Dietary PCDD/PCDF Exposure Estimates for the U.S. Population

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Introduction

Dioxin-like compounds (DLCs) are a group of environmental contaminants whose primary route of human exposure occurs via the consumption of fatty foods of animal origin. Since the mid-1990s, the U.S. Food and Drug Administration (FDA) has tested specific foods with the goal of describing and reducing DLC exposure. In 1999, FDA's dioxin monitoring program began analyzing foods collected under its Total Diet Study (TDS). Conducted annually since 1961, the TDS is FDA's ongoing market basket survey designed to monitor the U.S. food supply for levels of toxic chemical contaminants (pesticide residues, industrial chemicals and toxic elements) and nutritional elements. This paper reports on dietary exposure estimates for DLCs, specifically polychlorinated dibenzo-*p*-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF), calculated from results of PCDD/PCDF analyses of TDS samples from 2001 and 2002 and food consumption data collected in USDA's 1994-96, 1998 Continuing Survey of Food Intakes by Individuals (CSFII).[1]

Methods and Materials

Dietary exposure estimates. For dietary PCDD/PCDF exposure estimation, FDA relies on information obtained from the FDA's TDS. The TDS is FDA's ongoing market basket survey of approximately 280 core foods in the U.S. food supply to determine levels of various pesticide residues, contaminants, and nutrients in foods and to estimate dietary intake of these substances. Four times each year, samples of each TDS food are purchased in 3 different cities, prepared as they would be consumed (table-ready) and then composited for analysis. In 1999, FDA began analyzing selected TDS foods from one of the four sample collections for PCDD and PCDF congeners. Beginning in 2003, three dioxin-like PCB congeners were also included in the analyses. FDA is planning to include additional dioxin-like PCBs in the program.

The TDS foods represent the major components of the average U.S. diet as determined from data collected in national food consumption surveys. The majority of TDS foods were analyzed for PCDD/PCDF in both 2001 and 2002. For those foods, the average of the two analytical results was used for calculating exposure. For samples analyzed in only one of those years, a single analytical result was used. For each food, three possible TEQ concentration were calculated from the

analytical results reflecting assignment of zero, half the limit of detection (LOD), and the LOD for non-detects.

PCDD/PCDF concentration data from TDS samples were linked to the TDS diets, which are a set of consumption amounts for each TDS food based on results of the USDA 1994-96, 1998 CSFII. During the CSFII, two days of consumption records were collected for approximately 20,000 individuals. Survey participants reported detailed information about the types and amounts of foods consumed; in all, approximately 6,000 different foods were reported in the survey. For calculating the consumption amounts for TDS foods, two-day average per-capita (total population) consumption amounts were calculated for each survey food for total US population and 14 age-sex groups. Since there are many more foods reported in the CSFII than are analyzed in the TDS, the survey foods were grouped according to their similarity to TDS foods and the consumption amounts of all foods in the group were totaled to derive a consumption amount for each TDS food. These consumption amounts for each TDS food for each of the population groups are collectively referred to the TDS diets.

PCDD/PCDF exposure estimates were calculated by multiplying the 2001-2002 average PCDD/PCDF concentration by the TDS diets. Exposures were calculated on a per-person basis which was converted to a body weight basis by dividing the per-person exposure by the average body weights reported in the CSFII. To obtain PCDD/PCDF exposure estimates by food category, each TDS food was assigned to one of eight food categories (dairy, egg, meat, poultry, fish, fats, fruits/vegetables, and other), and the PCDD/PCDF exposure amounts were subtotaled for each category.

PCDD/PCDF analysis. TDS samples were analyzed by gas chromatography/high resolution mass spectroscopy (HRMS) for 17 PCDD/PCDF congeners listed in Table 1. Data for PCDD/PCDF congener concentrations in TDS samples are presented as Toxicity Equivalents or TEQs which are used to estimate the relative toxicity of congeners. This equivalency method is based on summing the TEQs of 17 PCDD/PCDF congeners in each sample. The TEQ is calculated by multiplying the concentration of each PCDD and PCDF congener by the corresponding 1998 World Health Organization Toxic Equivalency Factor or TEF listed in Table 1. Three TEQ values were generated for each PCDD and PCDF congener and for each TDS sample, reflecting assignment of zero, half the limit of detection (LOD), or LOD values to congener non-detects.

Results and Discussion

In 2001, the Joint FAO/WHO Expert Committee on Food additives (JECFA) established a Provisional Tolerable Monthly Intake (PTMI) of 70 pg WHO-TEQ/kg body weight/month.[2] The monthly PCDD/PCDF exposure estimate for all age-sex groups from TDS data for 2001 and 2002 was 11.6 pg WHO-TEQ/kg body weight/month (ND=0) representing 16.6% of the JECFA PTMI. For all age-sex groups combined, the food category contributing greatest to exposure was “meat and mixtures” (43.7%) followed by “other foods and mixtures” and “dairy foods and mixtures” (14.8% and 14.5%, respectively) when ND=0. The relatively high contribution of “other foods and mixtures” and “fruits, vegetables and mixtures” to overall exposure came from foods in these categories containing animal-based ingredients (e.g., lasagna, pizza, scalloped potatoes, French fries, etc.).

The age-sex group with the highest PCDD/PCDF exposure was 2-year-old children (27.1 pg WHO-TEQ/kg body weight/month) followed by 6-year-old children (21.1 pg WHO-TEQ/kg body weight/month) and 10-year-old-children (14.9 pg WHO-TEQ/kg body weight/month) when ND=0. In these age-sex groups, food categories contributing greatest to PCDD/PCDF exposure were "meat and mixtures" (35.3-39.1%) followed by "dairy foods and mixtures" (27.1-29.1%). The age-sex group with the lowest PCDD/PCDF exposure was women > 70 years followed by women 60-65 years and women 25-30 years (ND=0).

FDA's dietary exposure estimates include only PCDDs and PCDFs and not dioxin-like PCBs and, therefore, may underestimate overall DLC exposure. Since 2003, three dioxin-like PCBs have been included in FDA's dioxin monitoring program. FDA is planning to include additional dioxin-like PCBs in the program.

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References

1. United States Department of Agriculture/Agricultural Research Service. 2000. Continuing Survey of Food Intakes by Individuals 1994-96, 1998. NTIS No. PB2000-50027.
2. Joint FAO/WHO Expert Committee on Food Additives. 2001. *Summary and Conclusions of the Fifty-seventh Meeting*.

TABLE 1 - Toxicity Equivalency Factors (TEFs) for the Polychlorinated Dibenzo-*p*-dioxin (PCDD) and Polychlorinated Dibenzofuran (PCDF) Congeners Included in FDA Dioxin Analysis[1]

Congener	TEF
Polychlorinated Dibenzo-*p*-dioxins	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,6,7,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0001
Polychlorinated Dibenzofurans	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.5
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0001

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TABLE 2. Dietary PCDD/PCDF Exposure Estimate (pg WHO-TEQ/kg body weight/month) from Different Food Categories for Different Age-Sex Groups (ND=0).

	Age-Sex Group							
Food Category	All Groups	Infants 6-11 months	Children 2 years	Children 6 years	Children 10 years	Girls 14-16 years	Boys 14-16 years	Women 25-30 years
Dairy foods and mixtures	1.7 (14.5%)	3.7 (30.9%)	7.9 (29.1%)	5.7 (27.3%)	4.0 (27.1%)	1.4 (15.2%)	2.3 (19.0%)	1.1 (13.7%)
Eggs and mixtures	0.3 (2.6%)	0.7 (5.5%)	1.2 (4.3%)	0.5 (2.5%)	0.4 (2.5%)	0.2 (2.0%)	0.2 (1.9%)	0.2 (2.9%)
Fats, oils and mixtures	0.2 (1.6%)	0.1 (0.6%)	0.3 (0.9%)	0.3 (1.4%)	0.2 (1.0%)	0.1 (0.8%)	0.1 (1.2%)	0.1 (1.4%)
Fish and mixtures	1.0 (8.6%)	0.2 (2.0%)	1.0 (3.7%)	0.9 (4.4%)	0.6 (4.0%)	0.6 (7.0%)	0.6 (5.3%)	0.9 (12.0%)
Fruits, vegetables and mixtures	1.1 (9.5%)	2.2 (18.4%)	2.9 (10.7%)	1.8 (8.5%)	1.2 (7.9%)	0.8 (9.3%)	1.1 (9.6%)	0.9 (10.8%)
Meat and mixtures	5.1 (43.7%)	2.9 (24.0%)	9.6 (35.3%)	8.1 (38.4%)	5.8 (39.1%)	4.1 (45.3%)	5.3 (44.2%)	2.9 (36.2%)
Other foods and mixtures[4]	1.7 (14.8%)	1.8 (15.1%)	3.3 (12.2%)	3.0 (14.3%)	2.2 (15.0%)	1.4 (15.6%)	1.8 (15.0%)	1.4 (17.2%)
Poultry and mixtures	0.5 (4.7%)	0.4 (3.5%)	1.0 (3.6%)	0.7 (3.2%)	0.5 (3.5%)	0.4 (4.8%)	0.5 (3.9%)	0.5 (5.8%)
Total	11.6 (100.0%)	12.0 (100.0%)	27.1 (100.0%)	21.1 (100.0%)	14.9 (100.0%)	9.1 (100.0%)	12.0 (100.0%)	7.9 (100.0%)
		Men 25-30 years	Women 40-45 years	Men 40-45 years	Women 60-65 years	Men 60-65 years	Women > 70 years	Men > 70 years
Dairy foods and mixtures		1.1 (11.5%)	0.9 (11.3%)	1.2 (12.2%)	0.8 (10.9%)	0.9 (10.0%)	1.0 (13.7%)	1.3 (13.6%)
Eggs and mixtures		0.3 (3.2%)	0.2 (2.3%)	0.2 (2.3%)	0.2 (2.9%)	0.3 (3.6%)	0.2 (3.1%)	0.3 (2.6%)
Fats, oils and mixtures		0.1 (1.4%)	0.1 (1.7%)	0.2 (1.6%)	0.1 (1.8%)	0.2 (1.7%)	0.1 (1.9%)	0.2 (1.9%)
Fish and mixtures		0.5 (5.5%)	0.8 (9.6%)	0.7 (7.6%)	1.2 (15.7%)	1.2 (12.6%)	1.0 (13.6%)	1.2 (12.6%)
Fruits, vegetables and mixtures		0.8 (7.6%)	0.8 (9.6%)	0.9 (9.5%)	0.8 (10.8%)	1.0 (10.1%)	0.9 (12.3%)	1.2 (12.3%)
Meat and mixtures		5.0 (50.4%)	3.6 (43.7%)	4.6 (47.3%)	3.0 (39.6%)	4.3 (45.1%)	2.7 (36.5%)	3.9 (40.5%)
Other foods and mixtures[4]		1.5 (15.0%)	1.4 (16.6%)	1.3 (13.7%)	1.1 (14.1%)	1.3 (13.3%)	1.1 (14.0%)	1.2 (12.4%)
Poultry and mixtures		0.5 (5.4%)	0.4 (5.3%)	0.6 (5.9%)	0.3 (4.2%)	0.3 (3.6%)	0.4 (4.9%)	0.4 (4.1%)
Total		9.9 (100.0%)	8.3 (100.0%)	9.7 (100.0%)	7.6 (100.0%)	9.4 (100.0%)	7.5 (100.0%)	9.7 (100.0%)

[1]PCDD/PCDF concentrations from U.S. Food and Drug Administration Total Diet Study (2001, 2002).
[2]Food Consumption based on the USDA 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII).
[3]Abbreviations: ND, Nondetects; LOD, Limit of Detection; TEQ, Toxicity Equivalents; WHO, World Health Organization; PCDD, polychlorinated dibenzo-*p*-dioxin; PCDF, polychlorinated dibenzofuran.
[4]Grains and mixtures, legumes and mixtures, beverages (other than milk and juice), candy.
[5]Reflects treatment of samples for which no dioxin congener was detected.

TABLE 3. Dietary PCDD/PCDF Exposure Estimate (pg WHO-TEQ/kg body weight/month) from Different Food Categories for Different Age-Sex Groups (ND=0.5LOD)

	Age-Sex Group							
Food Category	All Groups	Infants 6-11 months	Children 2 years	Children 6 years	Children 10 years	Girls 14-16 years	Boys 14-16 years	Women 25-30 years
Dairy foods and mixtures	2.6 (12.3%)	17.3 (48.2%)	11.0 (24.3%)	8.3 (23.2%)	5.8 (22.2%)	2.1 (11.6%)	3.3 (14.7%)	1.7 (11.0%)
Eggs and mixtures	0.4 (1.8%)	0.8 (2.1%)	1.4 (3.0%)	0.7 (1.9%)	0.5 (1.8%)	0.2 (1.3%)	0.3 (1.2%)	0.3 (1.9%)
Fats, oils and mixtures	0.2 (1.2%)	0.1 (0.3%)	0.3 (0.7%)	0.4 (1.0%)	0.2 (0.8%)	0.1 (0.7%)	0.2 (0.9%)	0.2 (1.0%)
Fish and mixtures	1.1 (5.3%)	0.3 (0.7%)	1.1 (2.5%)	1.0 (2.9%)	0.7 (2.6%)	0.7 (4.1%)	0.7 (3.3%)	1.0 (6.7%)
Fruits, vegetables and mixtures	2.9 (13.6%)	7.7 (21.5%)	8.0 (17.7%)	4.8 (13.4%)	3.4 (13.1%)	2.4 (13.2%)	2.8 (12.3%)	2.1 (13.8%)
Meat and mixtures	5.9 (28.1%)	3.4 (9.4%)	11.2 (24.8%)	9.6 (26.7%)	6.9 (26.1%)	4.8 (27.2%)	6.2 (27.5%)	3.4 (21.9%)
Other foods and mixtures[4]	7.1 (33.8%)	5.3 (14.7%)	10.6 (23.4%)	9.9 (27.8%)	8.0 (30.4%)	6.8 (38.1%)	8.3 (37.0%)	6.1 (39.4%)
Poultry and mixtures	0.8 (3.9%)	1.1 (3.1%)	1.6 (3.5%)	1.1 (3.1%)	0.8 (3.1%)	0.7 (3.8%)	0.7 (3.1%)	0.7 (4.4%)
Total	21.1 (100.0%)	35.9 (100.0%)	45.2 (100.0%)	35.8 (100.0%)	26.3 (100. 0%)	17.8 (100.0%)	22.4 (100.0%)	15.6 (100.0%)
		Men 25-30 years	Women 40-45 years	Men 40-45 years	Women 60-65 years	Men 60-65 years	Women > 70 years	Men > 70 years
Dairy foods and mixtures		1.6 (8.8%)	1.5 (9.5%)	1.8 (10.4%)	1.3 (9.9%	1.5 (9.5%)	1.7 (12.5%)	2.1 (12.8%)
Eggs and mixtures		0.4 (2.1%)	0.2 (1.6%)	0.3 (1.7%)	0.3 (2.0%)	0.4 (2.7%)	0.3 (2.1%)	0.3 (2.1%)
Fats, oils and mixtures		0.2 (1.0%)	0.2 (1.3%)	0.2 (1.2%)	0.2 (1.4%)	0.2 (1.4%)	0.2 (1.5%)	0.2 (1.5%)
Fish and mixtures		0.6 (3.4%)	0.9 (5.7%)	0.8 (4.7%)	1.3 (9.6%)	1.3 (8.4%)	1.1 (8.3%)	1.3 (8.3%)
Fruits, vegetables and mixtures		2.1 (11.4%)	2.1 (13.6%)	2.1 (12.2%)	2.3 (16.6%)	2.4 (15.2%)	2.6 (19.1%)	3.0 (18.3%)
Meat and mixtures		5.9 (31.4%)	4.2 (26.9%)	5.4 (30.9%)	3.5 (25.4%)	5.0 (31.8%)	3.3 (24.0%)	4.5 (28.0%)
Other foods and mixtures[4]		7.1 (37.7%)	5.8 (37.3%)	5.9 (34.0%)	4.3 (31.5%)	4.3 (27.7%)	3.9 (28.4%)	4.1 (25.4%)
Poultry and mixtures		0.8 (4.3%)	0.7 (4.2%)	0.8 (4.8%)	0.5 (3.5%)	0.5 (3.3%)	0.6 (4.1%)	0.6 (3.6%)
Total		18.7 (100.0%)	15.6 (100.0%)	17.5 (100.0%)	13.6 (100.0%)	15.6 (100.0%)	13.6 (100.0%)	16.2 (100.0%)

[1]PCDD/PCDF concentrations from U.S. Food and Drug Administration Total Diet Study (2001, 2002).
[2]Food Consumption based on the USDA 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII).
[3]Abbreviations: ND, Nondetects; LOD, Limit of Detection; TEQ, Toxicity Equivalents; WHO, World Health Organization; PCDD, polychlorinated dibenzo-*p*-dioxin; PCDF, polychlorinated dibenzofuran.
[4]Grains and mixtures, legumes and mixtures, beverages (other than milk and juice), candy.
[5]Reflects treatment of samples for which no dioxin congener was detected.

TABLE 4. Dietary PCDD/PCDF Exposure Estimate (pg WHO-TEQ/kg body weight/month) from Different Food Categories for Different Age-Sex Groups (ND=LOD)

	Age-Sex Group							
Food Category	All Groups	Infants 6-11 months	Children 2 years	Children 6 years	Children 10 years	Girls 14-16 years	Boys 14-16 years	Women 25-30 years
Dairy foods and mixtures	3.5 (11.5%)	30.9 (51.7%)	14.1 (22.2%)	10.8 (21.5%)	7.6 (20.3%)	2.7 (10.3%)	4.3 (13.1%)	2.3 (10.1%)
Eggs and mixtures	0.5 (1.5%)	0.9 (1.4%)	1.6 (2.5%)	0.8 (1.6%)	0.6 (1.5%)	0.3 (1.1%)	0.3 (1.0%)	0.4 (1.5%)
Fats, oils and mixtures	0.3 (1.0%)	0.1 (0.2%)	0.4 (0.6%)	0.4 (0.9%)	0.3 (0.7%)	0.2 (0.6%)	0.2 (0.7%)	0.2 (0.9%)
Fish and mixtures	1.2 (4.1%)	0.3 (0.5%)	1.3 (2.0%)	1.2 (2.3%)	0.8 (2.0%)	0.8 (3.1%)	0.8 (2.6%)	1.1 (4.9%)
Fruits, vegetables and mixtures	4.6 (15.1%)	13.2 (22.1%)	13.1 (20.6%)	7.8 (15.5%)	5.7 (15.1%)	3.9 (14.6%)	4.4 (13.3%)	3.4 (14.8%)
Meat and mixtures	6.8 (22.2%)	3.9 (6.5%)	12.9 (20.3%)	11.0 (21.9%)	7.9 (21.0%)	5.5 (21.0%)	7.0 (21.4%)	3.9 (17.0%)
Other foods and mixtures[4]	12.6 (41.1%)	8.7 (14.6%)	17.9 (28.2%)	16.9 (33.4%)	13.8 (36.4%)	12.1 (45.9%)	14.8 (45.0%)	10.9 (46.9%)
Poultry and mixtures	1.1 (3.6%)	1.8 (3.1%)	2.2 (3.4%)	1.5 (3.0%)	1.1 (3.0%)	0.9 (3.4%)	0.9 (2.9%)	0.9 (3.9%)
Total	30.6 (100.0%)	59.8 (100.0%)	63.4 (100.0%)	50.5 (100.0%)	37.7 (100.0%)	26.5 (100.0%)	32.8 (100.0%)	23.2 (100.0%)
		Men 25-30 years	Women 40-45 years	Men 40-45 years	Women 60-65 years	Men 60-65 years	Women > 70 years	Men > 70 years
Dairy foods and mixtures		2.2 (7.8%)	2.0 (8.9%)	2.5 (9.7%)	1.9 (9.5%)	2.0 (9.3%)	2.4 (12.1%)	2.8 (12.5%)
Eggs and mixtures		0.5 (1.7%)	0.3 (1.3%)	0.4 (1.5%)	0.3 (1.7%)	0.5 (2.3%)	0.3 (1.7%)	0.4 (1.8%)
Fats, oils and mixtures		0.2 (0.8%)	0.3 (1.1%)	0.3 (1.1%)	0.2 (1.3%)	0.3 (1.2%)	0.3 (1.3%)	0.3 (1.4%)
Fish and mixtures		0.7 (2.6%)	1.0 (4.3%)	0.9 (3.6%)	1.4 (7.2%)	1.4 (6.6%)	1.2 (6.2%)	1.5 (6.4%)
Fruits, vegetables and mixtures		3.5 (12.7%)	3.4 (15.0%)	3.4 (13.3%)	3.7 (18.8%)	3.8 (17.4%)	4.3 (21.7%)	4.7 (20.9%)
Meat and mixtures		6.8 (24.5%)	4.8 (20.8%)	6.2 (24.6%)	3.9 (20.0%)	5.6 (26.0%)	3.8 (19.3%)	5.1 (22.6%)
Other foods and mixtures[4]		12.6 (45.9%)	10.3 (44.8%)	10.6 (41.9%)	7.5 (38.2%)	7.4 (34.0%)	6.7 (33.9%)	7.0 (31.0%)
Poultry and mixtures		1.1 (3.9%)	0.9 (3.8%)	1.1 (4.3%)	0.6 (3.3%)	0.7 (3.2%)	0.7 (3.8%)	0.8 (3.4%)
Total		27.5 (100.0%)	22.9 (100.0%)	25.2 (100.0%)	19.7 (100.0%)	21.7 (100.0)	19.6 (100.0%)	22.7 (100.0%)

[1]PCDD/PCDF concentrations from U.S. Food and Drug Administration Total Diet Study (2001, 2002).
[2]Food Consumption based on the USDA 1994-1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII).
[3]Abbreviations: ND, Nondetects; LOD, Limit of Detection; TEQ, Toxicity Equivalents; WHO, World Health Organization; PCDD, polychlorinated dibenzo-*p*-dioxin; PCDF, polychlorinated dibenzofuran.
[4]Grains and mixtures, legumes and mixtures, beverages (other than milk and juice), candy.
[5]Reflects treatment of samples for which no dioxin congener was detected.