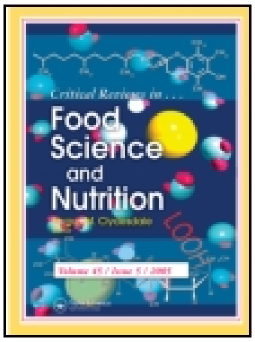

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Nutrients and Chemical Pollutants in Fish and Shellfish. Balancing Health Benefits and Risks of Regular Fish Consumption

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Dietary patterns and lifestyle factors are clearly associated with at least five of the ten leading causes of death, including coronary heart disease, certain types of cancer, stroke, non-insulin insulin-dependent diabetes mellitus, and atherosclerosis. Concerning specifically fish and seafood consumption, its beneficial health effects in humans are clearly supported by an important number of studies performed in the last 30 years. These studies have repeatedly linked fish consumption, especially those species whose contents in omega-3 fatty acids are high, with healthier hearts in the aging population. The nutritional benefits of fish and seafood are also due to the content of high-quality protein, vitamins, as well as other essential nutrients. However, a number of studies, particularly investigations performed in recent years, have shown that the unavoidable presence of environmental contaminants in fish and shellfish can also mean a certain risk for the health of some consumers. While prestigious international associations as the American Heart Association have recommended eating fish at least two times (two servings a week), based on our own experimental results, as well as in results from other laboratories, we cannot be in total agreement with that recommendation. Although a regular consumption of most fish and shellfish species should not mean adverse health effects for the consumers, the specific fish and shellfish species consumed, the frequency of consumption, as well as the meal size, are essential issues for adequately balancing the health benefits and risks of regular fish consumption.

Keywords Fish and shellfish, omega-3 fatty acids, environmental pollutants, dietary intake, health risks, health benefits

INTRODUCTION

Omega-3 Fatty Acids in Fish and Health

Dietary patterns and lifestyle factors are clearly associated with at least five 5 of the ten 10 leading causes of death, including coronary heart disease, certain types of cancer, stroke, non-insulin insulin-dependent diabetes mellitus, and atherosclerosis (Doyle, 2007; Brunner et al., 2008; Nettleton et al., 2009; Giovannini and Masella, 2012). With respect to the dietary habits, a proper balance of the intake of nutrients, concurrently with the avoidance of their excess or deficiency, is essential to keep a good health and to avoid lifestyle-related diseases (Hennig et al., 2007a, b, 2012). While poor dietary habits such as high intake of processed foods rich in fat and low intake of fruits and vegetables, linked to sedentary lifestyles, clearly contribute to worsening the quality of life, it is also well known that eating fish is potentially good for human health. The beneficial effects of regular fish and seafood consumption are supported by an important number of studies performed in the last 30 years. These studies have repeatedly linked fish consumption, especially those species whose content in omega-3 polyunsaturated fatty acids (PUFAs) is high, with healthier hearts in the aging population, an effect derived from triglyceride lowering and cardiovascular disease (CVD) reduction (Kris-Etherton et al., 2002; Mente et al., 2009; Russo, 2009; Abeywardena and Patten, 2011; Davidson et al., 2011; McManus et al., 2011; Musa-Veloso et al., 2011; Delgado-Lista et al., 2012; Hu and Willett, 20012; Kelley and Adkins, 2012; Siriwardhana et al., 2012). In addition to the beneficial effects of omega-3 fatty acids on heart, other positive effects of their regular intake have been also shown. For

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example, recently Pilkington et al. (2011) reported that omega-3 PUFAs had potential to protect the skin from ultraviolet radiation injury through a range of mechanisms.

In spite of the beneficial effects of omega-3 fatty acids, several areas of uncertainties remain. Thus, the optimal intake of omega-3 fatty acids is not firmly established, nor is their mechanism of action fully understood, while some studies have even shown conflicting results (Hooper et al., 2006; Järvinen et al., 2006; Domingo, 2007; Filion et al., 2010; Chen et al., 2011; de Lorgeril and Salen, 2012).

The benefits of fish and seafood consumption on health are mainly due to the content of high-quality protein (fish and seafood provide approximately 17% of the total animal protein and 6% of all protein consumed by humans), vitamins, as well as other essential nutrients. Moreover, unlike fatty meat products, fish are not high in saturated fat. Fatty fish are especially high in two kinds of omega-3 PUFAs: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). It has been estimated that the consumption of one fatty fish meal per day would result in an omega-3 fatty acid (EPA and DHA) intake of approximately 900 mg/day, an amount that beneficially would affect CHD mortality rates in patients with coronary disease (Kris-Etherton et al., 2002). In addition to CHD, omega-3 fatty acids (particularly EPA) have also protective effects in reducing arrhythmias and thrombosis, lowering plasma triglyceride levels, reducing blood clotting tendency, decreasing risks of certain cancers, and even preventing cognitive decline and dementia (Kris-Etherton et al., 2002). For coronary disease risk reduction and triglyceride lowering primarily, various organizations worldwide have made dietary recommendations for EPA and DHA from fish consumption (Kris-Etherton et al., 2002, 2009; Sydenham et al., 2012; van den Elsen et al., 2012; Wang et al., 2012). Specific recommendations have been also made for DHA intake for pregnant women, infants, and vegetarians/vegans. It is widely accepted that long-chain PUFAs are important for the growth and development of infants. Sufficient DHA during pregnancy and after birth is essential because it is the predominant structural fatty acid in the central nervous system and retina, being its availability crucial for brain development. According to the World Association of Perinatal Medicine, the Early Nutrition Academy, and the Child Health Foundation, the recommendations for long-chain PUFAs are the following (see Kris-Etherton et al., 2009): (1) pregnant and lactating women should achieve an average daily intake of least 200–300 mg of DHA, and (2) infant formula should provide DHA at levels between 0.2 and 0.5 weight (%) of total fat, and with minimum amounts of arachidonic acid equivalent to the amount of DHA. Dietary long-chain PUFAs should continue after the first 6 six months of life, but quantitative recommendations are not made due to insufficient evidence.

For the general population, a Dietary Reference Intake (DRI), more specifically an Adequate Intake (AI), was set for α-linolenic acid (ALA) by the Institute of Medicine (IOM) of the US National Academies. This amount is based on an intake that supports normal growth and neural development. Although there is no DRI for EPA and DHA, the US National Academies have recommended that approximately 10% of the Acceptable Macronutrient Distribution Range (AMDR) for ALA can be consumed as EPA and/or DHA (Kris-Etherton et al., 2009). This recommendation represents a current mean intake for EPA and DHA in the USA of approximately 100 mg/day, which is much lower than what many groups worldwide are currently recommending. The American Heart Association (AHA) recommends consumption of at least two 3-oz servings of fish per week, with a special suggestion for fatty fish (Kris-Etherton et al., 2002). In spite of the well-documented literature concerning the benefits of dietary omega-3 PUFAs on total mortality and combined cardiovascular effects, certain doubts about these effects, as well as on the potential protective reduction of cancer risk, have been raised (Domingo, 2007).

Based on the AHA's strategy for cardiovascular diseaseCVD risk reduction in the general population, in 2006 the AHA Nutrition Committee published a document where recommendations to improve diet and lifestyle were included (AHANC, 2006). Among these, fish consumption (especially oily fish) at least twice a week, was one of the main dietary recommendations. In 2004, Mahaffey, 2004 published a review on EPA and DHA concentrations in a number of fish and shellfish species. The highest concentrations were found in mackerel followed by salmon, while the lowest levels corresponded to lemonfishlemon fish and tiger sharks, and Malabar sole. Moreover, Ismail (2005) reported that shark, herring and mackerel, followed by sardine and salmon, were the edible marine species with the highest levels of omega-3 fatty acids. In a previous review, Sidhu (2003) found that mackerel (from the Atlantic), herring (from the Atlantic and Pacific), and European anchovy were species rich in omega-3 fatty acids, while salmon from various origins reached similar values to that of anchovy. In turn, after reviewing a number of studies, Smith and Sahyoun (2005) found that mackerel and salmon contained the highest PUFA (EPA + DHA) levels, while clams and lobsters showed the lowest concentrations.

With respect to the reduced risk of CHD derived from fish consumption, the possible contribution of some other nutrients in the fish, and/or other factors related to healthy lifestyle cannot be excluded (He et al., 2004). Notwithstanding, various investigations have stated that any fish consumption confers risk reduction of CHD compared to no fish consumption (He et al., 2004; König et al., 2005; Mozaffarian and Rimm, 2006).

Environmental Pollutants in Fish and Health

Certain dietary habits can also contribute to compromised health by being a source of exposure to environmental toxic contaminants. Many of these pollutants are fat soluble, and thus, any fatty food often contains higher levels of persistent organic pollutants than does vegetable matter. Nutrition can dictate the lipid milieu, oxidative stress, and antioxidant status within cells and the modulation of these parameters by an individual's nutritional status may have profound effects on biological processes. It may also influence the effects of environmental pollutants to cause disease or dysfunction (Hennig et al., 2007a, b, 2012).

An issue of notable concern related with a frequent fish and seafood consumption is the health risks potentially derived from exposure to chemical pollutants contained in those species. Until recently, methylmercury and polychlorinated biphenyls (PCBs) were the contaminants to which more attention had been paid. However, a number of recent studies have shown that fish and shellfish can be also a potential source of human exposure to other environmental contaminants, whose potential toxicity is well known. Among these pollutants stand out metals, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDFs) and polycyclic aromatic hydrocarbons (PAHs), but also other organohalogenated contaminants such as polybrominated diphenyl ethers (PBDEs), polychlorinated diphenyl ethers (PCDEs), polychlorinated naphthalenes (PCNs), and perfluorinated compounds (PFCs). Information on exposure and adverse effects of some of these organic pollutants in humans is still relatively limited. As above commented, in recent years a number of authors have reasserted the important cardioprotective effects of omega-3 fatty acids, especially the longer-chain fatty acids from marine sources, suggesting that their consumption should be increased in the diet to decrease cardiovascular risk significantly. However, caution in the consumption of certain fish species depending on their levels of environmental pollutants has been also suggested (Engler and Engler, 2006).

Human Exposure to Inorganic and Organic Environmental Pollutants

Among inorganic pollutants, toxic elements such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) are widely dispersed in the environment and persist for long periods in different media. These elements have no beneficial effects on humans, and there is no known homeostasis mechanism for them. Toxicity and threats to human health from any element are a function of their concentrations. However, it is well known that chronic exposure to As, Cd, Hg, and Pb at relatively low levels can cause adverse effects. Some subjects are basically exposed to toxic elements in the workplace. However, for most people the main exposure to metals occurs through the diet. Consequently, information about dietary intake of metals is essential to assess the human health risks they pose. On the other hand, persistent organic pollutants (POPs) are lipophilic, bioaccumulative, and semi-volatile toxic compounds. Some POPs are produced deliberately in a number of industrial activities, while others are formed accidentally or released as by-products of various activities, such as combustion. POPs are found in several worldwide ecosystems in complex mixtures, as a result of agricultural, industrial, and other human activities. They mean a significant health problem due to bioaccumulation through the food web and their potentially highly toxic effects. While the carcinogenic nature of some POPs is already well established, others are endocrine disruptors with a number of adverse effects on hormone homeostasis (Li et al., 2006; White and Birnbaum, 2009; Domingo, 2012a, b).

Human health risks derived from environmental exposure to metals and POPs continue being the subject of considerable research, regulation, and debate. It is well known that human exposure to metals and POPs may occur via various routes: dermal absorption, air inhalation, ingestion of contaminated soils, and principally through daily intake of foodstuffs. According to a number of studies, more than 90–95% of the toxic metals and POPs to which humans are exposed are originated in food, and approximately 90% of this normally comes from animal sources. Particular attention needs to be paid to fish. Although in general, fish and other seafood represent on average only relatively small percentages of the human diet, it has been demonstrated that the frequent consumption of these marine species may be one of the major routes for chemical pollutants to enter the human body (Bocio et al., 2005, 2007; Domingo, 2012a, b).

With respect to POPs, PCDD/PCDFs, together with PCBs, are the most well-known and studied. PCDD/PCDFs are among the most hazardous environmental contaminants, being toxic at extremely tiny amounts and bioaccumulating in humans, while PCBs are ubiquitous in the environment, being found in adipose tissue and blood of the general population, as well as in breast milk. The World Health Organization (WHO) identified various PCB congeners whose toxicity levels were similar to those of PCDD/PCDFs, and assigned to them toxic equivalency factors (TEFs) for the calculation of toxic equivalents (TEQ). On the other hand, although much less investigated than PCDD/PCDFs and PCBs, PCNs, PCDEs, and PBDEs are other polyhalogenated POPs with long half-lives, which are also widely distributed in the environment. Several PCN congeners display toxicities similar to the most toxic and well-studied dioxin, 2,3,7,8,-TCDD, through mechanisms mediated by aryl hydrocarbon receptor (AhR), while the major toxicity mechanism of PCDEs seems to be also related to their ability to bind to and activate AhR. In turn, PBDEs are a class of brominated flame retardants that have been produced in notable quantities and widely used in a variety of consumer products. In recent years, a marked increase in the levels of PBDEs in human tissues and fluids, especially breast milk, has been observed in some countries. As with other structurally similar classes of POPs, at least some PBDE congeners are endocrine disrupters. Although information is still rather scarce, for non-occupationally exposed individuals dietary intake is very probably the main route of exposure to PCNs, PCDEs, and PBDEs, as it also occurs for metals, PCDD/PCDFs and PCBs.

BALANCING HUMAN HEALTH BENEFITS AND RISKS OF FISH CONSUMPTION

In recent years, monitoring programs have been developed in various countries in order to determine the presence of chemical contaminants in foodstuffs, and to assess human health risks resulting from dietary exposure to these pollutants. Although the number of reported studies is notable, most investigations have been focused only on a reduced number of contaminants. For fish and seafood in particular, they have been mainly focused on methylmercury, PCBs, and more recently also on PCDD/PCDFs (Burger and Gochfeld, 2009; Mahaffey et al., 2011; Stern, 2007). With the objective of elucidating the relative risks and benefits of fish consumption, various authors have reviewed the scientific evidence for adverse and beneficial effects of that consumption. The revisions have been generally based on the assumption that fish and seafood intake should have clear health benefits, but also certain risks, as fish and shellfish species may contain chemical contaminants. One of the most referenced reviews on this issue (cited by 542 in Scopus, September 13, 2012) is that published by Mozaffarian and Rimm (2006). It was concluded that for major health outcomes among adults, based on both the strength of the evidence and the potential magnitude of the effect, the benefits of fish intake should exceed the risks. In fact, these authors remarked that in adults, the benefits of modest fish consumption (one to two servings per week) outweighed the risks, excepting only a few selected fish species, among women of childbearing age. However, that review has an important limitation concerning pollutants, as only methylmercury, PCDD/PCDFs and PCBs were included in the revision. Potentially toxic elements such as As, Cd, or Pb, as well as PAHs, a group of pollutants with known carcinogens in humans, were not reviewed. Other environmental contaminants such as PCDEs and PCNs, some congeners of which could act as dioxin-like compounds, or PBDEs, with potential toxic effects in humans, and PFCs among others, were not included in the review. Therefore, the conclusions may not be generalized, and they should be strictly limited only to the few contaminants reviewed.

In recent years, the Sioen's group from the University of Ghent (Belgium) has carried out a wide and comprehensive research on the nutritional-toxicological conflict related to fish and seafood consumption in different regions worldwide. A complete information on the most relevant conclusions obtained by that group, regarding the evaluation of benefits and risks related to food consumption, can be found in Sioen et al. (2007, 2008a, b, c) and Verbeke et al. (2008). These researchers performed also an exposure assessment using seafood consumption data from the Global Environment Monitoring System—Food Contamination Monitoring and Assessment Program (commonly known as GEMS/Food), being part of the Food Safety Department of the WHO, as well as nutrient and contaminant concentration data (Sioen et al., 2009). The results showed that Japan, Korea, Madagascar, and Philippines had the highest fish and seafood consumption, followed by the Nordic-Baltic countries and South-East Asia. It was observed that while the intake of nutrients such as high omega-3 fatty acids and vitamin D would still be lower than the recommendations, from the toxicological side the data indicated that none of the fish seafood groups had a median contaminant concentration above the European Union (EU) maximum limits. The results of Sioen et al. (2009) showed that in some countries the contaminant intake exceeded the international health-based guidance values, mainly focusing on sensitive subpopulations. However, it was found that when using less stringent guidance values relevant for non-sensitive subpopulations, the benefits of increased fish and seafood consumption would outweigh the health risks.

In 2012, a number of authors have reviewed data on risk-benefit analysis of fish and shellfish consumption. I here include the revisions that we consider more relevant. Sirot et al. (2012) determined in what quantities seafood consumption would provide nutritional benefits, while minimizing the risks linked to contaminants. An optimum consumption level was calculated for adults in order to minimize inorganic arsenic exposure and to increase vitamin D intake. It should guarantee that the consumer would reach the recommended intake of omega-3 PUFAs, Se and I, remaining below the tolerable upper intakes methylmercury, Cd, PCDD/PCDFs, and PCBs. According to the authors, this consumption level, which means approximately 200 g/week of certain fatty fish species, and approximately 50 g/week of lean fish, mollusks, and crustaceans, should be considered to determine food consumption recommendations in a public health perspective. Hellberg et al. (2012) reviewed the risk-benefit of seafood consumption primarily focused on risk-benefit assessments. The authors found that most studies remarked that the benefits far outweigh the risks among the general population, especially when a variety of fish is consumed at least twice per week. However, for certain populations (for examplee.g., pregnant women and young children), a more targeted approach is warranted in order to ensure that these groups consume fish that are low in contaminants but high in omega-3 fatty acids. On the other hand, Oken et al. (2012) summarized the issue of fish consumption choice from toxicological, nutritional, ecological, and economic points of view; identified areas of overlap and disagreement among these viewpoints, and reviewed effects of previous fish consumption advisories. These authors commented that although fish provides a rich source of protein and other nutrients, because of contamination by methylmercury and other toxicants, higher fish intake often leads to greater toxicant exposure. Therefore, they concluded highlighting the importance of a clear and simple guidance to effect desired changes. The authors also commented that more comprehensive advice might be developed to describe the multiple impacts of fish consumption (Oken et al., 2012).

Anyhow, the benefit risk-analysis is often a complicated process, as benefit-risk evaluations tend to be skewed towards acceptance of all that is traditional and well-known (benefits), and rejection or suspicion towards anything that is novel or highly processed (risks) regardless of real risks. Recent and interesting information on the state of the art on benefit-risk analysis can be found in Pohjola et al. (2012), Tijhuis et al., (2012), Ueland et al. (2012) and Verhagen et al. (2012).

A general conclusion of the aforementioned reviews seems to be that "*the benefits of fish intake exceed the risks*.". However, as above commented, most reviews included only a few contaminants. Another gap is the reduced number of species analyzed in most surveys, which were in general limited to few species such as salmon, tuna, and other big predators, as well as bivalves such as mussels and clams. It must be also remarked that in the great majority of reports found in the scientific literature there is not any information on the temporal trends in the concentrations of pollutants in the fish and seafood species analyzed.

A CASE-STUDY: CATALONIA, SPAIN

In 2000, we initiated in our laboratory an extensive program aimed at determining the daily intake of several chemical pollutants by the general population of Catalonia, Spain. In that program, we included the inorganic elements As, Cd, Hg, and Pb (Llobet et al., 2003a), hexachlorobenzene (Falcó et al., 2004), PCNs (Domingo et al., 2003), PCDD/PCDFs (Llobet et al., 2003b), PCBs (Llobet et al., 2003c), PBDEs (Bocio et al., 2003), and PCDEs (Bocio et al., 2004), as well as PAHs (Falcó et al., 2003). Initially, the group of fish and seafood included only samples of fresh hake, sardine, and mussels, together with tinned tuna and sardine. The daily intakes of chemical contaminants from each foodstuff were also calculated by multiplying the concentration in a specific item by the estimated daily consumption of the respective food group. Finally, the total dietary intake of each pollutant was calculated by summing each product over all the food groups.

The results of the first study belonging to our surveillance program showed that the highest levels of most inorganic and organic pollutants were, in general terms, detected in fish and seafood, which contributed most to the intake of As, Hg, and Pb (Llobet et al., 2003a), as well as to that of PCDD/PCDFs and PCBs (Llobet et al., 2003b, c), and PBDEs and PCDEs (Bocio et al, 2003, 2004). The group of fish and seafood was also an important contributor to the daily intake of Cd (first contributor) (Llobet et al., 2003a), hexachlorobenzene (HCB) (second contributor) (Falcó et al., 2004), PAHs (third contributor) (Falcó et al., 2003), and PCNs (fourth contributor) (Domingo et al., 2003). However, in spite of the considerable magnitude and scope of that first survey, for technical and economic reasons the total number of samples analyzed for the different groups of foodstuffs was rather limited, being the levels of contaminants only determined in three species of fresh fish and two of tinned fish. For the purposes of establishing recommendations concerning human consumption of fish and other seafood, and taking into account the potential important contribution of marine species to the dietary intake of environmental pollutants, we extended our original study to the 14 most consumed fish and shellfish species by the population of Catalonia (sardine, tuna, anchovy, mackerel, swordfish, salmon, hake, red mullet, sole, cuttlefish, squid, clam, mussel, and shrimp). On the other hand, in that study we also determined the intake of EPA and DHA by the consumers. Salmon, mackerel, and red mullet were the species showing the highest content of these omega-3 fatty acids. The monthly fish consumption limits for human health endpoints based on the intake of these chemical contaminants were calculated for a 70 years exposure. Although most of the analyzed marine species should not mean adverse health effects for the consumers, our results showed that the type of fish and shellfish, the frequency of consumption, and the meal size, are essential aspects for balancing the health benefits and risks of regular fish consumption (Domingo et al., 2006; Falcó et al., 2006; Bocio et al., 2007; Llobet et al., 2006, 2007).

To establish quantitatively the health risks derived from the dietary intake of the aforementioned chemical pollutants versus the potential benefits derived of the intake of EPA and DHA, using on the results of our studies, we designed a simple online program, Ribepeix (http://www.tecnatox.cat) with these main objectives: (1) to know the intake of the measured metals and POPs by a certain individual through his/her specific weekly fish and seafood consumption, (2) to compare the intakes of each of those contaminants with their tolerable/acceptable intakes, when these are already established by international regulatory organisms, (3) to know the intake of the omega-3 fatty acids EPA and DHA, and to compare these intakes with those recommended by international heart associations, and (4) to establish suggestions on potential changes in the particular fish and seafood consumption habits of any individual, changes that should allow optimizing the balance between benefits (omega-3 fatty acids) and risks (chemical contaminants) derived from a regular consumption (Domingo et al., 2007a, b).

The use of Ribepeix shows that some fish and shellfish species contain metals and organic pollutants at amounts that hypothetically might mean health risks for certain consumers. The level of the risks would depend not only on the specific fish species, but also on the frequency of consumption, and the meal size. Thus, based on our experimental results (Domingo et al. 2007a, b), it seems obvious that various fish and shellfish species should not be consumed at the frequency, and size of meals, recommended by the AHA. This would be, for example, the case of tuna and swordfish for methylmercury, or for most fish species according to the levels of PCDD/PCDFs (plus DL-PCBs) and PAHs (Table 1), for which the potential health risks would exceed the expected benefits. The results of using Ribepeix are an evident example in human nutrition (fish consumption in the present case) where potential competing health risks and benefits clearly exist. A risk-benefit analysis of French high fish consumption was also evaluated by Guevel et al. (2008), based on the quality-adjusted life year (QALY) method. However, that analysis was only performed according to the risks of methylmercury and the benefits of omega-3 fatty acids. The confidence interval of the overall estimation had a negative lower bound, which would mean that the increase in fish consumption might have a negative impact due to methylmercury contamination.

As a conclusion derived from the use of Ribepeix, we cannot be in agreement with the general recommendations of the AHANC (2006) with respect to fish consumption, as no differences among species, frequency of consumption, and meal size are specified in those recommendations. Anyhow, we strongly recommend fish consumption for all their nutritional benefits including those from the omega-3 fatty acids. However, we must highlight the potential health risks directly derived from the concurrent exposure to chemical pollutants, risks that cannot be dismissed and/or considered as negligible. In this sense, Ribepeix, properly and adequately updated over the time, and adapted to the dietary habits of the different countries and/or geographical areas, could be a very useful tool to improve individually the balance between benefits and risks of fish consumption. As Ribepeix is easy of using, it may be useful not only for professionals (cardiologists, general physicians, nutritionists, toxicologists, etc.), but also for the general population.

Taking also benefit of the information obtained in our laboratory on the levels of chemical pollutants in other food groups, we extended Ribepeix to a second online program: Ribefood (http://130.206.36.67/ribefood/), which allows simultaneously to calculate the human intake of a long series of micro- and macronutrients contained in widely consumed foodstuffs (including the 14 fish and seafood species of Ribepeix), and with an important nutritional value, determining also simultaneously the dietary intake of metals, PCDD/PCDFs, PCBs, PBDEs, PCNs, etc. (Martí-Cid et al., 2008a).

After our initial studies, we have updated the concentrations of the above pollutants in fish and seafood, as well as in other food groups (Domingo et al., 2008; Martí-Cid et al., 2008b, c; Martorell et al., 2010, 2011; Perelló et al., 2012). Moreover, the levels of a number of PFCs have been also included. In a first survey on PFCs (Ericson et al., 2008), we determined the levels of some PFCs in a few food samples acquired in Catalan markets and supermarkets. Among the studied food items, white fish (hake, whiting blue, sea bass, monkfishand monkfish), seafood (mussel, and prawn), canned fish (tuna, sardine, musseland mussel), and blue fish (salmon, sardine, and tuna) were separately selected. PFOS, PFOA, and PFHpA were the only detected PFCs, being fish, followed by dairy products and meats, the main contributors to PFOS intake by the Catalan population. In a recent study, sardine, tuna, red mullet, hake, cuttlefish, mussel, and prawn were selected for analysis of 13 PFCs (Domingo et al., 2012). Among the measured PFCs, only seven compounds could be detected in at least one composite sample, while PFBuS, PFHxA, PFHpA, PFDS, PFDA, and PFTDA were undetected in all samples. PFOS was, by far, the PFC showing the highest mean concentration in fish and shellfish, being detected in all analyzed species with the exception of mussels. High PFOS levels were found in sardine and red mullet. With regard to PFOA, the highest concentrations were detected in prawn and hake (Domingo et al., 2012). Recent studies around the world have reported that fish and seafood are, generally, the foodstuffs with the highest PFC concentrations (Domingo, 2012b).

Similarly to the objective of our above studies, recently Hoekstra et al. (2012) reported a quantitative risk-benefit assessment of fish consumption, which was made expressing risks and benefits in the same health metric Disability Adjusted Life Year (DALY). The net health effects expressed in DALYs of two scenarios were compared. The reference scenario was the current fish intake of the Dutch population, which is less than what is recommended by the health authorities, while the alternative scenario described the health effects if the population consumes 200 g of fish per week, which is close to the recommendation. All health effects due to fish consumption for which there is convincing evidence are incorporated in the assessment. The QALIBRA software (http://www.qalibra.eu/) was used to simulate the two scenarios. The results showed that there would have a net benefit for the population if 200 g of fish were weekly consumed.

Table 1 Monthly fish consumption limits for non-carcinogenic[a] and carcinogenic[b] health endpoints (left and right values, respectively) (Data data from Domingo et al., 2007b)

Pollutant	Sardine	Tuna	Anchovy	Mackerel	Swordfish	Salmon	Hake	Red mullet	Sole	Cuttlefish	Squid	Clam	Mussel	Prawn
MeHg[c]	12/–	2/–	12/–	12/–	0.5/–	16/–	4/–	4/–	12/–	>16/–	16/–	>16/–	>16/–	8/–
Cd	>16/–	>16/–	>16/–	>16/–	>16/–	>16/–	>16/–	>16/–	>16/–	>16/–	>16/–	16/–	16/–	>16/–
HCB	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16
PCDD/PCDFs	NA/2	NA/3	NA/3	NA/2	NA/8	NA/2	NA/16	NA/1	NA/4	NA/16	NA/4	NA/12	NA/4	NA/8
DL-PCBs	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16	>16/>16
PAHs	NA/2	NA/3	NA/1	NA/1	NA/2	NA/2	NA/4	NA/4	NA/4	NA/4	NA/4	NA/0.5	NA/0.5	NA/0.5

An average meal size of 0.227 kg was assumed. NA: RfD (oral reference dose, mg/[kg day]) is not available in the EPA's Integrated Risk.
Information System (IRIS) for this pollutant. Monthly consumptions indicated as >16 are, in fact, equivalent to unrestricted consumptions.
[a]Chronic systemic effects.
[b]Consumption limits for cancer risks were estimated using a risk level of 1 in 100,000 (10^{-5}). Cancer slope factors (CSF) expressed in (mg/[kg day]) were obtained from US EPA (2000) and are based on an exposure period of 70 years.
[c]A correction factor of 0.85 was applied to account for the proportion of organic Hg vs. total Hg.

INFLUENCE OF COOKING ON THE LEVELS OF ENVIRONMENTAL POLLUTANTS IN FISH

In most reports found in the scientific literature on the dietary intake of environmental contaminants, it can be noted that food analyses were basically performed only on uncooked/raw products. However, it is evident that a very important number of foodstuffs are consumed after being cooked. Therefore, we have also investigated the influence of various widely used cooking procedures (frying, grilling, roasting and boiling) on the concentrations of chemical pollutants in food, including fish and seafood. Although we have observed that certain cooking processes could either reduce or increase the levels of chemical contaminants in food, our results have shown that in general terms, the influence of cooking on the levels of these contaminants depends not only on the particular cooking process, but even more on the specific food item. Usually, cooking procedures that release or remove fat from the product should tend to reduce the total concentrations of the organic contaminants in the cooked food (Domingo, 2011). With respect specifically to fish (sardine, hake, and tuna were the species analyzed), there was a clear tendency to increase metal concentrations after cooking (Perelló et al., 2008). However, the cooking processes had different effects on the concentrations of PCDD/PCDFs. Thus, cooking reduced the levels in sardine, while it enhanced them in hake and tuna, with very scarce differences in this last species. In turn, the highest PCB levels were detected in sardine (raw and fried) followed by tuna (raw, fried, and grilled). As for PCDD/PCDFs, cooking showed also different effects on the levels of PCBs in fish. Cooking reduced PCB concentrations in sardine, very especially in the grilled samples, enhanced very slightly PCB levels in tuna, and reduced them in hake, while cooking processes (excepting frying for sardine) enhanced $\sum$PCDE levels in fish (Perelló et al., 2009a). Perelló et al. (2009b) reported that for cooked fish, the highest PBDE levels corresponded to sardine, with notable reductions in the fried and grilled samples. In hake, all cooking processes enhanced the levels of PBDEs, being especially relevant to the increase noted after roasting. On the other hand, the highest HCB concentrations were found in sardine, being lower in cooked than in raw samples. All cooking processes enhanced HCB levels in hake, while very scarce differences could be noted in tuna (raw and cooked). In turn, the highest concentrations of total carcinogenic PAHs, and total PAHs (16 individual compounds) were, in general terms, observed after frying, being the levels especially notable in sardine and tuna, while in hake the highest total PAH concentrations corresponded to roasted samples (Perelló et al., 2009b).

Recently, we have added PFCs to our studies on the influence of cooking on the levels of pollutants if fish and seafood samples. Information on this issue is rather scarce (Ericosn-Jogsten et al., 2009). In Canada, Del Gobbo et al. (2008) investigated the influence of cooking (baking, boiling, and frying) on the levels of PFCs in 18 fish species purchased from Canadian markets. All cooking methods reduced the concentrations of perfluorinated acids, being baking the most effective method. PFOS was the compound most frequently detected, while PFOSAs were detected only in scallops. In a recent study performed in our laboratory and focused on assessing the influence of cooking processes on the concentrations of PFCs in various food items (Ericson-Jogsten et al., 2009), the results were not sufficiently clear to conclude whether cooking with non-stick cookware could significantly contribute to reduce or to increase human exposure to PFCs.

CONCLUSIONS

There is a general consensus, especially among international heart associations, on the role of fish and other seafood consumption as a rich source of omega-3 PUFAs that may confer multiple health benefits. Nevertheless, a number of studies, mainly investigations performed in recent years, have shown that the unavoidable presence of environmental contaminants in fish and shellfish can also mean health risks for certain consumers. Initially, those studies were mainly focused on methylmercury and PCBs. However, recent studies have also included a series of other metals and organohalogenated compounds such as PCDD/PCDFs, PBDEs, PCDEs, PCNs, PFCs, and also PAHs. While prestigious international associations as the AHA have recommended eating fish (particularly fatty fish) at least two times (two servings a week), based on our own experimental results, together with data from other investigators, we cannot be in total agreement with that general recommendation. Although a regular consumption of most fish and shellfish species should be in principle beneficial, not meaning adverse health effects for the consumers, the specific type of fish and shellfish species consumed, the frequencies of consumption, as well as the meal sizes are essential issues that must be not obviated for adequately balancing the health benefits and risks of fish and seafood consumption. In relation to this, I would like strongly recommending that the National Food Safety Authorities, or similar national/regional organisms, include in their regular monitoring programs the analysis of those chemical pollutants more frequently found in fish and seafood. It should allow maintaining updated the health risks for the consumers derived from a regular fish intake. The content of omega3-fatty acids, as well as that of important nutrients contained in the most consumed fish species in specific regions/countries (health benefits), should be also included in those programs.

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