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Human Exposure to Dioxin-Like Compounds in Fish and Shellfish Consumed in South Korea

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ABSTRACT
Dietary intake is the most important source of exposure to dioxins for the general population. This pathway contributes more than 90% of the daily intake for the general population of Korea. The objective of this study was to assess current exposure to dioxin-like compounds in fish and shellfish consumed by the general population in Korea. Residues of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), and dioxin-like, non-, and mono-substituted polychlorinated biphenyls (co-planar PCBs) were quantified in 32 fish and shellfish collected from domestic fisheries markets. The contributions of individual DL-PCB congeners to the total 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) equivalents (TEQ) were greater than 50%. Concentrations of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalents based on the TCDD equivalency factors (TEFs) developed by the World Health Organization (TEQ_{WHO}) were compared to guidelines suggested for the protection of human health by the World Health Organization (WHO). The greatest TEQ concentration was observed in herring, followed by that in dried anchovy and Sailfin sandfish. The exposure to dioxin-like compounds from current fish consumption patterns was estimated to be 72 pg TEQ_{WHO}/day, which is equal to 1.2 pg TEQ_{WHO}/kg, bw/d, a value that is less than the current tolerable daily intake (TDI) guideline in Korea, which is 4 pg TEQ_{WHO}/kg, bw/d. The relatively great exposure was determined to be due to greater fish consumption rate in Korea, rather than greater concentrations of residues in food.

Key Words: TEQ, fish consumption, POPs, TDI, dioxin uptake rate.

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INTRODUCTION

Chemicals that are structurally similar to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) such as polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and dioxin-like (co-planar) PCBs can interact with the aryl hydrocarbon receptor (AhR) and thus have a common mode of toxic action (Safe 1990). These persistent and bioaccumulative dioxin-like compounds can enter the marine environment through various routes that include freshwater discharge, urban runoff, atmospheric deposition, and accidental spill. These compounds are of concern because they are known to cause reproductive failure, inhibition of growth, developmental disorder, and malfunctioning of immune system response (Tanabe *et al.* 1987; Svensson *et al.* 1994; Giesy and Kannan 1998; Schantz *et al.* 2001).

Humans can be exposed to residues through contaminated foods, drinking water, and inhalation and dermal contact, but for persistent and bioaccumulative chemicals such as PCDDs, PCDFs, and PCBs, dietary intake is the most important source of exposure for the general population. Meat, dairy products, fish and other seafood products, contribute more than 90% of the daily intake for the general population. Among food items, fish and shellfish are traditionally important in the diet of Koreans, who obtain a large amount of their nutrition, especially protein, from sea food. The nutritional benefits of fish consumption are due to the presence of essential omega-3, unsaturated fatty acids and minerals (Sidhu 2003). Consumption of omega-3 fatty acids in fish or fish oil reduces the risk of coronary heart disease and lessens hypertension and plasma triglycerides, and prevents cardiac arrhythmias and sudden death (Berry 1997; Albert *et al.* 2002). However, fish can also contain synthetic chemicals that may pose a potential health risk. Because they tend to accumulate in aquatic organisms, consumption of fish contaminated with PCDDs, PCDFs, and dioxin-like PCBs may contribute to the risk of adverse biological outcomes. The risk to humans of consuming fish is a function of contaminant concentrations in fish, consumption rate, and sensitivity of the individual, which is a function of age, gender, genetic profile, and health status. However, it is difficult to define or estimate the receptor-specific risk depending on individual exposure case. Therefore, it is better to estimate the exposure level and assess the risk for the general population at first step, using available information such as the concentrations of representative fish and fish consumption rate per capita, and then characterize the risk for a specific group such as anglers who are in the high end of fish consumption rate or a woman in pregnancy.

Few reports of the concentrations of dioxin-like chemicals are available for the Korean diet, although some information on concentrations in environmental media has been published (Im *et al.* 2002; Ok *et al.* 2002, 2003; Moon *et al.* 2005). The objective of this study was to evaluate the current health risk in Korea associated with consumption of marine fish and shellfish containing PCDDs, PCDFs, and dioxin-like PCBs. Specifically, concentrations of these target compounds were determined in domestic and 32 types of imported fish and shellfish that were collected in a random market basket survey. Rates of fish consumption for Korea were estimated (KREI 2002). Exposure to TEQ calculated from fish consumption rates and concentrations of TEQ for each type of fish and shellfish in the Korean diet was assessed and compared to WHO tolerable daily intake (TDI) and other guidelines.

MATERIALS AND METHODS

Fish Consumption Survey

The sampling strategy for determining the concentrations of the toxicant residues of concern was based on fish and shellfish that were most often consumed in Korea during the past 5 yr as well as lipid contents. Based on these criteria, several species of fish, crustaceans, bivalves, and echinoderms were selected for study (MOMAF 2002; KREI 2002). The fish and shellfish that were reported to be consumed most often and in the greatest quantities and that also have greater lipid contents received the greatest priority. Processed fish was also included, but seaweeds were not included because their lipid contents are low and they were not expected to contribute significantly to exposure of the target chemicals.

Rates of consumption of various fish and shellfish were determined by considering the amounts of production, taken and brought forward, import and export, feed and seed, reduction and non-edible processing (KREI 2002). The fish consumption rate may be overestimated because the amount of fish and shellfish supply included not only edible parts but also fish bone and shell. The average fish consumption rates between 1997 and 2001 were extracted and reported as grams per consumed per capita per day in the present study. The 32 types of fish and shellfish surveyed in this study include about 78% of the total mass of fish and shellfish consumed in Korea.

Average Body Weight Estimation

Information on the body weights of Koreans was obtained from "The Size Korea" project (MOCIE 1997). Information on average bodyweight (bw) was available from Size Korea projects conducted in 1979, 1986, 1992, and 1997 (MOCIE 1997). The data from Size Korea in 1997 were extracted and booked as four categories: adult older than 19, women of child-bearing age 18 to 39, old age over 60, and infant less than 6 years old.

Consequently, the average adult body weight for individuals greater than 19 yr of age was calculated to be 60 ± 2.2 kg, bw, whereas that of Americans has been estimated to be 70 kg, bw. The average body weight of women of child-bearing age (18–39 yr) was 53 kg $\pm$ 1.4. The average body weights of older persons (>60 yr) and infants (<6 yr) were 58 and 23 kg, respectively. In this study, the average body weight of Korean adults older than 19 yr was used for risk calculations.

Collection of Fish

Samples of 32 types of fish and shellfish were collected between June 23 and 25, 2003, from three commercial fish markets in the vicinity of Seoul, Korea, at Noryangjin, Garak-dong, and Sorae. Composite samples were made of individuals of each species collected at three different times. Priority in sample collection was (1) fresh living animals, (2) if dead then not frozen animals, and (3) frozen animals. The sampling was random and the fishermen were not informed about the survey while purchasing. At least four individuals of each item were purchased from each market. The purchased samples were taken immediately to the laboratory and dissected. Fish muscle was the principal tissue of investigation. However, care was taken to include other tissues or whole organisms consistent with Korean dietary habits. Equal quantities of tissue were taken from samples of the same species from the three markets and pooled into a single composite sample for extraction and further analysis.

Determination of Chemical Residues in Tissue

The residues of persistent organic pollutants (POPs) were determined for the 32 types of fish and shellfish. Target analytes comprised dioxins/furans, dioxin-like PCBs, total PCBs, polycyclic aromatic hydrocarbons (PAHs), tributyl tins (TBTs), and selected organochlorine pesticides. Approximately 10 g (ww) of tissue was extracted with dichloromethane:hexane (1:1) for multi-residue analysis, which was performed via a gas chromatography-high-resolution mass spectrometry (VG-Autospec high resolution mass spectrometer; Micromass, Manchester, UK) equipped with a Hewlett-Packard model 5890 Series II gas chromatograph and a CTC A200S auto sampler (CTC Analytics, Zurich, Switzerland). Concentrations were determined by internal standards, based on isotope dilution methods as described in Ikonomou *et al.* (2001). Briefly, after spiking with a mixture of PCDD, PCDF and PCB surrogate internal standards, samples (blended with activated sodium sulfate) were extracted with DCM. The lipid thus obtained was dissolved in 1 mL of 1:1 (v/v) DCM:Hexane and passed through gel permeation chromatography for separation of target compounds from lipids.

A chemical class separation of this extract was achieved by use of a silica gel and alumina-carbon fiber column. Samples were analyzed in batches of thirteen, including a spiked sample, certified reference material, and procedural blank. Concentrations were corrected for recovery of the internal surrogate standards. Data were acquired in the selected ion monitoring (SIM) mode to achieve maximum possible sensitivity. Instrumental resolution was routinely 10,000 mass units. Two or more ions, $M+$ and $(M+2)+$ in most cases, of known relative abundance were monitored for each molecular ion cluster representing a group of isomers, as were two for each of the ^{13}C-labeled surrogate standards. To check for possible interferences with polychlorinated diphenyl ethers (PCDEs) on PCDFs the corresponding PCDE ions were monitored in each of the groups of the PCDF isomers. The specific ions monitored for each group of PCDD/F isomers, the corresponding PCDEs and the MS calibrant lock-mass ions were those specified in the Environment Canada protocol. Prior to analyzing any "real" samples all the GC/HS QA/QC experiments specified in the protocol were performed and the data obtained were within the accepted tolerances. The criteria for analyte identification and quantification and the associated quality control measures undertaken to screen the data were also those specified in the Environment Canada Protocol for PCDD/F analysis. The same criteria and QA/QC tolerances were also applied to dioxin-like PCB analysis. Concentrations of identified compounds and their minimum detection limits (MDLs) were calculated by the internal standard method using mean relative response factors determined from the analysis of calibration standard solutions run before and after each batch of samples was analyzed.

TCDD Equivalents (TEQs)

Total concentrations of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) equivalents (TEQs) were estimated by use of TCDD equivalency factors (TEFs) developed by the World Health Organization (WHO) (TEQ_{WHO}) (van den Berg *et al.* 1998). The relative contribution of each congener was calculated as the product of its concentration and the appropriate congener-specific TEF. The total concentration of TEQ_{WHO} was then calculated as the sum of TEQ-D (TEQ by including 7 PCDD isomers), TEQ-F (TEQ including 10 PCDF isomers) and TEQ-P (TEQ by including 12 dioxin-like PCBs), using equation (1).

$$TEQ_{WHO} = \Sigma PCDD_i \cdot TEF_i + \Sigma PCDF_j \cdot TEF_j + \Sigma dioxin - likePCB_k \cdot TEF_k \quad (1)$$

where: TEQ_{WHO} = toxic equivalent quotients by the adoption of the 1998 WHO TEFs (TCDD equivalency factors), PCDD = polychlorinated dibenzo-*p*-dioxin, PCDF = polychlorinated dibenzofuran, PCB = polychlorinated biphenyl.

RISK ANALYSIS

Calculation of TEQ Exposure

The rate of exposure to TEQ due to consumption of each species was calculated by multiplying TEQ concentration by fish consumption rate (equation [2]). The mass of each species of fish consumed was calculated as the product of the fraction of the diet comprised by each species by the mass of fish and shellfish consumed (86 g/capita/d). The average Korean body weight was assumed to be 60 kg, bw. Total daily intake due to consumption of fish and shellfish was calculated by summing the product of consumption of each of 32 species by the concentration of TEQ in each species.

$$ADI = [\Sigma TEQ_i \cdot CR_i] / SR/BW \quad (2)$$

where: CR_i = fish consumption rate of species I, SR = a ratio of the surveyed fish consumption to the total, BW = average body weight.

The average daily intake (ADI) was also estimated by multiplying the arithmetic mean of the concentrations in 32 fish and shellfish by fish consumption rate (equation [3]).

$$ADI = C_m \cdot CR_m \quad (3)$$

where: C_m = average TEQ concentrations in surveyed fish, CR_m = average fish consumption rate.

RESULTS AND DISCUSSION

Patterns of Fish Consumption

Fish consumption rates are summarized in Tables 1 and 2. Consumption rates for fish and shellfish were 58 g and 28 g/person/d, respectively. Consequently, the average total amount of fish and shellfish consumed in Korea was estimated to be 86 g/person/d. Although rates of consumption of fish and shellfish have

Table 1. Annual mean fish and shellfish consumption rates (g/person/d) from 1997 to 2001 in Korea.

Year	Fish	Shellfish	Fish & shellfish
1997	59	29	88
1998	50	24	75
1999	54	30	84
2000	55	29	84
2001	70	29	99
Average	58	28	86

Table 2. TEQ uptake rates from fish and shellfish consumption in Korea.

Species	Concentration in fish (pgTEQ/g ww)	Fish consumption rate (kg/d)	TEQ uptake rate (pg/d)	TEQ contribution (%)
Herring	4.675	0.000608	2.842	5.07
Dried Anchovy	2.772	0.013366	37.052	66.13
Sailfin Sandfish	2.483	0.000046	0.114	0.20
Atka Mackerel	1.636	0.000700	1.145	2.04
Gizzard Shad	1.560	0.000290	0.452	0.81
Spanish Mackerel	1.475	0.000736	1.085	1.94
Flounder	1.360	0.000608	0.827	1.48
Mackerel	1.121	0.005388	6.042	10.78
Canned Mackerel[a]	0.934	0.000148	0.138	0.25
Horse Mackerel	0.704	0.000946	0.666	1.19
Big Eyed Herring	0.632	0.000118	0.075	0.13
Atlantic Cutlassfish	0.375	0.003724	1.397	2.49
Tunny	0.372	0.002076	0.773	1.38
Amberjack	0.338	0.000194	0.066	0.12
Rockfish	0.318	0.000392	0.125	0.22
Oyster	0.306	0.000760	0.232	0.41
Saury	0.236	0.001164	0.274	0.49
Crap	0.193	0.000420	0.081	0.14
Sea Squirt	0.187	0.000222	0.041	0.07
Flatfish	0.153	0.000760	0.116	0.21
Mussel	0.124	0.000350	0.044	0.08
Squid	0.121	0.015684	1.891	3.37
Kuruma Shrimp	0.109	0.000162	0.018	0.03
Granulated Ark Shell	0.079	0.000128	0.010	0.02
Short-necked Clam	0.059	0.000330	0.020	0.03
Redlip Croaker	0.046	0.001910	0.087	0.16
Porgy	0.034	0.000366	0.013	0.02
Alaska Pollock	0.034	0.007550	0.258	0.46
Canned Tuna[a]	0.032	0.003705	0.117	0.21
Ark Shell (blood clam)	0.027	0.000260	0.007	0.01
Imitation crab meat[a]	0.007	0.002293	0.016	0.03
Fish jelly[a]	0.004	0.001592	0.006	0.01

[a]Processed foodstuff.

not changed much in recent years, they are gradually increasing and a recent national report showed that fish consumption rates in 2002 and 2003 amounted to 99 g and 105 g, respectively (KREI 2004). Seaweeds were not included. If they are combined together, the total consumption rate of seafood can be more than 120 g.

During the period from 1997 to 2001, squid was the most consumed species, with rates as great as 15.7 g/person/d, which corresponds to 18.2% of total fish consumption. Dried anchovy, Alaska Pollock, and mackerel were followed by 13.4 g (15.5% of total fish consumption), 7.6 g (8.8%), and 5.5 g (6.3%) per person per day, respectively. However, mackerel was the species that contributed the greatest amount of lipid to the diet, followed by Atlantic cutlass fish, dried anchovy, and squid.

Relative Contributions of Dioxin-Like PCBs to TEQ

Concentrations of each of the chemicals of concern in fish and shellfish from Korean markets were detectable, but generally equal to or less than those reported from other parts of the world. Concentrations of PCDDs/PCDFs are reported as pg/g, whereas those of PCBs are reported as ng/g. (All concentrations are expressed on a wet weight basis.) Species that contained total concentrations of TEQ_{WHO} greater than 1.0 pg/g, ww, included herring, anchovy, sailfin sandfish, atka mackerel, gizzard shad, and Spanish mackerel. In this study, concentrations of PCDDs, PCDFs, and PCBs in herring were the greatest of the species studied, with a maximum concentration of 4.7 pg TEQ_{WHO}/g, ww. This is consistent with the observation that concentrations of TEQ in herring from the Baltic Sea have been found to be greater than those in other species (Kiviranta *et al.* 2003). The primary reason for this is that herring contain relatively more lipid than other species. Among the processed food, whole dried anchovy had the greatest concentrations. Concentrations of TEQ_{WHO} in invertebrates such as squid muscle and whole oysters were generally less than those of fish.

Concentrations of TEQ_{WHO} in fish and shellfish are summarized in Table 3. Concentrations of TEQ_{WHO} were significantly correlated with concentrations of TEQ-D ($r^2 = 0.88$), TEQ-F ($r^2 = 0.95$), and TEQ-P ($r^2 = 0.98$). Correlations were also observed between TEQ-D and TEQ-F ($r^2 = 0.87$), TEQ-D and TEQ-P ($r^2 = 0.81$), TEQ-F and TEQ-P ($r^2 = 0.88$). This finding suggests that these compounds are concurrent contaminants in aquatic organisms. AhR-active PCB congeners contributed between 50% and 90% of the total concentration of TEQ_{WHO}, which suggests that dioxin-like PCBs in fish and shellfish contribute a major portion of the TEQ_{WHO} and thus are the primary compounds contributing to human health risk (Table 3). This is similar to previously reported findings (Alcock *et al.* 1998). The relative contribution of PCBs to total concentrations of TEQ_{WHO} intake in the Korean diet was generally greater than 50%, whereas the contribution of PCBs to total TEQ intake was reported to be 37, 52, and 37% in the United Kingdom, The Netherlands, and United States, respectively (IOM 2003). Details on the occurrence and isomer-specific distribution patterns of PCDDs, PCDFs, and PCBs in fish and shellfish in the present study are reported separately (Oh *et al.* 2005).

Table 3. TEQ values in fish and shellfish in Korea.

SPECIES	Type	TEQ-D	TEQ-F	TEQ-P[b]	TEQ_{WHO}
Herring	Fillet	0.453	1.534	2.688 (57)	4.675
Dried Anchovy	Whole	0.162	0.597	2.014 (73)	2.772
Sailfin Sandfish	Fillet	0.250	0.845	1.388 (56)	2.483
Atka Mackerel	Fillet	0.115	0.463	1.058 (65)	1.636
Gizzard Shad	Fillet	0.211	0.271	1.078 (69)	1.560
Spanish Mackerel	Fillet	0.115	0.306	1.054 (71)	1.475
Flounder	Fillet	0.160	0.456	0.744 (55)	1.360
Mackerel	Fillet	0.000	0.315	0.807 (72)	1.121
Canned Mackerel[a]	Fillet	0.000	0.299	0.635 (68)	0.934
Horse Mackerel	Fillet	0.000	0.242	0.462 (66)	0.704
Big Eyed Herring	Fillet	0.012	0.114	0.507 (80)	0.632
Atlantic Cutlassfish	Fillet	0.000	0.101	0.274 (73)	0.375
Tunny	Fillet	0.000	0.045	0.327 (88)	0.372
Amberjack	Fillet	0.000	0.060	0.278 (82)	0.338
Rockfish	Fillet	0.000	0.024	0.294 (92)	0.318
Oyster	Whole	0.000	0.056	0.250 (82)	0.306
Saury	Fillet	0.000	0.013	0.223 (94)	0.236
Crap	Fillet	0.000	0.039	0.154 (80)	0.193
Sea Squirt	Fillet	0.024	0.112	0.051 (27)	0.187
Flatfish	Fillet	0.000	0.014	0.139 (91)	0.153
Mussel	Whole	0.004	0.028	0.093 (75)	0.124
Squid	Fillet	0.000	0.014	0.107 (88)	0.121
Kuruma Shrimp	Fillet	0.000	0.039	0.070 (64)	0.109
Granulated Ark Shell	Whole	0.000	0.014	0.065 (82)	0.079
Short-necked Clam	Whole	0.000	0.029	0.030 (51)	0.059
Redlip Croaker	Fillet	0.000	0.000	0.046 (100)	0.046
Porgy	Fillet	0.000	0.001	0.033 (96)	0.034
Alaska Pollock	Fillet	0.000	0.000	0.034 (100)	0.034
Canned Tuna[a]	Fillet	0.000	0.009	0.023 (71)	0.032
Ark Shell (blood clam)	Whole	0.000	0.000	0.027 (100)	0.027
Imitation crab meat[a]	Fillet	0.000	0.000	0.007 (100)	0.007
Fish jelly[a]	Fillet	0.000	0.000	0.004 (99)	0.004

[a]Processed foodstuff.[b]Values in parentheses mean the percentage of the dioxin-like PCBs' contribution to TEQ_{WHO}.

TEQ Intake

The total rate of intake of TEQ_{WHO} from the weighted average of the 32 fish and shellfish surveyed in this study was 56 pg TEQ_{WHO}/d (equation [2]). The surveyed amounts of fish and shellfish are 66 g/person/d, which would correspond to about 78% of the total average fish consumption (86 g/capita/d) in Korea. Therefore, an intake rate due to fish consumption could be as great as 72 pg TEQ_{WHO}/d, which is equal to 1.2 pg TEQ_{WHO}/kg, bw/d. If the arithmetic mean were used instead of the weighted average, the rate of intake would be 60.5 pg TEQ_{WHO}/d or 1.0 pg TEQ_{WHO}/kg, bw/d (equation [3]). The difference in the two estimates is due to the underestimation of the consumption rate of the more contaminated species and overestimation of lesser consumption rate of less contaminated species. Without using the weight-normalized consumption rates to determine exposure, health assessment conclusions can be misleading (Mariën 2002).

Daily intake of TEQ from the diet was predicted to result primarily from the consumption of dried anchovy. Intake of TEQ_{WHO} through consumption of dried anchovy was predicted to be 37 pg TEQ_{WHO}/g, ww. This represents 66% of the total predicted intake of TEQ (Table 2). The rate of TEQ_{WHO} intake from dried anchovy consumption by Koreans was predicted to be approximately three times greater than that predicted intake for the total diet fish consumption by Americans (10.8 ~ 14.5 pg TEQ_{WHO}/d) (Schecter *et al.* 2001). However, dried anchovy is mainly used for soup or sauce and flesh itself is discarded in Korea. Therefore, TEQ intake from the consumption of dried anchovy may be much less than current estimation.

The TEQ concentration of squid was 0.12 pg TEQ/capita/day. Dioxin intake rate by squid consumption was 1.89 pg/d. It was no more than 3.37% of the TEQ contribution, even though squid consumption rate was the highest as 15.7 g/capita/day. The contribution of mackerel, herring, squid, Atlantic cutlass fish, atka mackerel, Spanish mackerel, horse mackerel, and tunny was predicted to be only 1 to 10% of the total TEQ_{WHO} intake, respectively (Table 2).

Comparison of TEQ in Korean Seafood to Guidelines

Concentrations of TEQ in all food items studied were less than 4.0 pg $TEQ_{WHO\text{-}PCDD/F}$/g, ww, which is the harmonized European Union (EU) maximum allowable concentration that has been established by the European Council Regulation (EC 2001a). The greatest concentration of $TEQ_{WHO\text{-}PCDD/F}$ in this study was 2.0 pg $TEQ_{WHO\text{-}PCDD/F}$/g, ww, in herring (Table 3).

The tolerable daily intake (TDI) recommended by WHO is 1.0 ~ 4.0 pg TEQ_{WHO}/kg, bw/d in 1998 (Table 4). Other international guidelines are similar. The JECFA (Joint FAO/WHO Expert Committee on Food Additives) recommended 70 pg TEQ_{WHO}/kg, bw/month as a PTMI (provisional tolerable monthly intake), which is equal to 2.3 pg TEQ_{WHO}/kg, bw/d. EC-SCF (European Commission Scientific Committee on Food) also suggested 2 pg TEQ_{WHO}/kg, bw/d of TWI (tolerable weekly intake) in a similar range. The ATSDR (Agency for Toxic Substances & Disease Registry) established 1 pg TEQ_{WHO}/kg, bw/d as MRL (minimal risk level) value.

Table 4. Tolerable daily, weekly, and monthly intake guidelines for dioxin recommended from various organizations.

	pg TEQ/kg, bw/d	pg TEQ/kg, pg bw/wk	pg TEQ/kg, bw/mo	Reference
WHO	1–4[a]	7–28	30–120	WHO (1998)
EC-SCF	2	14[a]	60	EC (2001b)
JECFA	2.3	16.3	70[a]	JECFA (2001)
ATSDR	1[a]	7	30	ATSDR (2000)
United Kingdom	2[a]	14	60	COT (2001)
Japan	4[a]	28	120	EAJ (2000)
Korea	4[a]	28	120	KFDA (1999)

[a]Actual recommendation of each group and other values are converted for comparison.

The United Kingdom uses 2.0 pg TEQ_{WHO}/kg, bw/day as the TDI. Korea and Japan currently use 4.0 pg TEQ_{WHO}/kg, bw/d, but the final goal has been suggested to be 1.0 pg TEQ_{WHO}/kg, bw/d. The TEQ intake rate was estimated to be 2.2–2.4 pg TEQ_{WHO}/kg, bw/d from total food intake in the United States, however, the intake from fish was less than 10% (0.15–0.21 pg TEQ_{WHO}/kg, bw/d) (Schecter *et al.* 2001). Due to a greater rate of consumption of fish and contaminant concentrations, in Japan, daily intake of TEQ_{WHO} from foodstuffs has been reported to range from 2.3 to 3.2 pg TEQ_{WHO}/kg, bw/d and that from fish was 1.7 pg TEQ_{WHO}/kg, bw/d (Tsutsumi *et al.* 2001). TEQ_{WHO} intake due to current fish consumption in the average Korean diet is 1.2 pg TEQ_{WHO}/kg, bw/d, which is less than that of Japan and greater than those of other countries such as the United States. TEQ_{WHO} intake due to fish consumption does not currently exceed the 4.0 pg TEQ_{WHO}/kg, bw/d guideline for the TDI set by the Korean government. However, the TDI should be estimated from a total diet study. The dioxin intake rates from foodstuffs in Korea are not fully understood. Concentrations of TEQ_{WHO} in pork, mackerel, cheese, and milk from three different markets in Seoul, Korea, have been reported to be 2.0×10^{-2}, 2.4×10^{-2}, 2.8×10^{-2}, and 5.9×10^{-2} pg TEQ/g ww, respectively (Choi *et al.* 2002). Additional information is needed to be able to fully understand the TDI from total diets in Korea.

According to the annual food balance sheets from the KREI, intake of cereals has decreased, whereas animal foods have been increased; in which seafood supplies are gradually increasing. Traditionally, Koreans have eaten relatively large amounts of fish and shellfish. Fish provide a diet high in protein and unsaturated fatty acid such as omega-3, which provides nutritional and health benefits, primarily against cardiovascular disease (Moyard 2005a,b). The intake of fat and cholesterol can be reduced by substituting fish for fatty meats. However, dioxin-contaminated fish consumption may pose a health potential for cancer risk. Although it is desirable to minimize human exposure to hazardous contaminants, it should not be done in a way that results in a loss of the benefits of the presence of fish and shellfish in the diet. The quantitative comparison between the benefits of eating fish and the risks such as the increased cancer risk associated with ingestion of carcinogenic pollutants has been conducted (Anderson and Wiener 1995). Quantitative analysis of fish consumption and stroke risk was conducted by Bouzan *et al.* (2005). The authors reported that fish consumption confers substantial relative risk reduction compared to no fish consumption. It is reported that the inverse correlation between fish consumption rates and mortalities from health disease has been shown (Kromhout *et al.* 1985), although no inverse association between fish consumption and risk of all-cause mortality and incidence of coronary heart disease in Danish adults was found (Osler *et al.* 2003).

The public can maintain the benefits of eating fish while minimizing exposure to TEQ by selecting proper uncontaminated fish foodstuffs. Various processes such as source control and fisheries management need to be considered to reduce dioxin intake from contaminated fish foodstuff. Fish consumption advisories can help consumers reduce cancer risk from contaminated fish and shellfish. There may be large differences in chemical residues in fish tissues depending on species, habitats, size, and wild/farmed type, and so on. In addition, the cancer risk can be diminished by cooking or preparation method. If this type of information is made available to the public, then individuals can make informed decisions about personal risk management. Our results show how much TEQ were contributed by each species. For example, some fish, such as dried anchovy and mackerel in the present study, had the greatest potential risks and contributed as much as 66% and 10% of total dioxin uptake, respectively. This indicates that we can avoid most of the cancer risk through the management of fish consumption patterns and this is why we need to set fish consumption guidelines.

There are a number of ways the public can reduce exposure to TEQ without losing the benefit of relatively great proportions of fish in the diet. Sometimes risk can be reduced by fish size selection. The age-dependent tendency of dioxin contamination level was observed in herring species from the Gulf of Finland. It has been reported that one unit increase of TEQ concentration occurs for every year of a herring's life, indicating that small fish are less contaminated and thus safer to eat than larger herring (Kiviranta *et al.* 2003). If concentrations of TEQ in anchovy are similar, risk can be reduced by size selection on the species. Potential health risks can be also reduced by trimming, skinning, and eliminating fatty parts of fish and shellfish. Concentrations of contaminants were significantly greater in farmed Atlantic salmon compared to wild Pacific salmon (Hites *et al.* 2003). Furthermore, where the farmed salmon were raised made a big difference in their toxicant levels, with concentrations much higher in European fish than in North or South American salmon. The authors attribute these wide variations mainly to the fish oil/fish meal diet fed to farmed salmon, which was found to be contaminated in ranges corresponding to those found in the salmon. Dioxin-like compounds in fish can be reduced by removal of lipids through cooking processes. According to a Michigan fish advisory, more than 50% of the contaminants in fish can be eliminated by trimming fatty areas before cooking and allowing fat to drip away from fish when cooking (MDCH 2001). Depending on the contaminant and the cooking method, POPs concentrations can be decreased in salmon with a range of 13 to 51%, and removal of skin resulted in a further reduction of 9% (Bayen *et al.* 2005). In case of dried anchovy over 46 mm in size, 56% of dioxin TEQ can be reduced by removing intestines of dried anchovy (data not shown). Although current concentrations of TEQ_{WHO} in the average diet of Koreans does not exceed existing guidelines from other countries, the use of consumption advisories and education about methods of preparation can be used to lessen the rate of exposure. These kinds of fish consumption advisories will be helpful for risk management in the countries with greater fish consumption rates such as Korea and Japan.

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REFERENCES

Albert CM, Campos H, Stampfer MJ, *et al.* 2002. Blood levels of long-chain n-3 fatty acids and the risk of sudden death. N Engl Med 346:1113–8

Alcock RE, Behnisch PA, Jones KC, *et al.* 1998. Dioxin-like PCBs in the environment-Human exposure and the significance of sources. Chemosphere 37:1457–72

Anderson PD and Wiener JB. 1995. Eating fish. In: Graham JD and Wiener JB (eds), Risk versus Risk: Tradeoffs in Protecting Health and the Environment, Harvard University Press, Cambridge, MA, USA

ATSDR (Agency for Toxic Substances and Disease Registry). 2000. Minimal Risk Levels (MRLs) for Hazardous Substances. Available at http://www.atsdr.cdc.gov/mrls.html

Bayen S, Barlow P, Lee HK, *et al.* 2005. Effect of cooking on the loss of persistent organic pollutants from salmon. J Toxicol Environ Health (Part A) 68:253–65

Berry EM. 1997. Dietary fatty acids in the management of diabetes mellitus. Am J Clin Nutr 66:991–1007

Bouzan C, Cohen JT, Connor WE, *et al.* 2005. A quantitative analysis of fish consumption and stroke risk. Am J Prev Med 29:347–52

Choi D, Hu S, Jeong J, *et al.* 2002. Determining dioxin-like compounds in selected Korean food. Chemosphere 46:1423–7

COT (Committee on Toxicity). 2001. Committee on toxicity of chemicals in food, consumer products and the environment. Available at http://www.food.gov.uk/multimedia/pdfs/cot-diox-full.pdf

EAJ (Environmental Agency of Japan). 2000. Report on Tolerable Daily Intake (TDI) of Dioxins and Related Compounds (Japan). Available at http://www.env.go.jp/ en/rep/dioxin/tdi_report.pdf

EC (European Council Regulation). 2001a. No. 2375/2001 of 29 November 2001

EC. 2001b. Opinion of the Scientific Committee on Food on the Risk Assessment of Dioxins and Dioxin-like PCBs in Food. CS/CNTM/DIOXIN/20 final

Giesy JP and Kannan K. 1998. Dioxin-like and non-dioxin-like toxic effects of polychlorinated biphenyls (PCBs): Implications for risk assessment. Crit Rev Toxicol 28:511–69

Hites RA, Foran JA, Carpenter DO, *et al.* 2003. Global assessment of organic contaminants in farmed salmon. Science 303:226–9

Ikonomou MG, Fraser TL, Crewe NF, *et al.* 2001. A comprehensive multi-residue ultra-trace analytical method, based on HRGC/HRMS, for the determination of PCDDs, PCDFs, PCBs, PBDEs, PCDEs, and organo-halogen pesticides in six different environmental matrices. Can Data Rep Fish Aquat Sci 2272:1–94

Im SH, Kannan K, Matsuda M, *et al.* 2002. Sources and distribution of polychlorinated dibenzo-p-dioxins and dibenzofurans in sediments from Masan Bay, Korea. Environ Toxicol Chem 21:245–52

IOM (Institute of Medicine). 2003. Dioxins and Dioxin-Like Compounds, pp 30-6. The National Academies Press, Washington, DC, USA

JECFA (Joint FAO/WHO Expert Committee on Food Additives). 2001. Fifty-Seventh Meeting. Available at http://www.who.int/ipcs/food/jecfa/summaries/en/summary_57.pdf

Kiviranta H, Vartiainen T, Parmanne R, *et al.* 2003. PCDD/Fs and PCBs in Baltic herring during the 1990s. Chemosphere 50:1201–16

KFDA (Korea Food & Drug Administration). 1999. Available at http://www.kfda.go.kr

KREI (Korea Rural Economic Institute). 2002. Food Balance Sheet (in Korean), pp 119–71. Seoul, Korea

KREI. 2004. Food Balance Sheet (in Korean), pp 123–76. Seoul, Korea

Kromhout D. 1985. The inverse relation between fish consumption and 20-year mortality from coronary heart disease. N Eng J Med 312:1205–9

Mariën K. 2002. The importance of weight-normalized exposure data when issuing fish advisories for protection of public health. Environ Health Perspect 110:671–7

MDCH (Michigan Department of Community Health). 2001. Available at http://www.mdch.state.mi.us/pha/ fishadvi.htm

MOCIE (Ministry of Commerce, Industry and Energy). 1997. Size Korea. Available at http://sizekorea.ats.go.kr

MOMAF (Ministry of Maritime Affairs and Fisheries). 2002. Statistical Year Book of Maritime Affairs and Fisheries (in Korean). Seoul, Korea

Moon HB, Lee SJ, Choi HG, *et al.* 2005. Atmospheric deposition of polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) in urban and suburban areas of Korea. Chemosphere 58:1525–34

Moyad MA. 2005a. An introduction to dietary/supplemental omega-3 fatty acids for general health and prevention: Part I. Urol Oncol 23:28–35

Moyad MA. 2005b. An introduction to dietary/supplemental omega-3 fatty acids for general health and prevention: Part II. Urol Oncol 23:36–48

Oh JR, Ikonomou MG, Fernandez MP, *et al.* 2003. PCB and PCDD/F totals, TEQs and congener patterns in Korean coastal marine environment 1987, 1988, 1990 and 1996–1999. Arch Environ Contam Toxicol 44:224–36

Oh JR, Hong SH, Shim WJ, *et al.* 2005. A survey of polychlorinated dibenzo-p-dioxins and furans in Korean Seafood—a congener-specific approach. Mar Pollut Bull 50:1121–45

Ok G, Ji SH, Kim SJ, *et al.* 2002. Monitoring of air pollution by polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans of pine needles in Korea. Chemosphere 46:1351–7

Osler M, Andreasen AH, and Hoidrup S. 2003. No inverse association between fish consumption and risk of death from all-causes, and incidence of coronary heart disease in middle-aged, Danish adults. J Clinic Epidem 56:274–9

Safe S. 1990. PCBs, PCDD/F and related compounds: Environmental and mechanistic considerations which support the development of toxic equivalency factors. CRC Crit Rev Toxicol 21:51–88

Schantz SL, Gasior DM, Polverejan E, *et al.* 2001. Impairments of memory and learning in older Adults exposed to polychlorinated biphenyls via consumption of great lakes fish. Environ Health Perspect 110:671–7

Schecter A, Cramer P, Boggess K, *et al.* 2001. Intake of dioxins and related compounds from food in the U.S. population. J Toxicol Environ Health, Part A 63:1–18

Sidhu KS. 2003. Health benefits and potential risks related to consumption of fish or fish oil. Regul Toxicol Pharmacol 38:336–4

Svensson BG, Hallberg T, Schutz A, *et al.* 1994. Parameters of immunological competence in subjects with high consumption of fish contaminated with persistent organochlorine compounds. Arch Occup Environ Health 65:351–8

Tanabe S, Kannan N, Subramanian A, *et al.* 1987. Occurrence and distribution of toxic coplanar PCBs in the biota. Chemosphere 16:1965–70

Tsutsumi T, Yanagi T, Nakamura M, *et al.* 2001. Uptake of daily intake of PCDDs, PCDFs, and dioxin-like PCBs from food in Japan. Chemosphere 45:1129–37

van den Berg M, Birnbaum L, and Bosveld ATC. 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for human and wildlife. Environ Health Perspect 106:775–92

WHO (World Health Organization). 1998. Executive Summary of Assessment of the Health Risks of Dioxins: Re-evaluation of the Tolerable Daily Intake (TDI). Geneva, Switzerland