*). Calafat et al. (*1, 14*) concluded that the high prevalence of exposure to several PFCs and the differences among sex, race/ethnic groups, and socioeconomic status highlighted the need for additional research to identify sources of human exposure to PFCs, to study the environmental distribution of these chemicals, and to evaluate the potential human health effects resulting from these exposures.

The origin of the human blood contamination by PFCs is not well understood. In general, the consumption of contaminated foodstuffs is the main route of exposure to

* Author to whom correspondence should be addressed (telephone +34 977759380; fax +34 977759322; e-mail joseluis.domingo@urv.cat).
† Örebro University.
‡ "Rovira i Virgili" University.

10.1021/jf0732408 CCC: $40.75 © 2008 American Chemical Society
Published on Web 02/06/2008

environmental pollutants such as metals and POPs. However, to date there is little information concerning human exposure to PFCs through dietary intake. A few studies have determined the levels of various PFCs in fish and seafood (*19, 20*), whereas the concentrations of some PFCs were also determined in items belonging to food groups such as cereals, meats, and milk and dairy products (*21, 22*). The most complete studies performed until now correspond to that of the U.K. Food Standards Agency (*23*), where 20 composites from the 2004 U.K. Total Diet Study (TDS) were analyzed, and the recent investigation of Tittlemier et al. (*24*), who analyzed Canadian samples of fish and seafood, meat, poultry, frozen entrées, fast food, and microwave popcorn collected from 1992 to 2004 and prepared as for consumption.

Recently, we carried out a pilot study to provide preliminary data on the levels of 13 PFCs in the blood of residents in Tarragona County (Catalonia, Spain) (*2*). Seven PFCs could be detected, with PFOS showing the highest mean concentration. The other six compounds were below the detection limits (between 0.44 and 1.10 ng/mL for perfluorotetradecanoic acid and 1H,1H,2H,2H-PFOS, respectively). To assess the possible contamination linked to dietary habits, the purpose of the present study was to determine the levels of the PFCs in a total of 36 composite samples constituted of the most frequently consumed foodstuffs by the population of Tarragona County and to estimate the dietary intake of PFCs by that population.

MATERIALS AND METHODS

Sampling. In July 2006, food samples were acquired in local markets, large supermarkets, and grocery stores from different locations of Tarragona County. It is important to emphasize that foodstuffs were randomly purchased, which means that most of them were not necessarily local products and might potentially be of any origin. A total of 36 composite samples, corresponding to 18 different food groups, were analyzed. Duplicate samples were separately prepared for each food group. The 18 considered food items were the following: veal (steak, hamburger), pork (sausage, hot dogs, steak, hamburger, ham), chicken (breast, thighs, sausage), lamb (steak), white fish (hake, whiting blue, sea bass, monkfish), seafood (mussel, shrimp), canned fish (tuna, sardine, mussel), blue fish (salmon, sardine, tuna), whole milk, semiskimmed milk, dairy products (three different kinds of cheese, yogurt, "petit-Swiss" creamy yogurt, cream caramel, custard), vegetables (lettuce, tomato, green bean, spinach), pulses (lentils, beans, chickpeas), cereals (rice, spaghetti, bread), fruits (apple, orange, pear, banana), oils (olive oil, sunflower oil, corn oil) and fats (margarine), and eggs. For the preparation of all composite samples, only the edible part of each food was included. The quantity of each food in every sample was based on the dietary habits of the population of the area under evaluation (*25*). Each sample was part of a composite of its respective kind of food, in a representative percentage of the consumption by the population of the area. Approximately 200 g for each sample was freeze-dried during 24 h with a Telstar Laboratory Freeze-Dryer Cryodos-80. Samples were freeze-dried and kept in methanol-cleaned polypropylene containers at −20 °C until analysis. The freeze-drying process was tested using a reference sample to ensure no losses of the perfluoroalkyl compounds occurred.

Chemicals. Ammonium acetate (>99%, p.a. for HPLC) was purchased from Fluka (Steinheim, Germany), formic acid (98–100%) from Scharlau (Barcelona, Spain), and methanol (HPLC) from Labscan (Dublin, Ireland). Laboratory-produced ultrapure water was used. Ammonium hydroxide (25% in water), acetic acid (glacial, 100%), and sodium acetate were purchased from E. Merck (Darmstadt, Germany), and Supelclean ENVI-carb (120/400 mesh) was purchased from Supelco (Bellefonte, PA). Perfluorobutanesulfonate (PFBuS) tetrabutylammonium salt (>98%), perfluorooctanesulfonates (PFOS) potassium salt (>98%), perfluorodecanoic acid (PFDA, > 97%), and perfluorohexanoic acid (PFHxA > 97%) were purchased from Fluka. Perfluoroheptanoic acid (PFHpA, 99%), perfluorononanoic acid (PFNA, 97%), perfluorooctanoic acid (PFOA, 96%), perfluorodecanesulfonate (PFDS) ammonium salt [25 wt % in 2-butoxyethanol (37%) in water], and perfluoroundecanoic acid (PFUnDA, 95%) were purchased from Aldrich (Steinheim, Germany, and Milwaukee, WI). Perfluorooctanesulfonamide (PFOSA, 97%) was purchased from ABCR (Karlsruhe, Germany), and perfluorohexanesulfonate (PFHxS, 98%) was purchased from Interchim (Montlucon, France). Labeled $^{13}C_4$-PFOA, $^{13}C_4$-PFOS, and $^{13}C_5$-PFNA were from Wellington Laboratories (Guelph, ON, Canada).

Table 1. MS/MS Transitions for the PFCs Analyzed

compound	transitions[a]		
PFBuS	**298.9 → 80.0**	298.9 → 99.0	298.9 → 82.9
PFHxS	**398.9 → 79.9**	398.9 → 99.0	398.9 → 118.9
PFOS	498.9 → 80.0	**498.9 → 99.1**	498.9 → 129.9
PFDS	**598.9 → 79.9**	598.9 → 99.0	598.9 → 130.0
PFHxA	312.9 → 118.9	**312.9 → 268.9**	
PFHpA	362.9 → 118.9	362.9 → 168.9	**362.9 → 318.9**
PFOA	412.9 → 168.9	412.9 → 218.9	**412.9 → 368.8**
PFNA	462.7 → 168.9	462.7 → 219.0	**462.7 → 418.9**
PFDA	512.9 → 218.9	512.9 → 268.9	**512.9 → 468.9**
PFUnDA	562.9 → 168.9	562.9 → 268.9	**562.9 → 518.9**
PFDoDA	612.9 → 168.9	612.9 → 268.8	**612.9 → 568.8**
$^{13}C_4$PFOS	502.9 → 80.0	**502.9 → 99.1**	502.9 → 130.9
$^{13}C_4$-PFOA	416.9 → 168.9	416.9 →218.9	**416.9 → 371.8**
$^{13}C_5$-PFNA	467.9 → 168.9	467.9 → 219.0	**467.9 → 422.9**

[a] Transitions used for quantification are shown in bold.

Analytical Procedure. The composite freeze-dried food samples were homogenized, extracted, and cleaned up using liquid extraction, solid phase extraction (SPE), and additional cleanup with EnviCarb using modified methods by Powley et al. (*26*) and Taniyasu et al. (*27*). Briefly, 2 mL of 200 mM sodium hydroxide was added to 1 g of freeze-dried food sample in polypropylene centrifuge tubes, precleaned with methanol. Extraction standards ($^{13}C_4$-PFOS and $^{13}C_4$-PFOA) were added to monitor recovery of perfluoroalkyl sulfonates and carboxylates. Blank samples, treated as real samples in all steps, were extracted with every batch of food sample. After 30 min, 10 mL of methanol was added. Samples were vortex mixed before shaking at 500 rpm for 30 min. HCl (150 μL, 4 M) was added before centrifugation at 10000*g* for 15 min. The supernatant, lipids and particles excluded, was mixed with 25 mL of water. Waters Oasis WAX single-use cartridges (6 cm^3/150 mg), previously conditioned with 4 mL of methanol and 4 mL of water, were used for extraction and fractionation. SPE cartridges were eluted with 4 mL of acetate buffer solution (discarded), 8 mL of MeOH (wash step), and 2 mL of 2% NH_4 in MeOH to collect target compounds. The target fraction was eluted into 15 mL polypropylene tubes with 25 mg of EnviCarb and 50 μL of glacial acetic acid. After vortex mixing, this fraction was filtered (2 μm nylon filter) and evaporated under nitrogen. The final volume was set to 500 μL including $^{13}C_5$-labeled PFNA added as performance standard and 300 μL of 2 mM sodium acetate in water.

A total of 15 μL was injected into an HP 1100 LC system (Waldbronn, Germany) equipped with a quaternary pump, an automatic degasser, and a thermostated column compartment that was kept at 25 °C. Separation was achieved on a Waters Symmetry C18 (150 × 2.1 mm, 5 μm) column. Water (A) and acetonitrile mobile phasea (B), the first containing 10 mM ammonium acetate, were delivered at a flow rate of 300 μL/min. The gradient started at 35% B followed by a 10 min ramp to 90% B, a 5 min hold, and then reverting to initial conditions allowing 7 min of stabilization time. Detection was performed using an API 5000 MS/MS system (Applied Biosystems/MDS Sciex, Canada) with a Turbo Ion Spray ion source operating in the negative electrospray mode. The MS/MS transitions monitored are shown in **Table 1**. The most abundant transition was chosen for quantification. Other transitions were used for confirmation and calculation of the identity ratio by calculating the ratio between secondary and primary transitions in the samples compared to the calibration standard. For PFOS, the 498.9 → 99.1 transition was used for quantification, whereas the 412.9 → 368.9 and 362.9 → 318.9 transitions were used for the quantification of PFOA and PFHpA, respectively.

Quantification and Quality Assurance. Quantification was performed using the internal standard method. A seven-point calibration curve dissolved in 35% methanol in water was used to calculate relative response factors (RRFs) and showed good linearity over a range from 0.011 to 4.02 ng/mL for PFOS, and from 0.09 to 3.20 ng/mL for PFOA, with the injection of 15 μL. The recovery values of the mass-labeled standards were used to evaluate matrix effects on analyte ionization. Labeled $^{13}C_4$-PFOS was used as an internal standard for the sulfonates, whereas $^{13}C_4$-PFOA was used for the carboxylates. The performance standard, $^{13}C_5$-PFNA, was used to monitor the recovery of the internal standards. Method blank sample was analyzed with every batch of samples, as well as instrumental blank injections with methanol. External quality assurance was performed by successful participation (z scores < 2) in the first and second interlaboratory studies on PFCs (*28*).

Analytical data from 11 PFCs were obtained. The recovery of the labeled standards ($^{13}C_4$-PFOS and $^{13}C_4$-PFOA) ranged between 32 and 74% for $^{13}C_4$-PFOS and between 61 and 130% for $^{13}C_4$-PFOA. The recovery for all analytes was previously tested for the WAX method (*6*). Quantification was based on solvent calibration standards. Originally, instrumental analysis was performed using an LC single-quadropole MS instrument. However, this technique proved to be insufficiently selective and coelution at m/z 499, when PFOS was monitored, occurred. Identity confirmation of quantification (primary transition) was performed by calculation of the ratio of secondary to primary MS/MS transition in samples and comparison against calibration standard according to the method suggested by the Commission of the European Communities (*29*). The identity was within 30% of the calibration standards for all detected concentrations except for one egg sample, for which the ratio was <30%, but >50% of the expected value.

RESULTS

Table 2 summarizes the concentrations of PFOS, PFOA, and PFHpA (nanograms per gram of fresh weight) in the food samples. All levels were corrected for recovery of the ^{13}C-labeled internal standards. Among the PFCs analyzed, these three compounds were the only ones that could be detected at least in one composite sample. The concentrations of the remaining PFCs (PFBuS, PFHxS, PFDS, PFHxA, PFNA, PFDA, PFUnDA, and PFDoDA) were under the respective limit of detection (LOD), ranging from 0.001 to 0.65 ng/g of fresh weight in all samples. The LODs given in **Table 2** were calculated from the actual responses at the expected retention time of the target compounds or from the signal in the laboratory blank when this area was >50% of the signal detected in the sample. In general terms, it can be seen that the PFC levels detected in the composite food samples were relatively low. PFOS was found in 24 of the 36 samples analyzed, with levels ranging from below the LOD to 0.82 ng/g of food on a fresh weight basis. PFOA and PFHpA were found in only two samples of whole milk at levels of 0.055 and 0.058 ng/g of fresh weight for PFOA and 0.016 and 0.014 ng/g of fresh weight for PFHpA (**Table 2**).

The estimated dietary intakes of PFOS in six age groups of the population of Tarragona County are shown in **Table 3**. These groups are, in turn, divided according to gender. When the concentration of PFOS in a food item was lower than the LOD, that value was assumed to be either zero (ND = 0) or half of the LOD (ND = 1/2 LOD). Assuming ND = 0, adult men aged between 20 and 65 years showed the highest PFOS intakes: 65.2 (51–65 years), 62.9 (35–50 years), and 59.3 (20–34 years) ng/day. However, when the daily intakes of PFOS were estimated according to the respective average body weight for each age/gender group (*25*), children aged 4–9 years showed the highest values (1.9 and 1.8 ng/kg/day for boys and girls, respectively), whereas the lowest PFOS intake corresponded to seniors (>65 years old) (**Table 3**). Assuming ND = 1/2 LOD, again adult men aged between 20 and 65 years showed the highest PFOS intakes: 75.8 (51–65 years), 74.9 (35–50 years), and 72.0 (20–34 years) ng/day. If the daily intakes are estimated according to the respective average body weight for each group, children were again the group showing the highest PFOS intake (**Figure 1**).

On average, for a standard adult man (70 kg of body weight) living in Tarragona County, the dietary intake of PFOS was estimated to be 62.5 ng/day (if ND = 0) and 74.2 ng/day (if ND = 1/2 LOD) (**Figure 2**). Fish and seafood were the main contributors to PFOS intake (52% if ND = 0 and 45% if ND = 1/2 LOD). In contrast, the lowest contribution corresponded

Table 2. Concentrations (Nanograms per Gram of Fresh Weight) of PFOS, PFOA, and PFHpA in Various Food Samples[a]

food	PFOS	PFOA	PFHpA
vegetables			
mean	0.022	<0.027	<0.004
SD[b]	0.006		
pulses			
mean	<0.027	<0.045	<0.009
SD			
cereals			
mean	<0.069	<0.080	<0.008
SD			
white fish			
mean	0.407	<0.065	<0.004
SD	0.080		
seafood			
mean	0.148	<0.029	<0.002
SD	0.006		
tinned fish			
mean	0.271	<0.126	<0.007
SD	0.029		
blue fish			
mean	0.654	<0.132	<0.010
SD	0.240		
pork			
mean	0.045	<0.053	<0.006
SD	0.029		
chicken			
mean	0.021	<0.067	<0.004
SD	0.0003		
veal			
mean	0.028	<0.034	<0.003
SD	0.006		
lamb			
mean	0.040	<0.071	<0.012
SD	0.0001		
eggs			
mean	0.082	<0.055	<0.005
SD	0.008		
dairy products			
mean	0.121	<0.040	<0.007
SD	0.050		
whole milk			
mean	<0.014	0.056	0.015
SD		0.002	0.002
semiskimmed milk			
mean	<0.019	<0.028	<0.004
SD			
fruits			
mean	<0.017	<0.036	<0.004
SD			
margarine			
mean	<0.034	<0.115	<0.014
SD			
oil			
mean	<0.099	<0.247	<0.036
SD			

[a] Two composite samples were analyzed for each foodstuff ($n = 2$). [b] Standard deviation.

Table 3. Estimated Daily Intake of PFOS (Nanograms per Day) by the Population of Tarragona County (Catalonia, Spain) According to Sex[a] and Age

	group 1 (4–9 years of age)				group 2 (10–19 years of age)				group 3 (20–34 years of age)			
	M		F		M		F		M		F	
	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD
vegetables	2.8	2.8	2.6	2.6	3.5	3.5	3.5	3.5	4.1	4.1	3.8	3.8
pulses	0.4	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.4
cereals	0.0	6.9	0.0	6.9	0.0	9.1	0.0	6.2	0.0	8.2	0.0	5.6
fish and seafood	20.0	20.0	18.1	18.1	23.7	23.7	22.2	22.2	27.8	27.8	27.0	27.0
meat and meat products	4.7	4.7	4.7	4.7	6.0	6.0	5.1	5.1	7.5	7.5	4.6	4.6
eggs	2.8	2.8	1.6	1.6	2.5	2.5	1.7	1.7	3.1	3.1	1.9	1.9
dairy products	13.7	13.7	13.9	13.9	16.5	16.5	13.2	13.2	15.0	15.0	10.8	10.8
milk	2.1	3.7	1.9	3.4	1.9	3.5	1.5	2.6	1.5	2.6	1.5	2.8
fruits	0.0	1.7	0.0	1.7	0.0	1.8	0.0	1.7	0.0	1.8	0.0	1.8
oils and fats	0.0	1.1	0.0	1.1	0.0	1.4	0.0	1.0	0.0	1.4	0.0	1.0
ng/day	46.4	57.9	43.1	54.5	54.5	68.4	47.5	57.7	59.3	72.0	49.9	59.7

	group 4 (35–50 years of age)				group 5 (51–65 years of age)				group 6 (>65 years of age)			
	M		F		M		F		M		F	
	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD	ND = 0	ND = 1/2 LOD
vegetables	5.4	5.4	4.7	4.7	5.2	5.2	4.7	4.7	4.1	4.1	4.1	4.1
pulses	0.4	0.6	0.4	0.5	0.3	0.4	0.3	0.4	0.3	0.5	0.3	0.4
cereals	0.0	7.1	0.0	4.7	0.0	6.0	0.0	4.1	0.0	6.1	0.0	4.7
fish and seafood	35.2	35.2	28.5	28.5	39.2	39.2	32.6	32.6	28.9	28.9	30.4	30.4
meat and meat products	5.5	5.5	4.2	4.2	5.4	5.4	3.7	3.7	4.0	4.0	3.6	3.6
eggs	2.6	2.6	2.1	2.1	2.8	2.8	1.8	1.8	2.4	2.4	1.3	1.3
dairy products	12.5	12.5	10.5	10.5	11.0	11.0	11.9	11.9	8.4	8.4	9.1	9.1
milk	1.4	2.6	1.5	2.8	1.3	2.3	1.8	3.2	1.4	2.5	1.8	3.3
fruits	0.0	2.1	0.0	1.8	0.0	2.2	0.0	2.3	0.0	2.6	0.0	2.0
oils and fats	0.0	1.4	0.0	1.1	0.0	1.2	0.0	1.0	0.0	0.9	0.0	1.0
ng/day	62.9	74.9	51.9	60.8	65.2	75.8	56.6	65.5	49.5	60.4	50.5	59.8

[a] M, males; F, females.

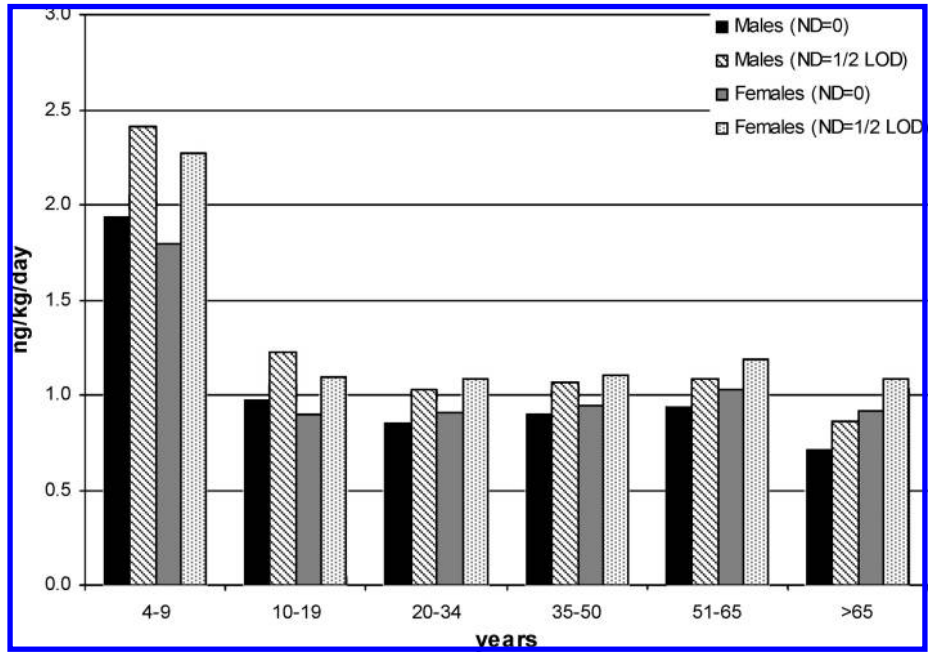

Figure 1. Estimated daily intake (ng/kg of body weight/day) of PFOS by the general population of Tarragona County (Catalonia, Spain) according to sex and age.

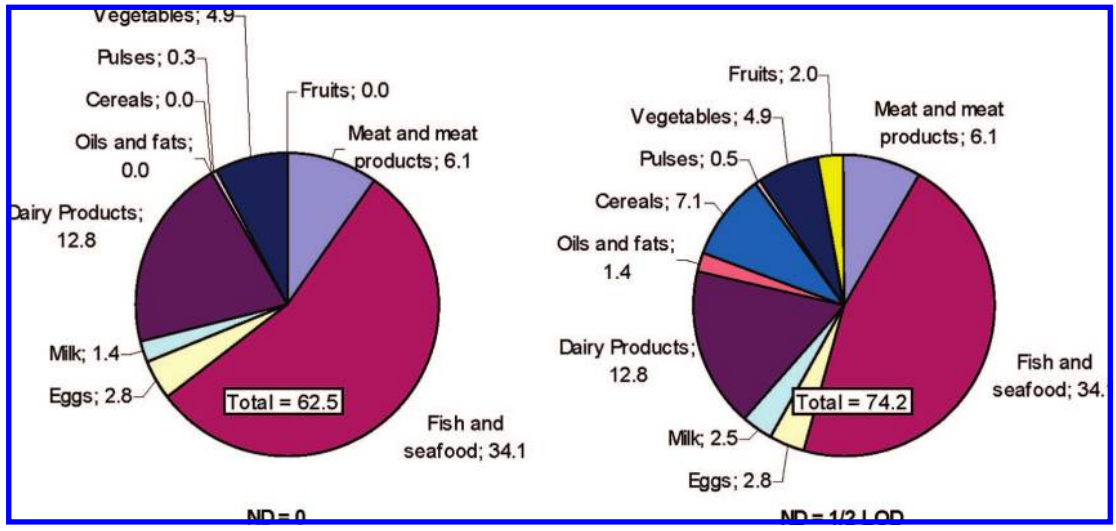

Figure 2. Dietary intake (ng/day) of PFOS from each food group by an adult man (70 kg of body weight) of Tarragona County (Catalonia, Spain).

in general terms to pulses, oils and fats, and fruits. With respect to the estimated intakes of PFOA and PFHpA by the same age/gender group of population (data not shown), it must be noted that the values are merely illustrative, having a reduced significance as, in fact, both PFCs were above the LOD in the whole milk samples only.

DISCUSSION

The concentrations found in the food items here analyzed are, in general terms, comparable to or somewhat lower than those found in the few previous dietary studies of PFCs in assorted foods. In a U.K. 2004 TDS, PFOS was detected in only 4 of 20 different analyzed food groups. PFOS was found at concentrations above the limit of detection in the potatoes (10 ng/g of fresh weight), canned vegetables (2 ng/g of fresh weight), eggs (1 ng/g of fresh weight), and sugars and preserves (1 ng/g of fresh weight). In turn, PFOA was detected in only the potatoes (1 ng/g of fresh weight). Other PFCs were found only occasionally, although 10 different PFCs were detected in the potatoes (*23*). Detection limits for other food groups in the U.K. TDS were significantly higher and in the range of 0.5−20 ng/g of fresh weight for PFOS. In the present study, PFOS was detected at mean levels from <0.014 to 0.654 ng/g of fresh weight.

In the U.K. 2004 TDS, the estimated average adult dietary intake for PFOS (upper and lower bound values) was 100 ng/kg of body weight/day, whereas the high-level dietary intake also for adults was 200 or 30 ng/kg of body weight/day (upper and lower bound values, respectively) (*23*). In the current survey, the dietary intake of PFOS for a standard adult man (70 kg of body weight) was 1.06 or 0.89 ng/kg of body weight/day (upper and lower bound figures, respectively).

Oral reference dose (RfD) values for PFCs have not yet been established by any government or regulatory agency. However, provisional RfDs for PFOS and PFOA have been estimated on the basis of a rat chronic carcinogenicity study and a rat multigenerational study, respectively (*20*). On this basis, the provisional RfDs would be 25 and 333 ng/kg/day for PFOS

and PFOA, respectively. Therefore, the current dietary intakes of PFOS and PFOA by all age/sex groups of the population of Tarragona County are notably lower than the provisional RfD values for PFOS and PFOA.

Recently, Tittlemier et al. (*24*) estimated the dietary exposure to perfluorinated carboxylates and PFOS for Canadians via the consumption of meat, fish and seafood, fast foods, and food items prepared in their packaging. Food samples were collected from 1992 to 2004 and prepared as for consumption. Nine composites contained detectable levels of PFCs: four meat-containing samples, three fish and shellfish, one fast food, and one microwave popcorn. PFOS and PFOA were detected the most frequently, with concentrations ranging from 0.5 to 4.5 ng/g of fresh weight. The mean dietary intake of total perfluorocarboxylates and PFOS in this Canadian study was estimated to be 250 ng/day (4.0 ng/kg of body weight/day; i.e., 250 ng/day divided by an average body weight of 62 kg) using results from the 2004 TDS composites. This intake is about 4 times that of our current study, and it was considerably lower (approximately 25 times) than the dietary intake estimated from the 2004 U.K. TDS (*23*). Tittlemier et al. (*24*) noted that concentrations of PFCs in composite samples were generally lower than those found in individual food items because PFC-free food items in the same composite diluted the total concentration of PFCs. Generally, highest concentrations in our study were found in marine food composites, indicating this group as the most important for dietary exposure of PFCs. For PFOS, this was also noted in the present study (**Table 2**). In addition, Falandysz et al. (*19*) reported that, in Poland, individuals with a high fish intake diet were found to have higher blood levels of PFCs than other subpopulations. Specifically, subjects who declared a high fish intake in their diet (mainly Baltic fish) on average contained the highest load of 10 PFCs when compared with the remaining subpopulations of the study (*19*).

In samples of a PFC-contaminated area of Germany, Kraft et al. (*21*) analyzed the levels of PFCs in cereals and grass ($n = 15$) and cow's milk ($n = 9$). In most cereal and grass samples ($n = 11$), concentrations were below the detection limit or between 2.0 and 10 ng of PFOA/g ($n = 4$), whereas in cow's milk PFC levels were not detectable. In another recent study, among nine analyzed PFCs, PFOS was the predominant fluorochemical found in seven types of seafood including fish, molluscs, crabs, shrimps, oysters, mussels, and clams, which were collected from fish markets in two cities of China (*20*). Concentrations of PFOS in seafood samples ranged from 0.3 to 13.9 ng/g of fresh weight.

In the present study, PFOA and PFHpA were above the LOD in two whole milk samples only and at low concentrations. The relatively current low levels found in most foodstuffs are in agreement with the comparatively low concentrations of PFOS and PFOA observed in the blood of residents of the same area (Tarragona County), which were similar to or lower than those found in other European countries and notably lower than those found in the United States (*2*). Tittlemier et al. (*24*) compared the dietary intake of PFOS and other PFCs with intakes of these compounds via other routes (air, water, dust, solution-treated carpeting). They concluded that diet is the most important source of PFCs: an estimated daily intake of 250 ng/day on a total from all sources of 410 ng/day. It is important to note that in the blood of Canadians, PFOS was also the main component among various analyzed PFCs, being detected at an average concentration of 28.8 ng/mL (*30*). This value is 4 times higher than the mean level of PFOS recently found in the population of Tarragona County, 7.6 ng/mL (*2*). These results suggest a correlation between dietary intake of PFOS and blood levels, as the dietary intake of PFOS by Canadians, 4.0 ng/kg of body weight/day (*24*) was also 4 times higher than that estimated in the present study, 1.06 ng/kg of body weight/day. However, it is not sufficiently clear if fresh foodstuffs are the main contributors to the levels of other PFCs in blood or whether food wrappers may be an important overlooked source of PFCs in humans. Thus, in our recent study on the concentrations of 13 PFCs in human blood, those of PFHxS, PFNA, PFOSA, PFDA, and PFUnDA were also above the detection limit, with the concentration of PFHxS preceded only by that of PFOS. Notwithstanding, in the current study PFHxS could not be detected in any of the analyzed food samples. In contrast, PFHpA, one of only three PFCs found in foodstuffs, could not be detected in blood.

Tittlemier et al. (*22*) determined the concentrations of perfluorooctanesulfonamides in Canadian TDS composite food samples collected between 1992 and 2004. They noted that the most significant dietary sources of perfluorooctanesulfonamides were foods packaged in paper products that were often treated with perfluoroalkyl compounds for oil resistance, such as French fries and pizza. Because perfluorooctanesulfonamides can be biotransformed to the more persistent PFOS, it would be very likely that dietary exposure to perfluorooctanesulfonamides was also an indirect route of exposure of Canadians to PFOS (*22*). In addition, Sinclair et al. (*31*) suggested that some PFOA residuals in nonstick cookware or microwave popcorn bags could remain after the fabrication process and be released under normal cooking temperatures. In a previous study, Begley et al. (*32*) concluded that fluoropolymer food-contact materials did not appear to be a significant source of PFCs (e.g., PFOA) relative to paper that will migrate to food and be consumed. When exposing rats to polyfluoroalkyl phosphate surfactants (PAPS), nonpolymeric fluorinated surfactants approved for application to food-contact paper products, D'eon and Mabury (*33*) showed a link between PAPs ingestion and in vivo production of perfluorinated acids.

In summary, the current study estimated for the first time the dietary intake of PFCs for various age/gender groups of a nonoccupationally exposed general population in Spain. The intakes of PFOS, and those of PFOA and PFHpA, the only PFCs that could be detected in at least one composite sample, were lower than that recently reported for Canada (*24*) and considerably lower than that previously reported for the United Kingdom (*23*), the only two countries where, to date, data concerning this issue have been reported. The differences between the results of our survey and those of the Canadian study may be mainly due to the food items included in the respective surveys, as well as to the fact that in Canada the analyzed foods were prepared for consumption, and was based on total perfluorocarboxylates and PFOS. Notwithstanding, the large difference between the U.K. 2004 TDS and the current one, as well as between the U.K. and Canadian studies, is rather hard to explain. It might be also due, at least in part, to the selection of the food group samples and the detection limits that were determined, as well as the parameters of the exposure analysis. However, this seems not to be a sufficient reason to explain such large differences.

There are still an important number of questions and knowledge gaps that are worthy of being investigated. In this regard, we have just initiated an additional study with two main goals: The first is to determine the levels of PFCs in

drinking water and in additional foodstuffs that, although not widely consumed, have compositions indicating possible contamination. These samples could explain why some PFCs not detected in the current foodstuffs were found in human blood (*2*). The second goal is to establish the role that food processing and packaging can play as a source of PFCs through dietary intake.

LITERATURE CITED

(1) Calafat, A. M.; Kuklenyik, Z.; Caudill, S. P.; Reidy, J. A.; Needham, L. L. Perfluorochemicals in pooled serum samples from United States residents in 2001 and 2002. *Environ. Sci. Technol.* **2006**, *40*, 2128–2134.

(2) Ericson, I.; Gomez, M.; Nadal, M.; van Bavel, B.; Lindström, G.; Domingo, J. L. Perfluorinated chemicals in blood of residents in Catalonia (Spain) in relation to age and gender: a pilot study. *Environ. Int.* **2007**, *33*, 616–623.

(3) Giesy, J. P.; Kannan, K. Global distribution of perfluorooctane sulfonate in wildlife. *Environ. Sci. Technol.* **2001**, *35*, 1339–1342.

(4) Kannan, K.; Tao, L.; Sinclair, E.; Pastva, S. D.; Jude, D. J.; Giesy, J. P. Perfluorinated compounds in aquatic organisms at various trophic levels in a Great Lakes food chain. *Arch. Environ. Contam. Toxicol.* **2005**, *48*, 559–566.

(5) Kärrman, A.; Langlois, I.; van Bavel, B.; Lindström, G.; Oehme, M. Identification and pattern of perfluorooctane sulfonate (PFOS) isomers in human serum and plasma. *Environ. Int.* **2007**, *33*, 782–788.

(6) Kärrman, A.; Ericson, I.; van Bavel, B.; Darnerud, P. O.; Aune, M.; Glynn, A.; Lignell, S.; Lindström, G. Exposure of perfluorinated chemicals through lactation: levels of matched human milk and serum and a temporal trend, 1996–2004, in Sweden. *Environ. Health Perspect.* **2007**, *115*, 226–230.

(7) Loganathan, B. G.; Sajwan, K. S.; Sinclair, E.; Senthil Kumar, K.; Kannan, K. Perfluoroalkyl sulfonates and perfluorocarboxylates in two wastewater treatment facilities in Kentucky and Georgia. *Water Res.* **2007**, *41*, 4611–4620.

(8) Olsen, G. W.; Burris, J. M.; Ehresman, D. J.; Froehlich, J. W.; Seacat, A. M.; Butenhoff, J. L.; Zobel, L. R. Half-life of serum elimination of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in retired fluorochemical production workers. *Environ Health Perspect.* **2007**, *115*, 1298–305.

(9) Butenhoff, J. L.; Olsen, G. W.; Pfahles-Hutchens, A. The applicability of biomonitoring data for perfluorooctanesulfonate to the environmental public health continuum. *Environ Health Perspect.* **2006**, *114*, 1776–1782.

(10) Fuentes, S.; Colomina, M. T.; Vicens, P.; Franco-Pons, N.; Domingo, J. L. Concurrent exposure to perfluorooctane sulfonate and restraint stress during pregnancy in mice: effects on postnatal development and behavior of the offspring. *Toxicol. Sci.* **2007**, *98*, 589–598.

(11) Fuentes, S.; Colomina, M. T.; Vicens, P.; Domingo, J. L. Influence of maternal restraint stress on the long-lasting effects induced by prenatal exposure to perfluorooctane sulfonate (PFOS) in mice. *Toxicol. Lett.* **2007**, *171*, 162–170.

(12) Lau, C.; Anitole, K.; Hodes, C.; Lai, D.; Pfahles-Hutchens, A.; Seed, J. Perfluoroalkyl acids: a review of monitoring and toxicological findings. *Toxicol. Sci.* **2007**, *99*, 366–94.

(13) Miyake, Y.; Yamashita, N.; Rostkowski, P.; So, M. K.; Taniyasu, S.; Lam, P. K.; Kannan, K. Determination of trace levels of total fluorine in water using combustion ion chromatography for fluorine: a mass balance approach to determine individual perfluorinated chemicals in water. *J. Chromatogr., A* **2007**, *1143*, 98–104.

(14) Calafat, A. M.; Needham, L. L.; Kuklenyik, Z.; Reidy, J. A.; Tully, J. S.; Aguilar-Villalobos, M.; Naher, L. P. Perfluorinated chemicals in selected residents of the American continent. *Chemosphere* **2006**, *63*, 490–496.

(15) Jin, Y.; Saito, N.; Harada, K. H.; Inoue, K.; Koizumi, A. Historical trends in human serum levels of perfluorooctanoate and perfluorooctane sulfonate in Shenyang, China. *Tohoku J. Exp. Med.* **2007**, *212*, 63–70.

(16) Harada, K.; Koizumi, A.; Saito, N.; Inoue, K.; Yoshinaga, T.; Date, C.; Fujii, S.; Hachiya, N.; Hirosawa, I.; Koda, S.; Kusaka, Y.; Murata, K.; Omae, K.; Shimbo, S.; Takenaka, K.; Takeshita, T.; Todoriki, H.; Wada, Y.; Watanabe, T.; Ikeda, M. Historical and geographical aspects of the increasing perfluorooctanoate and perfluorooctane sulfonate contamination in human serum in Japan. *Chemosphere* **2007**, *66*, 293–301.

(17) Midasch, O.; Schettgen, T.; Angerer, J. Pilot study on the perfluorooctanesulfonate and perfluorooctanoate exposure of the German general population. *Int. J. Hyg. Environ. Health* **2006**, *209*, 489–496.

(18) Kannan, K.; Corsolini, S.; Falandysz, J.; Fillmann, G.; Kumar, K. S.; Loganathan, B. G.; Mohd, M. A.; Olivero, J.; Wouwe, N. V.; Yang, J. H.; Aldous, K. M. Perfluorooctanesulfonate and related fluorochemicals in human blood from several countries. *Environ. Sci. Technol.* **2004**, *38*, 4489–4495.

(19) Falandysz, J.; Taniyasu, S.; Gulkowska, A.; Yamashita, N.; Schulte-Oehlmann, U. Is fish a major source of fluorinated surfactants and repellents in humans living on the Baltic Coast? *Environ. Sci. Technol.* **2006**, *40*, 748–751.

(20) Gulkowska, A.; Jiang, Q.; So, M. K.; Taniyasu, S.; Lam, P. K.; Yamashita, N. Persistent perfluorinated acids in seafood collected from two cities of China. *Environ. Sci. Technol.* **2006**, *40*, 3736–3741.

(21) Kraft, M.; Kamphausen, R.; Shulze-Wiehenbrauck, H. Environmental pollution with perfluorinated chemicals in North-Rhine-Westphalia, Germany. Health risks for the public? In Proceedings of the Conference on Perfluroalkyl Acids and Related Chemistries: Toxicokinetics and Mode of Action, Feb 14−16, 2007; Society of Toxicology: Arlington, VA, 2007;BM-8.

(22) Tittlemier, S. A.; Pepper, K.; Edwards, L. Concentrations of perfluorooctanesulfonamides in Canadian total diet study composite food samples collected between 1992 and 2004. *J. Agric. Food Chem.* **2006**, *54*, 8385–8389.

(23) U.K. Food Standards Agency. Fluorinated Chemicals: U.K. Dietary Intakes. Food Survey Information Sheet 11/06. 2006; available at http://www.food.gov.uk/science/surveillance/fsisbranch2006/fsis1106, accessed Dec 20, 2007.

(24) Tittlemier, S. A.; Pepper, K.; Seymour, C.; Moisey, J.; Bronson, R.; Cao, X. L.; Dabeka, R. W. Dietary exposure of Canadians to perfluorinated carboxylates and perfluorooctane sulfonate via consumption of meat, fish, fast foods, and food items prepared in their packaging. *J. Agric. Food Chem.* **2007**, *55*, 3203–3210.

(25) Bocio, A.; Domingo, J. L. Daily intake of PCDD/PCDFs in foodstuffs consumed in Tarragona, Spain. A review of recent studies (2001–2003) on human PCDD/PCDF exposure through the diet. *Environ. Res.* **2005**, *97*, 1–9.

(26) Powley, C. R.; George, S. W.; Ryan, T. W.; Buck, R. C. Matrix effect-free analytical methods for determination of perfluorinated carboxylic acids in environmental matrices. *Anal. Chem.* **2005**, *77*, 6353–6358.

(27) Taniyasu, S.; Kannan, K.; So, M. K.; Gulkowska, A.; Sinclair, E.; Okazawa, T.; Yamashita, N. Analysis of fluorotelomer alcohols, fluorotelomer acids, and short- and long-chain perfluorinated acids in water and biota. *J. Chromatogr., A* **2005**, *1093*, 89–97.

(28) van Leeuwen, S. P.; Kärrman, A.; van Bavel, B.; de Boer, J.; Lindström, G. Struggle for quality in determination of perfluorinated contaminants in environmental and human samples. *Environ. Sci. Technol.* **2006**, *40*, 7854–7860.

(29) CEC. Commission of the European Communities. Commission Decision 2002/657/EC implementing council Directive 96/23/EC concerning the performance of analytical methods and the interpretation of results. *Off. J. Eur. Communities* **2002**, *L221*, 08–36.

(30) Kubwabo, C.; Vais, N.; Benoit, F. M. A pilot study on the determination of perfluorooctanesulfonate and other perfluorinated compounds in blood of Canadians. *J. Environ. Monit.* **2004**, *6*, 540–545.

(31) Sinclair, E.; Kim, S. K.; Akinleye, H. B.; Kannan, A. Quantitation of gas-phase perfluoroalkyl surfactants and fluorotelomer alcohols released from nonstick cookware and microwave popcorn bags. *Environ. Sci. Technol.* **2007**, *41*, 1180–1185.

(32) Begley, T. H.; White, K.; Honigfort, P.; Twaroski, M. L.; Neches, R.; Walker, R. A. Perfluorochemicals: potential sources of and migration from food packaging. *Food Addit. Contam.* **2005**, *22*, 1023–1031.

(33) D'eon, J. C.; Mabury, S. A. Production of perfluorinated carboxylic acids (PFCAs) from the biotransformation of polyfluoroalkyl phosphate surfactants (PAPS): exploring routes of human contamination. *Environ. Sci. Technol.* **2007**, *41*, 4799–4805.

Received for review November 6, 2007. Revised manuscript received December 20, 2007. Accepted December 21, 2007. This study was financially supported by the Department of Health, Generalitat de Catalunya, Barcelona, Catalonia, Spain.

JF0732408