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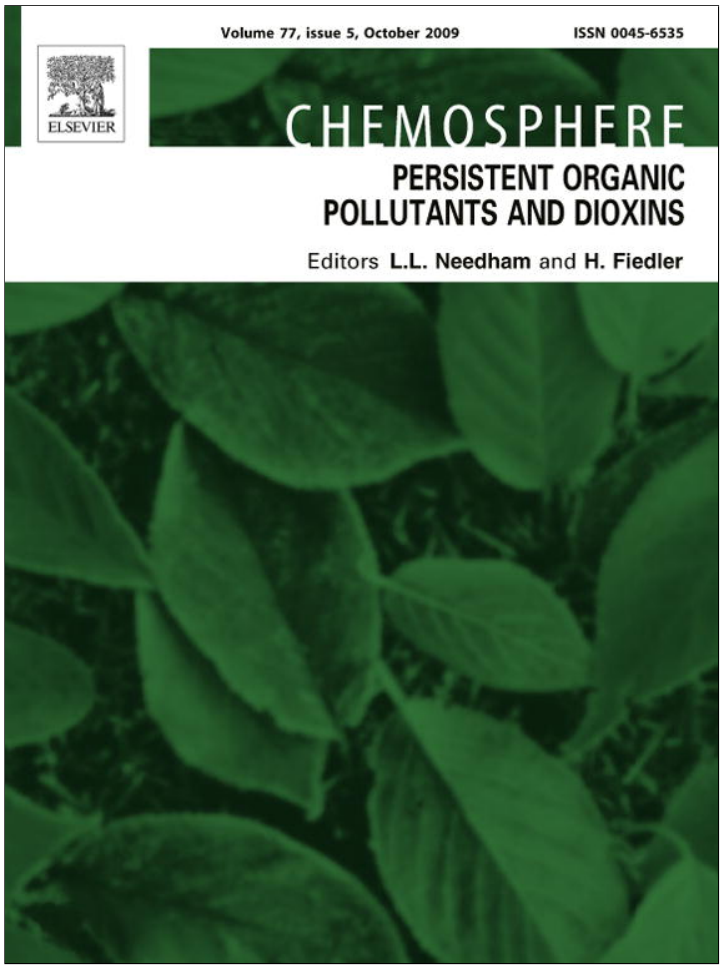

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Evaluation of background exposures of Americans to dioxin-like compounds in the 1990s and the 2000s

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ABSTRACT

The US Environmental Protection Agency's 2004 Dioxin Reassessment included a characterization of background exposures to dioxin-like compounds, including an estimate of an average background intake dose and an average background body burden. These quantities were derived from data generated in the mid-1990s. Studies conducted in the 2000s were gathered in an attempt to update the estimates generated by the Reassessment. While these studies suggest declines in the average background dose and body burden, a precise quantification of this decline, much less a conclusion that a decline has indeed occurred, cannot be made because of the inconsistency of study design and data sources, and the treatment of non-detects in the generation of congener average concentrations. The average background intake of the Reassessment was 61.0 pg TEQ/day, and using more current data, the average background intake was 40.6 pg TEQ/day. The average body burden from the surveys in the mid-1990s was 22.9 pg TEQ/g lipid weight (pg/g lwt). More recent blood concentration data, from NHANES 2001/2, suggest an adult average at 21.7 pg/g TEQ lwt. These TEQ values include the 17 dioxin and furan congeners and 3 coplanar PCBs, and were generated substituting ND = ½ DL or ND = DL/sq rt (2). Results are provided for ND = 0 and analyses conducted to evaluate the impacts of this substitution. A more detailed examination of beef and pork data from similarly designed national statistical surveys show that declines in pork are statistically significant while the beef concentrations appeared to have remained constant between the time periods.

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1. Introduction

In April 1991, the United States (US) Environmental Protection Agency (EPA) began a scientific reassessment of the health risks of exposure to 2378-TCDD and dioxin-like compounds (hereafter referred to as the Reassessment). This effort has resulted in a comprehensive multi-volume assessment report (US EPA, 2003a), which was reviewed by the EPA's Science Advisory Board in 1994 and 2000, and by the National Academies of Science (NAS) beginning in 2004 and concluding in 2006 (NAS, 2006). To date, EPA has not finalized the Reassessment; the NAS review draft (US EPA, 2003a) is the most current draft of the Reassessment. The characterization of background exposures to dioxin-like compounds in the Reassessment included an estimate of a background intake dose, expressed in pg Toxic Equivalent (TEQ)/day or pg TEQ/kg body weight/day, and a body burden, expressed in pg TEQ/g lipid weight (pg/g lwt), or pg TEQ/g whole weight (pg/g wwt), representative of the general population of the US. While information was provided on childhood exposures and exposures to special populations, this update focuses on the background adult exposure estimates provided in the Reassessment.

The NAS Review Draft (US EPA, 2003a) of the Reassessment provided these estimates: the background daily dose was 65.8 pg TEQ/day (42.7 pg of dioxin/furan, or PCDD/PCDF, TEQ and 23.1 pg coplanar PCB TEQ) and the background body burden was provided as 25.4 pg TEQ/g lipid (20.1 pg/g of PCDD/PCDF TEQ and 5.3 pg/g coplanar PCB TEQ). These estimates were developed as arithmetic averages using data generated during the middle 1990s. Congener averages and resulting TEQ concentrations were derived assuming non-detects were equal to one-half the detection limit (ND = ½ DL). These estimates also were derived using the World Health Organization (WHO) 1998 Toxic Equivalency Factor (TEF) scheme (Van den Berg et al., 1998). To avoid confusion, all TEQ values in this study were derived using the WHO-2005 TEFs (Van den Berg et al., 2006). In addition to a rederivation based on a different TEF scheme, these NAS Review Draft estimates were re-derived assuming non-detects are equal to zero (ND = 0).

The purpose of this study is twofold: to provide updated estimates of dose and body burden of dioxin-like compounds, using

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data collected between 2000 and 2004, and to examine the data more closely to determine whether declines have occurred. This examination highlights the disparity in study design, data sources, and laboratories conducting the trace analyses for the background food samples and blood. These updated dose and body burdens are derived in a manner that is as analogous as possible to the mid-1990s estimates of the Reassessment, so that comparisons of the two sets of estimates can be meaningful. Current estimates will be derived using both substitution methods, ND = ½ DL and ND = 0. The update on the intake dose will use more recent data on PCDD/PCDFs and PCBs in food. The body burden data from the Reassessment included six different regional studies of PCDD/PCDFs and PCBs in background populations, and this will be updated using the more valid national, statistical survey known as the National Health and Nutritional Examination Survey, or NHANES. Statistically based, national averages of congener concentrations in blood were derived from individuals within the 2001/2 NHANES data set, and these averages were derived at ND = 0 and ND = DL/$\sqrt{2}$.

In addition to these substitutions, a variation is to substitute non-detects with the detection limit (ND = DL), or even more rigorously, to statistically extrapolate below the detection limit based on the distribution of the population above the detection limit. While arguments can be presented for adoption of any of the substitution methods, the Reassessment concluded that the background characterizations were best generated at ND = ½ DL. That is used here for generation of intake doses, although the available analysis of NHANES data used the alternative, ND = DL/$\sqrt{2}$. If the analytical detection limits are sufficiently low and/or quantifications are possible for a large majority of congener measurements in a population, then average congener concentrations calculated at ND = 0 and any of the other substitution methods will be similar. On the other hand, a meaningful disparity in congener averages (or other statistical measures, for that matter) at ND = 0 versus one of the other methods suggests that the detection limits may be too high for the matrix being studied. For example, if 2378-TCDD (the most toxic congener) is not detected frequently (as is often the case), then the TEQ concentration can be heavily influenced by which substitution method is used for non-detects for 2378-TCDD. A primary focus of this study is to evaluate the impact of the substitution method on the generation of survey average congener and TEQ concentrations, and the subsequent impact to the background characterizations of dioxin dose and body burden.

It is noted that the focus of this evaluation is on TEQ and not on the individual congeners which comprise the TEQ. Such an analysis could mask different trends in the exposure to individual congeners.

2. Methods

In the Reassessment, dose estimates were provided for inhalation, soil ingestion, soil dermal contact, water ingestion, and for 10 food ingestion categories including beef, pork, poultry, "other meats" (game, lamb, unidentified meat in casseroles, etc.), eggs, milk, dairy, marine fish, freshwater fish, and vegetable oils. Each pathway estimate was derived as a point estimate using an arithmetic average adult per capita contact rate (i.e., inhalation rate, water ingestion rate, food ingestion rate, and so on) coupled with a concentration in the exposure media derived as an arithmetic average concentration from one or more surveys. The dose estimates were dominated by ingestion of animal food products: ingestion of beef, pork, poultry, other meats, dairy, eggs, milk, and fish comprised 93% of total exposures. For this reason, and for the sake of expediency, other pathways (water/soil/vegetable oil ingestion, inhalation, soil dermal contact) are not updated here, while newer food survey information is used to update the food intake estimates.

The Reassessment body burden estimate was derived as an arithmetic average from six different blood surveys of general background populations totaling 316 individuals. Substantially more valid characterizations of national background adult body burdens are now available from NHANES, and these are used here. Specifically, arithmetic average congener concentrations are available from the NHANES 2001/2 surveys for use in this update.

As noted earlier, the Reassessment average body burdens and intake doses were derived using the WHO-1998 TEFs (Van den Berg et al., 1998). These quantities are re-derived using the WHO-2005 TEFs (Van den Berg et al., 2006), and all current TEQ quantities are similarly derived using the 2005 TEFs. Furthermore, all the TEQ quantities provided include the 17 dioxin and furan congeners, and the three coplanar (non-ortho) PCBs including PCBs 77, 126, and 169. Only in the case of the human blood data are concentrations presented for mono-ortho PCBs, and these are presented for information purposes only in Table 3.

Following the update to these quantities, there is a more in-depth analysis of the national statistical surveys conducted by the EPA and the USDA for beef and pork. Like the NHANES study, the national surveys on beef and pork are statistically-based surveys. The surveys conducted in mid-1990s were conducted in partnership by EPA and USDA, and they were later repeated with the same survey design by USDA alone in the early 2000s. These studies were stratified by animal classes, and a 2-stage sampling design selected first slaughterhouses and then animals within slaughterhouses to sample. By using this statistical approach, national statistics could be generated which covered the large majority of all beef and pork consumed in the US (only home-produced foods or imported foods would not be considered, and these categories comprise a very small fraction of total consumption). More details on the surveys are provided in the references (Winters et al., 1996a,b; Lorber et al., 1997; Hoffman et al., 2006). Beef and pork were chosen for an in-depth analysis because a preliminary evaluation of the data suggests an important difference in temporal trends: the beef data showed little or no change over time while the pork data suggested the steepest of declines in concentration. The statistically weighted results from the surveys are first examined, and then a second analysis of a subset of the raw data from both surveys is conducted.

The 2002/3 beef and pork surveys (Hoffman et al., 2006) did not sample all animal types that were sampled in the mid-1990s surveys (Winters et al., 1996a,b; Lorber et al., 1997): the 2002/3 surveys focused on animal classes comprising about 90% of all animals slaughtered. For this second analysis, the raw data from the two surveys for only the animal classes sampled in the 2002/3 surveys were retrieved and analyzed. Specifically, 51 steer and heifer (beef) and 56 market hog (pork) samples from the mid-1990s surveys were compared with 139 steer and heifer and 136 market hog samples from the early 2000s surveys. The analysis does not consider the statistical weighting of these animals. This decision was made because of the possibility that statistical weighting could result in an unintended bias for the mid-1990s surveys, which had much fewer animals (51 and 56 animals) as compared to the 2002/3 surveys (139 and 136 animals) even though they were both representing the same overall populations of steers/heifers and market hogs. In order to study the data from the two time periods in the most analogous way, the data were "normalized". The beef and pork surveys of the early 2000s had lower detection limits for nearly all congeners as compared to the analogous surveys of the mid-1990s. Therefore, the procedure to "normalize" the data sets entailed reassigning several values in the 2002/3 data sets, and a smaller number of values in the mid-1990s surveys. Specifically, the congener quantified values in the 2002/3 dataset which

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fell below the early mid-1990s detection limits were set to non-detects to create an artificial dataset. In the few cases where the earlier surveys had lower DLs than the 2002 survey, similar transformations were made to the 2002 survey. Specifically, only 2 of 20 beef congeners (2378-TCDD and PCB 77) and 2 of 20 pork congeners (OCDD and PCB 77) had lower detection limits in the mid-1990s surveys, and so the 2002/3 data were transformed for these congeners.

In addition to comparing congener means (at ND = 0) and prevalence of quantified detects in these normalized data sets, the Wilcoxon rank sum test was applied to each pair of analogous congener sets – 2378-TCDD in beef for both survey time periods, for example. The Wilcoxon rank sum test is a test for assessing whether two sample sets of data come from the same distribution. The test is non-parametric so that no assumption for a particular distribution function (e.g., log normal) is required. The null hypothesis is that the distributions that the samples were drawn from are equivalent. The test examines whether there is a difference in the location of the two distributions. The two sided version of the test (used here) is applied when there is no reason to expect that the difference in location is in one direction or another. The rule-of-thumb is that when the p value from this test is less than or equal to 0.05, it is concluded that the null hypothesis is false; that is, it is likely that the distributions from which the samples are drawn are not the same distributions. This test is run using the shareware statistical package R, version 2.8.1.

Finally, the updated intake estimates are compared with another effort to characterize dioxin intakes from food consumption. This was an effort conducted by the US Food and Drug Administration (FDA) using data from food samples collected between 2001 and 2004, and it includes only dioxins and furans.

3. Results

3.1. Dose intake updates

3.1.1. Food ingestion rates

The beef/pork/poultry/dairy/milk ingestion rates in the Reassessment were mean adult per capita ingestion rates taken from EPA's 1997 *Exposure Factors Handbook* (EFH; US EPA, 1997), and rates in that guidance were developed from the United States Department of Agriculture (USDA) Continuing Survey of Food Intakes among Individuals (CSFII) 1-day 1989–1991 survey. EPA has now analyzed the CSFII 2-day 1994–1996 surveys (US EPA, 2003b) but arrives at essentially the same food consumption rates suggesting that there had been little change in dietary habits between the late 1980s and mid-1990s. For example, beef intake rises from 0.71 to 0.73 g/kg-day, while pork ingestion drops from 0.22 to 0.20 g/kg-day. Further CSFII surveys and the NHANES national survey can provide updated food consumption rates at a later date, but it is expected that average per capita consumption will change little. Because little change in dietary habits is reflected in EPA's two compilations of CSFII data, the same contact rates used in the Reassessment are used in this update. By not changing contact rates, the analysis and conclusions regarding changes in TEQ intakes are based on changes in the presence of PCDD/PCDF and PCBs in foods. Because these rates are in whole weight (wwt) units, PCDD/PCDF and PCB concentrations reported on a lipid weight (lwt) basis must be changed to a wwt basis. The assumptions on the lipid content of consumed foods from the Reassessment are used here, including milk being 1.8% lipid, dairy – 12%, beef – 17%, pork – 19%, and poultry – 9%. Rates expressed in the Reassessment in g/kg-day have been converted to a g/day basis assuming a 70-kg adult; this was also assumed in the Reassessment. The fish ingestion rates for the Reassessment were developed from a 2000 EPA Office of Water document on fish consumption rates (US EPA, 2000), and these rates were used here as well. The Reassessment distinguished between freshwater (5.9 g/day) and marine fish (9.6 g/day). The two rates are added here, for a total of 15.5 g/day, to correlate with fish concentration values from a recent and comprehensive Food and Drug Administration (FDA) survey of market basket fish that included freshwater and marine species (FDA, 2007).

3.1.2. Beef/pork/poultry concentrations

The Reassessment relied on national, statistically-based surveys of these products, conducted in conjunction with USDA, collecting samples from slaughterhouses around the US in the mid-1990s (Winters et al., 1996a,b; Ferrario et al., 1997; Lorber et al., 1997). The mean concentrations found from these surveys, calculated assuming ND = ½ DL, were used in the Reassessment. The references for these surveys also included congener averages calculated at ND = 0, and these averages are used in this study to calculate intakes at ND = 0. Important differences were noted for the two substitution methods. For example, the pork average lipid concentration dropped from 1.41 pg TEQ/g lwt at ND = ½ DL to 0.47 pg TEQ/g lwt at ND = 0. These surveys were redone with mostly the same statistical design by USDA in 2002/3, and the mean concentrations, calculated assuming ND = ½ DL and 0, are used here (Hoffman et al., 2006). As will be discussed below, the analytical chemistry was different in the two sets of surveys, resulting in detection limits that importantly influenced the mean concentrations calculated using both substitutions for non-detects. In saying that the surveys were redone with "mostly" the same design, it is noted that another difference was that the mid-1990s surveys included all classes of animals which are slaughtered, so that 100% of all animals are represented by at least one sample. In contrast, the updated surveys did not sample all slaughter classes; they captured about 90% of all slaughter classes. For example, the beef survey conducted in the mid-1990s included: steers (which comprise about 52% of all animals slaughtered), heifers (28%), beef and dairy cows (about 9% each), and bulls (about 2%). When redone in the early 2000s, only the steers and heifers were sampled. This might be important because the bulls had the highest TEQ concentrations measured in the earlier survey. The TEQ concentrations in the two bull samples were 3 to 10 times higher than the other four animal classes (Winters et al., 1996a). This was not an unexpected result because bulls live the longest (hence accumulate more dioxins) and do not excrete PCDD/PCDFs and PCBs through milk. So while they only comprise about 2% of all beef consumed, they could make at least a small difference in national average TEQ concentrations in beef.

3.1.3. Other meats

"Other meats" represents total meat intake, as characterized in the *Exposure Factors Handbook* (EPA, 1997) minus the intake rates for beef, pork, and poultry. Other meats could include lamb, game, etc. Because concentrations are not available, it was assumed that the concentrations were equal to the average of beef, pork, and poultry.

3.1.4. Milk/dairy

Composite milk samples were taken around the country in four sampling events from April 1996 to January 1997 from EPA's Environmental Radiation Ambient Monitoring System (ERAMS), and analyzed for dioxin-like compounds (Lorber et al., 1998). Results were used to characterize exposure to milk and dairy (dairy lipid concentrations were assumed to be equal to milk lipid concentrations) in the Reassessment. This monitoring network was revisited in July, 2000 and January, 2001 to similarly gather a national sample for measurement of dioxin-like compounds and other toxic

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contaminants (Schaum et al., 2003; Schuda et al., 2004), and results from this second sampling were used in this update. Schaum et al. (2003) note that the PCDD/PCDF TEQ concentrations are 15% less at ND = 0, but that PCB TEQ concentrations are unaffected by the treatment of non-detects. Congener-specific data provided in Lorber et al. (1998) suggest no difference in PCDD/PCDF or PCB concentrations at ND = 0.

3.1.5. Fish

To characterize PCDD/PCDF concentrations in fish, the Reassessment used data from a 1990 national survey of PCDD/PCDF in fish from EPA (US EPA, 1992), from a market-basket survey in Mississippi conducted in 1995 (Fiedler et al., 1997), and from an FDA study entailing about 180 retail samples of fish and shellfish from around the country collected in 1995 and 1996 (Jensen and Bolger, 2001). Similar market basket/retail data from around North America in the mid-1990s and earlier were used to characterize PCB TEQ concentrations (Mes et al., 1991; Schecter et al., 1997). The final average concentrations used to characterize all fish (which were broken out into freshwater and marine fish in the Reassessment) were 0.54 pg/g PCDD/PCDF TEQ wwt and 0.61 pg/g PCB TEQ wwt. To update the PCDD/PCDF concentrations, data more recently collected by FDA was used. Specifically, the FDA collected a total of 722 samples of fish from the marketplace between 2001 and 2003, including 531 finfish (catfish, trout, tuna, bass, wild and aquaculture, halibut, flounder, etc.) and 191 shellfish (clam, crab, oyster, etc.), and measured them for PCDD/PCDFs (FDA, 2007). The average PCDD/PCDF TEQ concentration at ND = ½ DL was 0.33 pg/g TEQ wwt (note: this was the average over all 722 fish, not weighted by fish consumption patterns. For example, 120 catfish samples contributed 120 concentrations to the 722 sample set concentration-average even though catfish is not necessarily that prominent in a typical diet). There were no data found to update PCB concentrations, so the earlier weighted average concentration of 0.61 pg/g TEQ wwt was used to characterize exposure in the early 2000s. In order to provide concentrations at ND = 0 for the Reassessment recalculation, simplifications were made because the detailed data from the various references used by the Reassessment were unavailable. First, the FDA (2007) more recent data did, in fact, include average concentrations at ND = 0, 0.23 pg/g TEQ. As a simplistic assumption, it will be assumed that a similar 30% reduction (i.e., 100% – [0.23/0.33] $*$ 100%) in calculated PCDD/PCDF TEQ mean concentration pertains to the Reassessment data – it would drop from 0.54 to 0.38 pg/g TEQ at ND = 0. For PCBs, information was available on the effect of the detection limit on the results presented in one of two articles used by the Reassessment to determine a concentration of PCBs in fish. Specifically, the marine fish average PCB TEQ concentration from Schecter et al. (1997) would drop from 0.26 to 0.22 pg/g TEQ wwt, and the freshwater fish drops from 1.04 to 0.64 pg/g TEQ wwt when assuming ND = 0 (using raw data from Schecter et al. and 2005 TEFs). Using this information, the weighted concentration of 0.61 pg/g TEQ wwt for PCBs was assumed to drop to 0.47 pg/g TEQ wwt at ND = 0 (considering the fraction of total fish consumption that is marine versus freshwater, as well as the percent decline within each category).

3.1.6. Eggs

In the same recent market-basket survey which included fish noted above, the FDA (FDA, 2007) collected 71 egg samples, with an average PCDD/PCDF concentration of 0.06 pg/g TEQ wwt (ND = ½ DL), compared to 0.08 pg/g TEQ wwt in the Reassessment from Hayward and Bolger (2000). At ND = 0, the recent FDA data show a drop to 0.04 pg/g TEQ wwt, and the Reassessment notes a recalculation to 0.013 pg/g TEQ wwt at ND = 0. Updated data for PCBs, as well as data for ND = 0, could not be found, so the Reassessment value of 0.10 pg/g TEQ wwt was used in this update for both ND = ½ DL and ND = 0.

Table 1 provides a summary of the data used to calculate intake doses for the two time periods. Contact rates as generated within the Reassessment, and used for both time periods, are shown in the first column. The next two columns provide the PCDD/PCDF and PCB TEQ concentrations for the mid-1990s, and the final two columns provide the PCDD/PCDF and PCB TEQ concentrations for the estimate pertinent to the early 2000s. The TEQ concentrations assuming ND = 0 are shown in parenthesis. When congener-specific concentration data were available (for example, for beef/pork/poultry/milk), the TEQ concentrations were derived using the WHO-2005 TEF values (Van den Berg et al., 2006). For the Reassessment concentrations, using these more recent 2005 TEF values led to TEQ concentrations that were 6–7% lower when compared to the WHO-1998 TEF values. This is primarily driven by reductions in the TEF for two important furan congeners: 12378-PCDF dropped from 0.05 to 0.03, and 23478-PCDF dropped from 0.5 to 0.3. Also, to be consistent with the current food data, which for beef, pork, and poultry only included three coplanar (non-ortho) PCB congeners – 77, 126, and 169 – the earlier food data PCB TEQ concentrations were recalculated using these three congeners only, and this resulted in about an additional 1–2% reduction in TEQ as reported on in the Reassessment (only a small difference is noted because PCB 126 dominates PCB TEQ concentration and the PCB 126 TEF did not change from WHO-1998 to WHO-2005). When congener-specific data were unavailable (for fish, specifically), it was assumed that the recalculation from the WHO-1998 TEQ to the WHO-2005 TEQ resulted in a 6% decline, and this was used for all pertinent estimates.

Finally, it was noted earlier that the pathways of inhalation, water consumption, soil ingestion and dermal contact, and vegetable fat ingestion only explained a small percentage of overall exposure. The Reassessment calculated total PCDD/PCDF TEQ adult dose from these pathways to be 3.1 pg TEQ/day, of a total of 43.1 pg TEQ/day, and the PCB TEQ dose was 0.8 pg TEQ/day, of a total of 23 pg TEQ/day (quantities noted here used WHO-1998 TEFs). These estimates will be reduced by 6% to consider the change to WHO-2005 TEQ, but no efforts are made to further reduce these to consider ND = 0 or the difference between the mid-1990s and more current times.

Table 2 shows the pathway-specific TEQ intakes, for both time periods, and calculated at ND = ½ DL and 0. This exercise suggests a reduction in dose from the mid-1990s to the early 2000s. The mid-1990s dose was estimated at 61.0 pg TEQ/day at ND = ½ DL and 43.7 pg TEQ/day at ND = 0. For the early 2000s, the dose at ND = ½ DL was 40.6 pg TEQ/day and at ND = 0, it was 34.5 pg TEQ/day.

An examination of the food concentration data in Table 1 provides some insight as to the trends in exposure over time. Specifically, it is seen that for all food categories except beef, there was a reduction in TEQ concentration when viewing the analogous substitution method. For example, there was a reduction in pork concentrations from 0.260 pg/g TEQ wwt in the mid-1990s to 0.036 pg/g TEQ wwt in 2002/3 at ND = ½ DL, and at ND = 0, reductions were also noted, going from 0.083 pg/g TEQ wwt to 0.022 pg/g TEQ wwt. These are reductions greater than 70%. Hoffman et al. (2006) recognized the importance of the substitution method for non-detects when the USDA reported on these updated national food surveys, and in comparing their new data with the earlier mid-1990s surveys, they presented results at both ND = ½ DL and 0 as was done here, although their presentation was lipid-based. They found beef, pork and poultry to drop when comparing the two time periods at ND = ½ DL. However, at ND = 0, pork and poultry were lower but beef concentrations were higher in the 2002/3 data set. This is also seen

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Table 1
Exposure contact rates and toxic equivalent (TEQ) media concentrations used to generate background adult intake estimates for the mid-1990s and the early 2000s (TEQ concentrations presented at ND = ½ DL with ND = 0 provided in parenthesis. All food concentrations in pg/g as consumed, and consumption rates are similarly g consumed/day).

Exposure pathway	Ingestion rate (g/day)	Mid-1990s, pg TEQ/g food consumed		Early 2000s, pg TEQ/g food consumed	
		PCDD/PCDF	PCB	PCDD/PCDF	PCB
Beef	49.7	0.171 (0.060)	0.073 (0.073)	0.120 (0.114)	0.022 (0.022)
Pork	15.4	0.260 (0.083)	0.007 (0.005)	0.036 (0.022)	0.006 (0.005)
Poultry	35.0	0.063 (0.040)	0.017 (0.017)	0.018 (0.013)	0.007 (0.007)
Other meat	24.5	0.165 (0.061)	0.032 (0.032)	0.058 (0.049)	0.012 (0.011)
Fish	15.5	0.54 (0.38)	0.61 (0.47)	0.33 (0.23)	0.61 (0.47)
Milk	175.0	0.017 (0.017)	0.007 (0.007)	0.012 (0.010)	0.005 (0.005)
Dairy	55.0	0.111 (0.110)	0.045 (0.045)	0.079 (0.067)	0.035 (0.035)
Eggs	16.8	0.080 (0.013)	0.10 (0.10)	0.06 (0.04)	0.10 (0.10)

Table 2
Estimated TEQ intakes for the mid-1990s and the early 2000s, calculated at non-detects equal one-half detection limit and non-detects equal zero.

Exposure pathway	Mid-1990s, PCDD/PCDF/ PCB TEQ intakes (pg/day)		Early 2000s, PCDD/PCDF/ PCB TEQ intakes (pg/day)	
	ND = ½ DL	ND = 0	ND = ½ DL	ND = 0
Beef	12.1	6.6	7.1	6.7
Pork	4.1	1.4	0.6	0.4
Poultry	2.8	2.0	0.9	0.7
Other meat	4.8	2.3	1.7	1.5
Fish	17.8	13.2	14.6	10.9
Milk	4.1	4.1	3.0	2.7
Dairy	8.6	8.6	6.3	5.6
Eggs	3.0	1.9	2.7	2.4
Other[a]	3.7	3.7	3.7	3.7
Totals	61.0	43.7	40.6	34.5

[a] "Other" pathways include consumption of water, inhalation of air, ingestion of soil, soil dermal contact, and vegetable fat intake. See text for more detail.

in Table 1 – the average beef PCDD/PCDF concentration at ND = 0 in the mid-1990s was 0.060 pg/g TEQ wwt, while in the 2002/3 survey, it was 0.114 pg/g TEQ wwt. This higher 2002/3 concentration could reflect a small rise in concentrations or a relatively stable concentration profile in beef over time. Specifically, this might simply be the result of improved analytical methods with lower detection limits in the more recent survey. The mean concentration for the second population might be higher than the first population because more samples showed non-zero concentrations with the lower detection limits.

This same comparison was done for the national milk surveys done by EPA. The milk TEQ concentrations were found to decline by about the same amount, about 30%, whether calculating at ND = ½ DL or 0. This is because both TEQ average concentrations were derived from eight composites from national milk sampling, and as such, there was a large volume of milk to analyze per composite, low detection capabilities, and sufficiently high frequencies of detection for all congeners. The data on fish and eggs were from disparate data sets, so while a decline from the mid-1990s to the early 2000s is seen in Table 1, this decline cannot be examined further.

So, in summary, this comparison of means at both substitution methods suggests that "real" reductions in TEQ concentrations possibly occurred for pork, poultry, and milk, while for beef the trend is unclear – there may have been a small decline or there may have even been a small increase in concentrations. In order to gain further insight into the impact of the detection limit, the prevalence of non-detects in the data, and the substitution method on the national average concentrations, the differences between the two time periods for both beef and pork are now examined in more depth below. As noted in the Methods section, these two were chosen because they represent the extremes here – the beef data looks ambiguous while the pork data seems to show the greatest decline.

3.2. Corroborating evidence for TEQ intakes in the 2000s

The updated intake estimate can be compared with a similar effort to derive national intakes of TEQ by food. The FDA analyzes the presence of various contaminants in a "Total Diet Survey" (TDS) which is conducted annually. They develop the list of sampled foods from CSFII data, and then combine concentrations of contaminants found with average per capita CSFII intake rates to derive estimates of average dietary intakes for males and females, for various age categories. Based on food sampled between 2001 and 2004 (with concentrations calculated at ND = 0, ½ DL, and DL), and CSFII 94–96 average per capita consumption rates, FDA calculated intakes of PCDD/PCDF TEQ for 8 adult categories, 4 male and 4 females, at age ranges 25–30, 40–45, 60–65, and >70 years (FDA, 2007). Taking the average intakes for these eight categories, daily PCDD/PCDF TEQ intakes at ND = ½ DL and 0 are 31 and 16 pg TEQ/day, respectively. These were calculated using the WHO-1998 TEF values, and as noted above, WHO-2005 TEF values suggest about a 7% reduction in TEQ food concentrations, so the estimate of 31 pg TEQ/day might be 29 pg TEQ/day using the updated TEFs. To make this estimate of 29 pg TEQ/day more comparable to current estimates, it may also be appropriate to subtract out TDS categories described as "fruit, vegetables, and mixtures" and "other foods and mixtures" (grains and mixtures, legumes and mixtures, beverages other than milk and juice, and candy) since these categories were not included in the food intakes of the Reassessment dose estimates. The other food categories of the TDS are analogous to the Reassessment categories, and include, for example, "meat and mixtures", "poultry and mixtures", "fish and mixtures", and so on. The average adult intakes of the "fruits, vegetables, and mixtures" and "other foods and mixtures" categories equals about 6 pg TEQ/day, so subtracting these from the overall estimate leads to 23 pg TEQ/day. This compares reasonably well to the current updated estimate at ND = ½ DL of 21 pg TEQ/day (derived from information in Table 1; specifically, PCDD/PCDF concentrations combined contact rates and then summed to get 21 pg TEQ/day of PCDD/PCDF only), and perhaps it can be stated that the FDA intake estimates corresponding to the early years of 2000s support the calculations done in this paper corresponding to the same time frame.

It should be noted that these FDA intake estimates, which were provided for ND = 0, ½ DL, and DL, were themselves influenced by detection limits. For example, the adult dose for "other foods and mixtures" was 4.9 pg TEQ/day at ND = ½ DL, while it was 1.1 pg TEQ/day at ND = 0. In contrast, the exposures at ND = ½ DL and 0 were fairly similar for "meat and mixtures": it was 3.7 pg TEQ/day at ND = ½ DL and 3.2 pg TEQ/day at ND = 0. Similar

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results using the two substitution methods could arise for two reasons: very high concentrations for quantified samples (relative to the detection limit) so that the effect of substitutions for NDs is minimized, and/or very high frequencies of detection even if the quantifications are near the detection limit.

3.3. Body burden update

Ferriby et al. (2007) provided a statistical analysis of a subset of NHANES 2001/2 samples that were analyzed for PCDD/PCDF and dioxin-like PCBs and provided on the NHANES web site by the Centers for Disease Control (CDC) along with sample weights. Scott et al. (2008) provided an addendum to this original study, to look at the impact of changing to WHO-2005 TEFs, and also to look at the effect of the substitution method on the calculated TEQ quantities. They calculated TEQs assuming ND = 0 and ND = DL/$\sqrt{2}$ in both articles. A random, one-third sample of all NHANES individual blood samples from individuals over the age of 20 were analyzed for dioxin-like compounds by CDC. Ferriby et al. (2007) used only those samples for which there were complete congener information (not including individuals with congener data missing), resulting in a sample set of 1081 individuals. TEQ statistics (means, percentiles) for all individuals and various subsets of individuals were provided in Ferriby et al. (2007), but only a limited amount of information on specific congeners were provided in the article; congener-specific arithmetic means were supplied by personal communication for this study. The nationally extrapolated arithmetic mean values at ND = 0 and ND = DL/$\sqrt{2}$ were used here.

This blood data, along with the congener average concentrations given in the Reassessment (derived from six different blood surveys of the mid-1990s), are provided in Table 3. The Reassessment did not provide congener concentrations at ND = 0, but noted that the overall TEQ concentration was only lower by about 1 pg/g at ND = 0. Also, the human body burden from the Reassessment was recast slightly for this study. The Reassessment body burden was given as 25.4 pg/g TEQ lwt, but in fact the available body burden data only had the coplanar PCB congeners. Based on other data, the Reassessment extrapolated the concentration of mono-ortho PCBs not collected to arrive at 25.4 pg/g TEQ lwt. Without these mono-ortho PCB congeners, the Reassessment body burden estimated from the profile provided in Table 2 using WHO-1998 TEFs is 23.6 pg/g TEQ lwt, and when recalculated using WHO-2005 TEFs, the body burden is instead 22.9 pg/g TEQ lwt. This latter value is used in this study to characterize the mid-1990s background body burden at ND = ½ DL, and at ND = 0, the body burden will be 21.9 pg/g TEQ lwt.

The analysis of congener-specific body burden data is influenced by the level of the detection limit and the treatment of non-detects. As noted, the average TEQ concentration at ND = ½ DL and ND = 0 for the mid-1990s data are similar at 22.9 and 21.9 pg/g TEQ lwt. There is only a 4% drop in average TEQ concentration from ND = ½ DL to ND = 0. This suggests acceptably low detection limits, which makes sense since the mid-1990s surveys were conducted only for analysis of dioxin-like compounds with appropriate methods and a sufficient volume of blood. In contrast, samples from NHANES 2001/2 were analyzed for multiple contaminants and, as a result, there was a low sample volume available for analysis of dioxins, furans, and PCBs. A large number of non-detects for certain key congeners may reflect the higher detection limits because of this reduced sample volume. For example, 2378-TCDD was only detected 13% of the time and, as seen in Table 3, there is a disparity with 2378-TCDD averages calculated at ND = DL/$\sqrt{2}$ and 0; it dropped from 2.5 to 0.7 pg/g lwt. Five of ten furan congeners were never quantified in the 2001/2002 NHANES individual data set. Overall, there is a 20% drop in average TEQ concentration when calculated at ND = 0 as compared to ND = ½ DL: 21.7 pg/g TEQ lwt at ND = DL/$\sqrt{2}$ and 17.2 pg/g TEQ lwt at ND = 0. Scott et al. (2008) acknowledges this detection limit issue, specifically for 2378-TCDD and 12378-PCDD, and particularly for younger individuals, and cautions that interpreting this biomonitoring data should be done with discretion and these limitations acknowledged.

However, information can be gleaned from the concentrations of congeners found most often. The hepta and octa PCDD congeners were found in 99% and 82%, respectively, of the individual samples in NHANES 2001/2, so the means calculated with both substitution methods are similar. While the prevalence of these and other specific congeners in the mid-1990s data is not known, it is surmised that they were also found at high frequencies. Given that presumption, it can be seen that there were declines in these congeners from the mid-1990s to the early 2000s: for 1234678-HpCDD, the concentration declined from 79 to 54 pg/g lwt, and for OCDD, the decline was from 664 to 452 pg/g lwt. Interestingly, PCB 126, which has the highest TEF of the dioxin-like PCBs at 0.1 and was also detected very frequently in the NHANES individual samples (89%), appeared to about double in the time frame studied, from about 18 pg/g lwt to 35 pg/g lwt.

The key issue for comparing the two time periods is that the data were not analogously derived, as were the beef, pork, poultry, and milk surveys. So, while these data support a hypothesis that there was a drop in body burden TEQ from the mid-1990s to the early 2000s, this is not conclusive and the amount of decline cannot be quantified with any certainty from the data.

Table 3
Average concentrations (pg/g lipid) of individual congeners and TEQs in human blood from the Dioxin Reassessment (mid-1990s data) compared to NHANES 2001/2 data.

Congener	Mid-1990s, mean concentrations ND = ½ DL	NHANES 2001/2		
		Mean concentrations		Percent detected
		ND = DL/$\sqrt{(2)}$	ND = 0	
2378-TCDD	2.1	2.5	0.7	13
12378-PCDD	5.2	4.6	3.7	35
123478-HxCDD	6.2	5.1	2.9	34
123678-HxCDD	73.1	47.1	46.9	93
123789-HxCDD	7.1	6.0	4.0	42
1234678-HpCDD	79.2	53.8	53.7	99
OCDD	664.0	452.1	419.2	82
2378-TCDF	0.7	1.8	ND	1
12378-PCDF	0.8	1.9	ND	1
23478-PCDF	6.2	6.5	5.8	66
123478-HxCDF	6.5	6.4	6.0	82
123678-HxCDF	5.3	5.4	4.8	70
123789-HxCDF	0.7	2.0	ND	0
234678-HxCDF	2.2	2.2	0.4	11
1234678-HpCDF	13.2	11.6	11.4	90
1234789-HpCDF	1.2	2.4	ND	0
OCDF	2.1	7.4	ND	0
PCB 77	31.1	–[a]	–[a]	
PCB 81	3.2	9.2	ND	0
PCB 118	–[a]	14760	13830	75
PCB 105	–[a]	4420	1630	24
PCB 126	18.1	35.4	34.9	89
PCB 156	–[a]	7660	6060	56
PCB 157	–[a]	3530	370	9
PCB 169	19.4	23.7	23.2	89
PCB 189	–[a]	10	3350	<1
PCDD/PCDF TEQ	20.5	17.5	12.9	
Coplanar PCB TEQ	2.4	4.3	4.3	
Total TEQ (PCDD/PCDF/cop PCB)	22.9	21.7	17.2	
Mono-ortho PCB TEQ	–[a]	0.9	0.7	

ND: all samples "non-detects".
[a] No data available. PCBs 105, 114, and 123 not included in table because measurements were not made of these congeners in any of the surveys.

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Patterson and colleagues at the US Centers for Disease Control, who generate the NHANES data, believed that this NHANES 2001/2 individual data set contained a significant number of non-detects for certain congeners, so in publications of these data they only provided the 90th and 95th percentile TEQ concentrations from this population (Needham et al., 2005; Patterson et al., 2008). However, they also prepared serum pools from NHANES 2001/2 comprised of 34 people per pool (total of 1734 individuals), with individuals in each pool described by sex, age – with groupings of 12–19 years, 20–39 years, 40–59 years, and >60 years, and also by race – with groupings of non-hispanic whites (NHW), non-hispanic blacks (NHB), and Mexican Americans (MA). Geometric mean TEQ concentrations of these 24 groups (2 sex $*$ 4 age $*$ 3 race) are provided in Patterson et al. (2008), using procedures to derive geometric means from pooled samples described in Caudill et al. (2007). Congener-specific geometric means of these 24 groups were provided for this effort (personal communication, D. Patterson). A weighted average adult geometric mean for each congener was derived using all results except the 12–19 age group results, by using NHANES age (Klein and Schoenborn, 2001) and race (NCHS, 1996) adjustments. The geometric mean total TEQ, including PCDD/PCDFs and the three coplanar PCBs, is 14.3 pg/g TEQ lwt. This is lower than the arithmetic mean concentrations that were derived from this same data set – 21.7 (ND = DL/$\sqrt{2}$) and 17.2 pg/g TEQ lwt (ND = 0). This difference is to be expected because the distribution of TEQ in the population is log normal. The arithmetic mean was sought for this update because it is the analogous metric to that used in the Reassessment. The Reassessment did not provide a justification for use of the arithmetic mean for characterizing background body burden – likely it was selected because it corresponds most closely to the average intakes developed in the Reassessment. The question of which metric is more appropriate for population health risk assessment was examined in Crump (2006), who argued that an arithmetic mean is always preferred over a geometric mean whenever the dose response is convex. He also examined several data sets for which the dose response was not convex, and concluded that even for those cases, an arithmetic mean was still preferred. Any further discussion is beyond the scope of this paper; both means are presented here for information purposes.

As a final note, Table 3 also calculates the contribution of mono-ortho dioxin-like PCBs (PCBs 105, 114, 118, 123, 156, 157, 167, and 189) to the body burden. While these PCBs were not measured in the mid-1990s surveys, five of them were measured in NHANES 2001/2. Their contribution was less than 1 pg/g TEQ lwt in the NHANES results. This is different than the finding in the Reassessment, which calculated a mono-ortho dioxin-like PCBs contribution of 1.8 pg/g TEQ lwt to total body burden, based on WHO-1998 TEFs. The change from 1.8 pg/g TEQ lwt to characterize the mid-1990s body burdens to the NHANES result of less than 1 pg/g TEQ lwt is likely not the result of a decline over that time, but rather the change from use of WHO-1998 TEFs to WHO-2005 TEFs. Applying WHO-1998 TEFs to the NHANES 2001/2 data would lead to additional increments from 4 to7 pg TEQ/g lwt, not increments less than 1 pg TEQ/g lwt. So instead of observing that mono-ortho PCBs additions went from 1.8 to less than 1 pg/g, it might be appropriate to observe that mono-ortho PCB contributions increased from 1.8 to between 4 and 7 pg/g TEQ lwt. Four of the mono-ortho PCBs (PCBs 105, 118, 156, and 157) saw a decline in their TEFs by over a factor of 10 each from the 1998 to the 2005 TEFs. So while mono-ortho PCBs have been left out of this analysis, their overall contribution to food and body burden might be more carefully considered in the future.

3.4. A closer examination of beef and pork surveys to ascertain temporal trends

Tables 4 and 5 are lipid-based congener-specific results for the mid-1990s surveys on beef and pork, respectively, including detection limits for each survey, the percent detect, and the average

Table 4
Detection limits, percent detect, and average concentrations of individual congeners and TEQs in beef from the Dioxin Reassessment (mid-1990s data) compared to comparable data collected in 2002/2003 time frame (averages calculated at ND = 0 in parenthesis).

Congener	Beef mid-1990s[a]			Beef 2002/3[b]		
	Detection limit[c] (pg/g wwt)	Detect	Concentration (pg/g lwt)	Detection limit[c] (pg/g wwt)	Detect (%)	Concentration (pg/g lwt)
2378-D	0.05	11	0.05 (0.03)	0.06	22	0.06 (0.04)
12378-D	0.5	2	0.35 (0.04)	0.03	95	0.23 (0.23)
123478-D	0.5	8	0.64 (0.18)	0.03	97	0.30 (0.30)
123678-D	0.5	21	1.42 (1.21)	0.04	100	1.63 (1.63)
123789-D	0.5	9	0.53 (0.26)	0.05	87	0.32 (0.32)
1234678-D	0.5	45	4.48 (4.39)	0.12	99	3.97 (3.97)
OCDD	3.0	13	4.78 (3.26)	1.75	32	3.92 (3.24)
2378-F	0.05	0	0.03 (0)	0.04	10	0.03 (0.01)
12378-F	0.5	0	0.31 (0)	0.08	0	0.05 (0)
23478-F	0.5	4	0.36 (0.06)	0.03	87	0.16 (0.15)
123478-F	0.5	8	0.55 (0.27)	0.06	76	0.41 (0.40)
123678-F	0.5	7	0.40 (0.12)	0.09	46	0.25 (0.23)
123789-F	0.5	0	0.31 (0)	0.04	0	0.03 (0)
234678-F	0.5	5	0.39 (0.10)	0.07	47	0.21 (0.19)
1234678-F	0.5	14	1.00 (0.75)	0.18	46	0.81 (0.75)
1234789-F	0.5	0	0.31 (0)	0.03	31	0.05 (0.04)
OCDF	3.0	0	1.88 (0)	0.09	26	0.15 (0.11)
PCB 77	1.0	19	1.0 (0.6)	5.2	11	3.6 (0.9)
PCB 126	0.4	100	4.1 (4.1)	0.07	100	1.2 (1.2)
PCB 169	0.2	94	0.7 (0.7)	0.10	94	0.3 (0.3)
PCDD/PCDF TEQ			1.00 (0.35)			0.71 (0.67)
cPCB TEQ			0.43 (0.43)			0.13 (0.13)
Total TEQ			1.43 (0.78)			0.84 (0.80)

[a] Data from Winters et al. (1996a,b).
[b] Unpublished data summaries provided by J. Huwe (personal communication).
[c] Detection limits were presented on a whole weight basis, but because the matrix sampled was a "fat" sample from the carcass, 80% or higher, these detection are close to essentially being lipid-based detection limits. See text for more detail.

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Table 5
Detection limits, percent detect, and average concentrations of individual congeners and TEQs in pork from the Dioxin Reassessment (mid-1990s data) compared to comparable data collected in 2002/2003 time frame (averages calculated at ND = 0 in parenthesis).

Congener	Pork, mid-1990s[a]			Pork 2002/3[b]		
	Detection limit[c] (pg/g wwt)	Detect (%)	Concentration (pg/g lwt)	Detection limit[c] (pg/g wwt)	Detect (%)	Concentration (pg/g lwt)
2378-D	0.1	2	0.10 (0.01)	0.06	1	0.04 (0.002)
12378-D	0.5	2	0.45 (0.01)	0.03	23	0.03 (0.02)
123478-D	0.5	7	0.52 (0.10)	0.03	52	0.08 (0.07)
123678-D	0.5	33	1.10 (0.80)	0.04	73	0.18 (0.17)
123789-D	0.5	3	0.47 (0.04)	0.05	95	0.03 (0.01)
1234678-D	0.5	50	10.15(9.93)	0.12	79	1.20 (0.19)
OCDD	1.0	57	52.77 (52.40)	1.75	41	9.14 (8.75)
2378-F	0.05	2	0.09 (0.004)	0.04	0	0.02 (0)
12378-F	0.5	0	0.45 (0)	0.08	1	0.05 (0.001)
23478-F	0.5	6	0.56 (0.14)	0.03	36	0.08 (0.07)
123478-F	0.5	13	0.98 (0.60)	0.06	36	0.17 (0.14)
123678-F	0.5	8	0.58 (0.58)	0.09	16	0.13 (0.08)
123789-F	0.5	0	0.45 (0)	0.04	1	0.03 (0.003)
234678-F	0.5	8	0.57 (0.16)	0.07	4	0.09 (0.05)
1234678-F	0.5	52	3.56 (3.35)	0.18	33	0.68 (0.60)
1234789-F	0.5	10	0.57 (0.17)	0.03	13	0.05 (0.04)
OCDF	1.0	49	2.30 (1.85)	0.09	19	0.44 (0.39)
PCB 77	1.5	13	1.6 (0.4)	5.2	7	3.6 (0.6)
PCB 126	0.2	26	0.3 (0.2)	0.07	55	0.2 (0.2)
PCB 169	0.1	29	0.3 (0.2)	0.10	61	0.3 (0.3)
PCDD/PCDF TEQ			1.37 (0.44)			0.19 (0.11)
cPCB TEQ			0.04 (0.03)			0.03 (0.03)
Total TEQ			1.41 (0.47)			0.22 (0.14)

[a] Data from Lorber et al. (1997).
[b] Unpublished data summaries provided by J. Huwe (personal communication).
[c] Detection limits were presented on a whole weight basis, but because the matrix sampled was a "fat" sample from the carcass, 80% or higher, these detection are close to essentially being lipid-based detection limits. See text for more detail.

concentration at ND = ½ DL and 0. The detection limits are indicative of the different analytical methods used, and subtleties including laboratory procedures to validate the methods, calculate the detection limits, subtract out blank concentrations, and differentiate between the "limit of detection" and "limit of quantification". These limits are provided on a "wet weight", or sample, basis. Because the surveys were on animal samples that were predominantly fat – "back fat" from the cattle and subcutaneous "belly fat" from the swine, which are both 80% lipid or higher – these sample-basis detection limits are very close to what lipid-basis detection limits would be. Both the US EPA laboratory which conducted the analysis for the mid-1990s surveys and the USDA laboratory which conducted the analysis for the 2002/3 data developed both LODs (limits of detection) and LOQs (limits of quantification), and LOQs were 2–3 times higher than LODs. For purposes of generating average concentrations, the laboratories assigned best estimate values for samples which contained concentrations higher than the LOD but lower than the LOQ. Further detail on these methods can be found in the articles describing the surveys (Winters et al., 1996a,b; Ferrario et al., 1997; Lorber et al., 1997; Hoffman et al., 2006).

One thing to note is that the detection limits for the most toxic congener, 2378-TCDD, is similar for both surveys at between 0.05 and 0.10 pg/g wwt, and the resulting concentrations and percent detects are similar for both surveys and both years. However, the detection limits for the penta through hepta dioxin and furan congeners were lower for the 2002/3 surveys, and this led to a much higher frequency of detection and a narrower difference between congener averages calculated at the two substitution methods. For example, 123789-HxCDD was detected at only a 3% rate with an average of 0.47 pg/g lwt at ND = ½ DL and 0.04 pg/g lwt at ND = 0 for the mid-1990s pork survey which had a detection limit of 0.5, but in the 2002/3 pork survey which had a detection limit an order of magnitude lower at 0.05, the detection frequency was 95% with similar averages at the two substitution methods: 0.03 pg/g lwt at ND = ½ DL and 0.01 pg/g lwt at ND = 0. A few exceptions to this trend are noted. The OCDF congener in the mid-1990s pork survey had a higher detection limit than the 2002/3 pork survey, 1.0 versus 0.09 pg/g wwt, but this congener was found 49% of the time in the mid-1990s with a somewhat small difference in average concentrations between the two substitution methods, 2.30 and 1.85 pg/g lwt, while it was detected only 19% of the time in 2002/3 with lower concentrations found, 0.44 and 0.39 at the two substitution methods. This likely reflects a true decline in OCDF concentrations over time.

Perhaps the most informative data in these two surveys comes from congener averages where the substitution method made little difference in the calculated averages, regardless of the magnitude of the detection limits or the detection frequencies. When calculated averages for the two substitution methods are very similar, two things could be occurring: (1) the quantified positive occurrences are so much higher than the detection limit that it does not matter how frequently these positives are found or how high the detection limit is, or (2) the quantified positive occurrences are in fact near the detection limit, but there is such a high frequency of occurrence that the magnitude of the detection limit, and hence the difference between 0 and ½ DL, will not factor significantly into the calculation of averages.

An examination of the results in Tables 4 and 5 suggest that the following congeners showed small differences in calculated averages by the two substitution methods in both survey years: for beef, the congeners were 123678-HxCDD, 1234678-HpCDD, OCDD, 1234678-HpCDF, PCB 126, and PCB 169, and for pork, the congeners were 123678-HxCDD, 1234678-HpCDD, OCDD, 123678-HxCDF, 1234678-HpCDF, OCDF, PCB 126, and PCB 169. It is noted that some of these congeners were infrequently quantified, and the fact that the concentrations were similar at ND = ½ DL and 0 suggests that the positives found were much higher than the detection limit such that the magnitude of the detection limit did not influence the means. For example, for beef measured in the mid-1990s, 123678-

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HxCDD was detected only 21% of the time, although the mean at ND = ½ DL at 1.42 pg/g TEQ lwt was similar to the mean at ND = 0 at 1.21 pg/g TEQ lwt.

Of the congeners noted for beef, a small increase was seen for 123678-HxCDD for the 2002/3 survey (at 1.63 pg/g lipid) as compared to the mid-1990s survey (at 1.42 pg/g lwt), while small declines (no more than a few tenths of a pg/g lwt concentration) were noted for the other three dioxin and furan congeners. A steep decline was noted for PCB 126, going from 4.1 to 1.2 pg/g lwt. Of the congeners noted for pork, steep declines in the mean concentrations – between 5 and over 10 times – were noted for the dioxins and furans. For example, 1234678-HpCDD drops from about 10 to 1 pg/g lwt, and OCDD drops from 53 to 9 pg/g lwt (both substitution methods). However, the PCB congeners appeared to remain the same between time periods for pork, at 0.2–0.3 pg/g lwt.

These declines in pork concentrations are perhaps the strongest evidence for a decline in a food concentration over time. Declines, while not as high as pork, would be seen if doing a similar congener-by-congener analysis of the poultry and milk surveys. The reasons for this decline in pork are unknown, but could be due to changes in feed, declines in congener concentrations in feed, changes in pork production practices (such as, perhaps, a quicker time to slaughter and hence less time for accumulation of dioxin-like compounds in the 2002/3 animals), or changes resulting from breeding practices.

To bring more statistical rigor into the comparisons, raw data from the beef and pork surveys of the early 2000s were retrieved and analyzed as per procedures described in the Methods section above. Prevalence of detections and mean concentrations at ND = 0 for the mid-1990s and the transformed early 2000s surveys are shown in Table 6. To emphasize the possibility that in fact prevalence or mean concentrations increased, numbers are bolded for the early 2000s results when an increase is implied. Also, Table 6 shows the results of the Wilcoxon test comparing each pair of congener-specific data sets. The null hypothesis, that is, the paired distributions are equal, is rejected if the *p* value that results from the test is 0.05 or less. If the null hypothesis is rejected, this means that the congener data from the two years are likely, with statistical significance, to come from distinct distributions.

It appears clear from Table 6 that beef PCDD/PCDF concentrations remained fairly steady over the two time periods. The PCDD/PCDF concentrations for the transformed 2002/3 data set were very close in magnitude and nearly matched the concentrations found in the mid-1990s. Of 17 dioxin and furan congener pairs, the frequency of positive occurrences increased for 13 congeners in the latter survey, and concentrations slightly increased for 5 congeners. Only one dioxin or furan congener pair was found by the Wilcoxon test to reject the null hypothesis, and this was a case where no occurrences above the detection limit for 2378-TCDF were found in the early survey, and very few (10%) were found in the normalized data set at just about the detection limit. It does appear PCB congener concentrations changed between the two time periods: two PCB congeners declined in beef from the mid-1990s to the early 2000s – the mean concentrations of PCBs 126 and 169 showed declines with a high frequency of detection (>67%), while PCB 77 seemed to show an increase in concentration and frequency of distribution. The Wilcoxon test showed that all PCB congeners appear to have different distributions.

In contrast, declines seem fairly consistent for the PCDD/PCDF congeners in the pork survey. Only the concentration and the frequency of occurrence of PCBs 77 and 169 rose in the normalized pork survey data. Declines in average concentration appear in several congeners, such as 123678-HxCDD, 1234678-HpCDD, OCDD, and several furan congeners. The Wilcoxon test rejected 9 of 17 PCDD/PCDF congeners, again suggesting that in fact the pork data in the 2000s did come from a different distribution.

To further study the distributions, two congeners were selected to see whether mean concentrations may have been driven by a relatively small number of samples with higher concentration. The two congeners selected were 123678-HxCDD and 1234678-HpCDF; these were selected because they appear to the highlight the trends elucidated above. Specifically, in both cases for beef, relatively similar mean concentrations were found while the concentrations for pork showed a large (nearly a factor of 10) decline. For

Table 6
Comparison of beef (steers and heifers) and pork (barrows and gilts) for the two survey time periods when the detection limits are "normalized" to mid-1990s detection limits. All results calculated at non-detect equal to zero.

Congener	Beef, mean concentrations, pg/g lipid, (percent detect in parenthesis)			Pork, mean concentration, pg/g lipid (percent detect in parenthesis)		
	Mid-1990s	Early 2000s	Wilcoxon test[a]	Mid-1990s	Early 2000s	Wilcoxon test[a]
2378-D	0.02 (14)	**0.05 (22)**		0.01 (2)	0.001 (1)	
12378-D	0.04 (2)	**0.07 (8)**[b]		0.01 (2)	0 (0)	
123478-D	0.18 (8)	0.16 (**14**)		0.10 (7)	0.01 (2)	
123678-D	1.21 (21)	**1.46 (52)**		0.80 (33)	0.05 (5)	R (p = 2E-7)
123789-D	0.26 (9)	0.17 (**13**)		0.04 (3)	0 (0)	
1234678-D	4.39 (45)	3.87 (**73**)		9.93 (50)	1.00 (33)	R (p = 9E-4)
OCDD	3.26 (13)	3.09 (**28**)		45.7 (55)	8.57 (48)	R (p = 0.003)
2378-F	0 (0)	**0.01 (10)**	R (p = 0.02)	0.004 (2)	0 (0)	
12378-F	0 (0)	0 (0)		0 (0)	0 (0)	
23478-F	0.06 (4)	0.03 (3)		0.14 (6)	0.04 (2)	
123478-F	0.27 (8)	0.26 (**14**)		0.60 (13)	0.09 (4)	R (p = 0.02)
123678-F	0.12 (7)	0.12 (**9**)		0.58 (8)	0.05 (2)	R (p = 0.04)
123789-F	0 (0)	0 (0)		0 (0)	0 (0)	
234678-F	0.10 (5)	0.08 (**7**)		0.16 (8)	0.04 (0)	R (p = 0.04)
1234678-F	0.75 (14)	0.69 (**29**)		3.35 (52)	0.54 (13)	R (p = 5E−08)
1234789-F	0 (0)	**0.01 (1)**		0.17 (10)	0.03 (2)	R (p = 0.03)
OCDF	0 (0)	0 (0)		1.85 (49)	0.33 (6)	R (p = 1E−4)
PCB 77	0.16 (2)	**0.89 (11)**	R (p = 0.05)	0 (0)	**0.64 (7)**	R (p = 0.05)
PCB 126	4.1 (100)	1.2 (96)	R (p = 9E−16)	0.2 (26)	0.1 (20)	
PCB 169	0.7 (94)	0.3 (67)	R (p = 3E−10)	0.2 (29)	**0.3 (60)**	R (p = 2E−4)

[a] The Wilcoxon test is designed to evaluate the null hypothesis, that is, that the congener-specific sample sets from each survey come from the same distribution. The sets are evaluated as coming from different distributions if the test returns a "*p*" value of 0.05 or less. The "R" indicates rejection of the null hypothesis, suggesting the sample sets came from different distributions, and the *p* value is provided in parenthesis. See text for more detail.

[b] The results are bolded in the early 2000s column if they represent an increase over the mid-1990s survey.

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Table 7
A brief examination of the frequency distribution of two congeners in the normalized data sets of beef and pork. These distributions are for 123678-HxCDD and 1234678-HpCDF, at ND = 0.

Congener	Concentration range (pg/g lwt)	Beef		Pork	
		Mid-1990s	Early 2000s	Mid-1990s	Early 2000s
123678-HxCDD	>0.50	33	53	32	5
	>1.00	25	37	25	1
	>2.00	18	22	9	<1
1234678-HpCDF	>0.50	22	29	50	13
	>1.00	16	23	41	11
	>2.00	14	11	34	6

beef, there was a higher prevalence of occurrences in the normalized early 2000s data for both congeners. For pork and both congeners, there were large declines in prevalence of quantified concentrations, and the Wilcoxon test further suggested that the congener results came from different distributions.

The results of this distributional analysis are shown in Table 7, which shows the percent occurrences by congener/survey/pork-beef above three concentrations: 0.5, 1.00, and 2.00 pg/g lwt. Overall, it can be seen that the beef distributions seems fairly similar across surveys – a bit higher frequencies were noted in 2000, but when it got to the frequency above 2.00 pg/g, the occurrences seemed fairly similar: for 123678-HxCDD, the occurrence frequencies were 18 and 22% for the mid-1990s and early 2000s, respectively, and for 1234678-HpCDF, they were 14% and 11%. For pork and both congeners, again the older surveys showed substantially higher frequencies of occurrences for all three concentration ranges, and at the highest range, there were still large differences: for 123678-HxCDD, the mid-1990s survey showed 9% above this number with <1% for the early 2000s, and for 1234678-HxCDF, the disparity was also noticeable: the mid-1990s survey showed 34% above this concentration with 6% for the early 2000s.

4. Summary and conclusions

This study attempts to provide an update to the background body burden and intake dose estimates described in EPA's Reassessment (US EPA, 2003a). These estimates were current as of the mid-1990s and the updates are current as of the early 2000s. Besides simply updating the exposure estimates, this study examines the data to ascertain whether a decline in exposures has occurred during this time. Using the same procedures and analogous data when available, the intake dose calculated at 61.0 pg TEQ/day (at ND = ½ DL; 43.7 at ND = 0) for the Reassessment was updated to 40.6 pg TEQ/day (34.5 at ND = 0). Corroborating evidence for the quantifications of early 2000s intake estimates come from the FDA. The FDA conducted a market-basket survey of dioxins and furans (not dioxin-like PCBs) in food in the early 2000s and they also developed intake estimates for their results. Their analysis results in an average intake of 23 pg TEQ/day for the foods considered in EPA's Reassessment, while the assessment in this paper arrived at a similar intake value of 21 pg TEQ/day for the early 2000s (both estimates derived at ND = ½ DL).

The body burden data also suggest a decline. The average body burden at ND = ½ DL from surveys in the mid-1990s was given in the Reassessment as 22.9 pg TEQ/g lwt, and it was 21.9 pg TEQ/g lwt at ND = 0. More recent blood concentration data, from NHANES 2001/2, suggest an adult average at 21.7 pg TEQ/g lwt at ND = DL/$\sqrt{2}$ and 17.2 pg TEQ/g lwt at ND = 0. Drawing conclusions regarding a possible decline in body burdens is difficult, however, given the disparity in study designs. The data from the mid-1990s included six regional studies involving 316 people, while the early 2000s data was from a national statistical sample.

Generally, the disparity in study designs, the use of different laboratories, and the treatment of non-detects in the calculation of mean congener concentrations makes it challenging to draw conclusions that a decline has occurred in both food and human blood, much less quantify that decline. However, the weight-of-evidence is highly suggestive of an overall decline in exposures between the two time periods. The following are key points in this weight-of-evidence argument:

(1) Analogously designed national surveys of dioxin-like compounds in beef, pork, poultry, and milk provide the best means to track trends over time. While there were some differences between the surveys conducted in the mid-1990s and early 2000s, lower average concentrations were found in the surveys done in the early 2000s when viewing the data in different ways. The average TEQs calculated at ND = ½ DL and 0 dropped for pork, poultry, and milk when looking at analogous numbers (i.e., looking at both time points at ND = ½ DL and then both time points at ND = 0). The trend for beef was not as clear – concentrations appeared unchanged if not even slightly rising between the two surveys.
(2) The impact of the substitution method is minimized when average congener concentrations are similar whether calculated using ND = ½ DL or ND = 0. In a closer examination of beef and pork congener results over the two time periods, a total of 12 congeners were identified (6 from beef, 6 from pork) which were quantified sufficiently for both time periods and surveys, regardless of the substitution method. Declines over time, some as high as an order of magnitude, were seen in 10 of those 12 congeners, with PCB 126 showing no change for pork and one dioxin congener in beef suggesting a slight rise between the two time periods.
(3) Comparing results from the beef/pork/poultry surveys in the two time frames is complicated by the fact that a different laboratory analyzed the samples – an EPA laboratory analyzed the mid-1990s survey samples while a USDA laboratory analyzed the early 2000s survey samples. The USDA laboratory achieved lower detection limits. A subset of the raw food survey results, for beef and pork specifically, were retrieved for a more in-depth analysis. In this exercise, the surveys were "normalized" to be more analogous to each other; specifically, the higher congener-specific detection limit from both surveys was selected to represent both surveys which required reassignment from "detected and quantified" for some of the congener-specific results to be reclassified as "non-detected". In that way, results like frequency of detection and congener averages between surveys start from the same analytical basis (see text for more detail). The average beef concentrations in the early 2000s calculated at ND = 0 were now remarkably similar to the mid-1990s survey, as were the normalized "frequencies of detection" between the two time periods. However, the pork

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concentrations in 2002/3 were still lower than the mid-1990s survey, and were "detected" less frequently. Wilcoxon rank sum tests indicate that about half of the dioxin and furan congener measurements in the early 2000s pork survey were drawn from statistically distinct distributions from the mid-1990s pork survey, while the same test showed only one PCDD/PCDF congener was possibly from a different distribution in beef. This provides additional support to a finding that concentrations truly declined in pork. Finally, a frequency distribution evaluation examined two congeners from these normalized beef and pork data sets. The purpose of this examination was to see if perhaps the big difference between pork seen in the two dates may have been driven by a small number of very high concentrations. In fact, this was not borne out by this evaluation – the frequencies of occurrence above key concentrations (0.5, 1.0, and 2.0 pg/g lwt) were consistently different for the two congeners in pork (it was always higher in the mid-1990s surveys), while the frequencies of occurrence above these concentrations were fairly similar for the two surveys for beef.

(4) As noted above, a decline in body burdens was suggested, but this evidence was weak because the data sets were not analogous. However, like for beef and pork, perhaps informative evidence can be found in congeners found frequently enough such that little or no difference in averages were seen at the two substitution methods. For 1234678-HpCDD, the mean concentration declined from 79 to 54 pg/g lwt, and for OCDD, the mean concentration declined from 664 to 452 pg/g lwt. Interestingly, PCB 126 appeared to about double in the time frame studied, from about 18 pg/g lwt to 35 pg/g lwt.

More data continues to be generated and it will be studied to further ascertain the possibility of downward trends in exposure. The USDA has nearly completed analysis from a third round of national surveys of beef, pork, and poultry conducted in 2007, and they will publish their results possibly during 2009. Data from NHANES 2003/2004 is available and already, Lakind et al. (2008) have downloaded it and evaluated it by comparing it to NHANES 1999/2000 data and 2001/2 data. They only looked at dioxins and furans (not dioxin-like PCBs), and they calculated national means by assuming ND = DL/$\sqrt{2}$, as did Ferriby et al. (2007), and used the WHO-2005 TEFs to calculate TEQ concentrations. They found that the mean concentration from 1999/2000 for PCDD/PCDFs was 15.4 pg TEQ/g lipid, that it rose to 18.1 pg TEQ/g lipid in 2001/2, and then declined to 13.9 in 2003/4. Their 2001/2 national mean of 18.1 pg TEQ/g lipid is analogous to the finding listed in Table 1 for PCDD/PCDFs TEQ of 17.5 pg TEQ/g lipid. The numbers are slightly different and it is not clear why; one possible reason is that Ferriby et al. (2007) extracted only data from NHANES for individuals over 20 years of age with a complete set of data while the extrapolations in Lakind et al. (2008) were on all individuals in NHANES above 20 years old with data, with no discussion of censoring of any of the data. In any case, the data appeared to show a decline from 2001/2 to 2003/4. Interestingly, it showed a rise from the 15.4 pg TEQ/g lipid derived from the 1999/2000 data. More importantly, this 1999/2000 mean concentration is lower than the mid-1990s data EPA used in the NAS review draft, in which a mean of 20.5 pg TQ/g lipid (Table 2) was derived. The difference may merit further investigation; one issue discussed in Lakind et al. (2008) is that the percent non-detected in the 1999/2000 data was the highest of the three sample years, with 2378-TCDD, for example, being 99% non-detected. In any case, all evaluations in Lakind et al. (2008) (on medians, 95th percentiles, at the two substitution method) show a decline in the 2003/4 NHANES in comparison to the 2001/2 data.

These and other data sets and evaluations will provide a continued tracking of the trends in intakes and body burdens of dioxin-like compounds. Issues will no doubt continue to arise relating to the chemistry of the trace amounts of these compounds in the environment, in our food, and in our bodies. No doubt, conclusions about whether declines continue to occur and the quantification of those declines will be an issue for ongoing debate.

Disclaimer

The views expressed in this article are those of the authors and do not necessarily reflect the views or policies of the US Environmental Protection Agency, the Centers for Disease Control, and the US Department of Agriculture. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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