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Polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs) in the serum of US Air Force veterans in 2002

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Abstract

We measured levels of PCDDs, PCDFs, non-*ortho*, and mono-*ortho* substituted PCBs in 106 US Air Force Vietnam veterans, participants of the Air Force Health Study (AFHS) who attended the final medical examination in 2002. Twelve veterans were Ranch Hands involved in aerial spraying of herbicides in Vietnam (1962–1971), and 94 were Comparisons who flew transport missions in Southeast Asia (SEA) during the same time period. These veterans had no previous 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) measurement because they had not attended any of the previous AFHS examinations, or their previous measurements were missing or not valid.

The mean TCDD levels in 2002 were 1.7 pg/g lipid in Comparisons and 5.5 pg/g lipid in Ranch Hands. The mean PCDD toxic equivalent – TEQ (1997) in Comparisons was 12.6 pg/g lipid, 5.4 pg/g lipid for PCDFs, 5.2 pg/g lipid for non-*ortho* PCBs, and 9.4 pg/g lipid for mono-*ortho* PCBs, with a total mean TEQ (1997) of 32.6 pg/g lipid. Corresponding mean TEQs in Ranch Hands were 15.5 pg/g lipid for PCDDs, 4.6 pg/g lipid for PCDFs, 2.2 pg/g lipid for non-*ortho* PCBs, and 9.3 pg/g lipid for mono-*ortho* PCBs, yielding the total mean TEQ (1997) of 31.6 pg/g lipid. Using the re-evaluated 2005 WHO TEFs, the total mean TEQs (2005) decreased by about 28% in both Comparisons and Ranch Hands, to 23.6 pg/g lipid and 22.8 pg/g lipid, respectively. This was mainly due to changes of TEFs for the group of mono-*ortho* PCBs, which decreased the mono-*ortho* PCBs TEQs by almost 90% in both Ranch Hands and Comparisons.

Keywords

TCDD; PCDDs; PCDFs; PCBs; Vietnam veterans; Agent Orange

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1. Introduction

The Air Force Health Study is a 20-year prospective study examining the health, mortality and reproductive outcomes in US Air Force veterans of Operation Ranch Hand, the unit responsible for the aerial spraying of herbicides, including 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD)-contaminated Agent Orange, in Vietnam from 1962 to 1971 (Michalek et al., 1990; Wolfe et al., 1995; Pavuk et al., 2003). Comparison Air Force veterans flew or serviced transport aircraft in Southeast Asia (SEA) during the same time period and did not spray herbicides. They were matched on age, race and military occupation to Ranch Hand veterans and were included as referents. These veterans spent on average less than 30% of their time in SEA in Vietnam and were stationed in other SEA countries like the Philippines, Thailand, Taiwan, Guam, and Japan (Pavuk et al., 2005). The study included comprehensive physical examinations and in-person interviews conducted in 1982, 1985, 1987, 1992, 1997, and 2002.

Levels of the TCDD have been measured in 2551 Ranch Hand and Comparison veterans, who attended at least one physical examination and provided blood for TCDD analysis. The majority of samples were collected and analyzed in 1987, with subsequent measurements in 1992, 1997, and 2002. TCDD measurements made in 1992, 1997, and 2002 were transformed to correspond to 1987 levels using a first order kinetics model with a half-life of 7.6 years (Michalek and Tripathi, 1999; Michalek et al., 2002). Agent Orange and other herbicides used in Vietnam were contaminated only by TCDD, so the early decision was made to not measure other dioxins or dioxin-like compounds (Wolfe et al., 1990). As a result, with the exception of TCDD, no PCDDs, PCDFs, or PCBs were measured in the Vietnam veterans participating in the Air Force Health Study prior to 2002 (also known as Ranch Hand Study). To our knowledge, only one other earlier study reported measurements of organochlorines other than TCDD in a group of Vietnam War veterans (Schecter et al., 1993, 1996).

The group of Air Force veterans investigated in our present study had PCDDs, PCDFs, coplanar or non-*ortho* PCBs (cPCBs) and mono-*ortho* PCBs (mPCBs) measured in their sera. These veterans included 94 Comparisons not involved in spraying herbicides and 12 Ranch Hands who attended the 2002 physical examination and did not have a previous valid TCDD measurement.

2. Methods

A detailed description of the AFHS methods was published elsewhere (Wolfe et al., 1990). In the present study, 94 Comparisons and 12 Ranch Hand veterans who attended the 2002 physical examination at the Scripps Clinic, California, had 40 ml of their blood collected for dioxin analysis. Participation was voluntary and informed consent was given at the examination site. Ninety-four Comparison veterans were selected who did not have an earlier TCDD measurement either because they did not attend any of the previous medical examinations ($n = 61$), or did not have a valid TCDD measurement at some previous exam, or had refused to have serum collected or for other reasons ($n = 34$). From the twelve selected Ranch Hands, eleven did not have a TCDD measurement and one did not attend any

of the previous physical examinations. Serum was harvested from blood within 2 h of blood collection, frozen and stored at -20°C . Specimens were later shipped on dry ice to the Brooks City-Base (TX) and stored at -70°C . In January 2003, samples were sent to the dioxin laboratory at the Centers for Disease Control and Prevention in Atlanta (GA) for organochlorine analysis.

Seven polychlorinated dibenzo-*p*-dioxins (PCDDs), ten dibenzofurans (PCDFs), four coplanar or non-*ortho* substituted polychlorinated biphenyls (cPCBs; PCBs 77, 81, 126, and 169), and six mono-*ortho* substituted PCBs (mPCBs; PCBs 118, 105, 167, 156, 157, and 189) were measured in serum using high-resolution gas chromatography isotope-dilution high-resolution mass spectrometry (HRGC/ID-HRMS). We do not report results for PCB 77 and OCDF because the relevant QA/QC procedures for these analytes were not met. Details of the procedures were first described by Patterson (Patterson et al., 1986, 1987) and modified in the current analysis as described below.

In brief, serum samples were spiked with $^{13}\text{C}_{12}$ -labeled internal standards and the analytes of interest were isolated using liquid extraction procedure followed by a multi-column automated cleanup and enrichment procedure (Turner et al., 1997). The analytes were separated on a DB-5 ms capillary column ($30\text{ m} \times 0.25\text{ mm} \times 0.25\text{ }\mu\text{m}$ film thickness) using a Hewlett–Packard 6890 gas chromatograph and selected analytes quantified by ID-HRMS using selected ion monitoring (SIM) at 10000 resolving power using a Finnigan MAT95 mass spectrometer in the electron impact (EI) mode. The concentration of each analyte was calculated from an individual linear calibration curve. Each analytical run was conducted blinded and consisted of three unknown serum samples, a method blank, and a quality control sample. All data were reviewed by comprehensive quality assurance and quality control procedures. Analytical results were reported on both a whole-weight and lipid-adjusted basis. Serum lipids were calculated using an enzymatic summation method (Akins et al., 1989). Detection limits, on a whole weight and lipid-adjusted basis were reported for each analyte, corrected for sample weight and analyte recovery. World Health Organization Toxic Equivalency Factors (WHO-TEF) were used to report PCDDs, PCDFs, and dioxin-like PCBs Toxic Equivalents (TEQs) (van den Berg et al., 1998, 2006). For levels measured below the limit of detection, we substituted the limit of detection divided by square root of 2 (Hornung and Reed, 1990).

3. Results

Demographic characteristics of 106 US Air Force veterans who participated at the 2002 physical examination and did not have a previous TCDD measurement are presented in Table 1. No major differences were noted. This was not a random nor representative sample of all the veterans who participated in AFHS. The 2002 mean serum TCDD in the Comparison veterans without a previous TCDD measurement was 1.7 pg/g lipid . This was about three times lower than TCDD in a small subgroup of Ranch Hands ($n = 12$), 5.5 pg/g of lipid (Table 2), and lower than TCDD previously measured in a much larger Comparison group whose serum was collected in 1987, 1992, or 1997 (4.1 pg/g lipid , Pavuk et al., 2003). Table 2 shows the measured values for PCDDs, PCDFs, cPCBs, and mPCBs, as well as 1997 and 2005 WHO TEFs and percent of analyzed samples above the detection limit for

each congener. In spite of the much smaller number of Ranch Hands, the percentages of congeners measured above the detection limit were consistent with the percentages in the larger Comparison group. The 2005 WHO re-evaluation of Toxic Equivalency Factors (TEFs) increased the TEF for OCDD from 0.0001 to 0.0003, decreased TEFs from 0.05 to 0.03 for 1,2,3,7,8-PnCDF and from 0.5 to 0.3 for 2,3,4,7,8-PnCDF (van den Berg et al., 2006). For coplanar PCBs, the TEFs increased for PCB 81 from 0.0001 to 0.0003 and for PCB 169 from 0.01 to 0.03. The most pronounced change was made in the group of mono-*ortho* substituted PCBs, where the entire group was assigned the TEF of 0.00003, about an order of the magnitude below the previous levels that ranged from 0.001 to 0.00001 for 1997 WHO TEFs (van den Berg et al., 1998).

The mean TEQ for the Comparisons was 12.6 pg/g lipid for PCDDs, 5.4 pg/g of lipid for PCDFs, 5.2 pg/g lipid for cPCBs, and 9.4 pg/g lipid for mPCBs, yielding the total mean TEQ of 32.6 pg/g lipid using 1997 WHO TEFs (Table 3). Corresponding mean TEQs in Ranch Hands were 15.5 pg/g lipid for PCDDs, 4.6 pg/g lipid for PCDFs, 2.2 pg/g lipid for cPCBs, and 9.3 pg/g lipid for mPCBs, for a total mean TEQ of 31.6 pg/g lipid. Using 2005 WHO TEFs (van den Berg et al., 2006), the PCDDs TEQ did not change materially, 12.7 pg/g lipid in Comparisons and 15.5 pg/g lipid in Ranch Hand. The PCDFs TEQs in Comparisons decreased by 30%, to 3.8 pg/g lipid and by 28% in Ranch Hands to 3.3 pg/g lipid, while cPCBs TEQs increased by about 10% in Comparisons to 5.8 pg/g lipid, and by 24% in Ranch Hands to 2.9 pg/g lipid. The most profound effect of using the re-evaluated TEFs was seen in mPCBs where in Comparisons, mPCBs TEQ decreased by 86% to 1.3 pg/g lipid and by 88% in Ranch Hands to 1.1 pg/g lipid (Table 3).

As expected, a smaller percent contribution from PCDDs TEQ to the total TEQ in Comparisons was observed, 39% versus 49% in Ranch Hands. This was mainly due to the differences in the TCDD contribution to the total TEQ, which was 5% in the Comparisons and 17% in the Ranch Hands (Table 2). Similar percent contribution from mPCBs TEQ (29% versus 29%) and PCDFs (15% versus 17%), and a larger percent contribution from cPCBs TEQ, 16% in Comparisons versus 7% in Ranch Hands were found (Fig. 1) when 1997 WHO TEFs were used. When 2005 WHO TEFs were used in calculations of TEQs, percent contribution increased for PCDDs TEQ, from 39% to 54% for Comparisons and from 49% to 68% for Ranch Hand. In contrast, as mentioned earlier, mPCBs TEQs decreased and the percent contribution to the total mean TEQ decreased from 29% to 5% in both Comparisons and Ranch Hands.

When comparing the data from the AFHS to the US male population based on NHANES 2001–2002 data (Patterson et al., 2005), similar but generally lower levels for the Comparisons were observed for all four groups of congeners (Table 4). For the Comparisons 45–59 y age group, the differences were relatively small, e.g. the 90th percentile for PCDDs TEQ was 16.3 pg/g lipid versus 19.5 pg/g lipid, and for total TEQ it was 38.6 pg/g lipid versus 43.3 pg/g lipid for the Comparisons and NHANES, respectively. Small differences were also observed for PCDFs TEQ, cPCB TEQ, and mPCBs TEQ. In contrast, in the 60+ years age group, the Comparison levels were only about half of US population estimates for PCDDs TEQs (22 pg/g lipid versus 39.6 pg/g lipid), about 60% for cPCBs TEQs (6.4 pg/g lipid versus 10.4 pg/g lipid) and little less than 70% for total TEQ (48.8 pg/g lipid versus

72.7 pg/g lipid). The 90th percentile TEQs in 12 Ranch Hand veterans were similar to results for the 60+ years age group of Comparison veterans, but with cPCBs TEQ being only about half of the Comparisons levels (3.1 pg/g lipid versus 6.4 pg/g lipid). The use of 2005 WHO TEFs at the 90th percentile resulted in decreases in PCDFs and increases in cPCBs, as well as substantial decreases in mPCBs TEQ. Decreases in total TEQ were similar in magnitude to the mean TEQ levels shown in Table 3. The use of 2005 WHO TEFs in NHANES data resulted in changes of similar direction and magnitude as those observed in the AFHS veterans (Table 4).

The mean PCDD/F/cPCBs TEQ for Comparison veterans presented here was lower than background levels of some non-random samples of the general population in the United States or Germany (Table 5, Schechter et al., 2002; Fürst and Pöpke, 2002), but about twice as high as the general population mean estimate from Australia (Harden et al., 2004), and similar but higher than in US samples collected in 1996–2001 (Patterson et al., 2004). Mono-*ortho* PCBs TEQ in a pooled blood sample from 13 non-occupationally exposed individuals from Germany was about 50% higher (Fürst and Pöpke, 2002) than in Comparisons. In one Vietnam veterans' study that measured PCDDs, PCDFs, cPCBs, and mPCBs in serum collected in 1991–1992 (Schechter et al., 1996), the total mean TEQ, using I-TEFs (NATO, 1988), was almost three times as high as in the present study, with a substantial elevation in mPCB TEQ, 50 pg/g lipid versus about 9 pg/g lipid in our samples from 2002 using 1997 WHO TEFs.

4. Discussion

This study examined levels of PCDDs, PCDFs, and dioxin-like non-*ortho* and mono-*ortho* PCBs in AFHS Comparison and Ranch Hand veterans who did not have a previous valid TCDD measurement and attended the 2002 physical examination. It is important to note that these men were not randomly selected and so may not be a representative sampling of their respective cohorts. We found low levels of PCDDs, PCDFs, and PCBs in both Ranch Hand and Comparison veterans but the mean TCDD level in 2002 was still almost three times higher in Ranch Hands (5.5 pg/g lipid versus 1.7 pg/g lipid). Occupational exposure to TCDD contaminated herbicides in Ranch Hand veterans occurred 30–40 years before the blood collection.

Using 1997 WHO TEFs to calculate TEQs, TCDD contributed only about 5% to the total TEQ (1.7 pg/g lipid out of 32.6 pg/g lipid) in Comparison veterans while it still contributed about three times more in this small group of Ranch Hands (17%). The total mean TEQ levels were similar (Tables 2 and 3). The difference in PCDD TEQs corresponded approximately to the difference in TCDD but Comparisons and Ranch Hands had a similar total mean TEQ mainly due to higher levels of coplanar/non-*ortho* PCB congeners in Comparisons, specifically PCB 126, 48.3 ng/g lipid versus 19 ng/g lipid in Ranch Hands. The total cPCB TEQ in Comparisons was more than twice the level in Ranch Hands. The differences between the Comparisons and Ranch Hands mean TEQ levels of PCDFs and mono-*ortho* PCBs were small (Table 3). The highest TCDD measured in Comparisons was 11.7 pg/g lipid and in Ranch Hands it was 34 pg/g lipid (data not shown). One of the Comparison veterans had a total TEQ of 292 pg/g of lipid, mostly from non-*ortho* PCBs and

mono-*ortho* PCBs TEQ (160 pg/g lipid and 80.4 pg/g lipid, respectively), and only moderately elevated TCDD (11.7 pg/g lipid). We do not know the source(s) of this Comparison veteran's exposure to organochlorines.

The introduction of 2005 WHO TEFs (van den Berg et al., 2006) had considerable impact on results of this study. The total mean TEQs decreased by about 28% in both Comparisons and Ranch Hands, from 32.6 pg/g lipid to 23.6 pg/g lipid, and from 31.6 pg/g lipid to 22.8 pg/g lipid. This was mainly due to a change of TEFs for the group of mono-*ortho* PCBs, that was assigned the factor of 0.00003 for all mono-*ortho* substituted congeners instead of the 1997 WHO range of factors that varied from 0.00001 (PCB 167) to 0.0001 (PCBs 118, 105, 123, 189), and 0.0005 (PCBs 114, 156, 157). The change in mPCBs TEQ resulted in a decrease of 86% from 9.4 pg/g lipid to 1.3 pg/g in Comparisons, and an 88% decrease from 9.3 pg/g lipid to 1.1 pg/g lipid in Ranch Hands. The change of the TEF for OCDD did not materially change our results for PCDDs TEQ. Changes in TEFs for PCDF congeners resulted in about a 30% decrease in PCDFs TEQs in both Comparisons and Ranch Hands, while we observed a 10% increase for cPCBs TEQ in Comparisons and 24% increase in Ranch Hands; the cPCBs TEQ remaining twice as high in Comparisons, 5.8 pg/g lipid versus 2.9 pg/g lipid in Ranch Hands.

The elevated TCDD in the Ranch Hands veterans did not translate into a higher mean total TEQ than in Comparison veterans but that may be due to the small number of Ranch Hands ($n = 12$) and non-random selection of participants in the present analysis. By design, Comparisons were matched to Ranch Hands on age, race, and military occupation, with enlisted ground crew being the higher exposed, enlisted flyers the middle exposed, and officers the lower exposed group. A higher proportion of officers in the Ranch Hand group were present in this study (50% versus 39%) than in some earlier studies, e.g. Pavuk et al. (2003).

Comparison of the 90th percentiles of AFHS data to US general population levels based on NHANES 2001–2002 data showed similar levels in the 45–59 y age group, and quite lower levels for 60+ years age group in Comparisons for all four congener groups. The Ranch Hand group levels were similar to the NHANES 40–59 y age group results with the exception of higher PCDDs TEQ. The use of 2005 WHO TEFs for the AFHS data resulted in similar changes for 90th percentiles TEQs as described earlier for mean TEQs. About 25% decrease in total TEQs for both Comparisons age groups and Ranch Hands were observed, mainly due to large decreases in mPCBs TEQs; 96% in Comparisons and 88% in the 40–59 y and 89% in the 60+ years age group of Ranch Hands, with almost no change in PCDDs TEQs. The 90th percentile PCDFs TEQs decreased by 30% in Comparisons and Ranch Hand and cPCBs TEQs increased to a lesser degree by about 10% in Comparisons and 20% in Ranch Hands. Applying the new 2005 WHO TEFs resulted in the increase in the percent contribution from PCDDs TEQs through substantial decreases in mPCBs TEQs and to a smaller extent in PCDFs TEQs. Similar changes applying 2005 WHO TEFs were also observed in NHANES data. Total TEQs decreased by 23% in the 45–59 y age group and by 20% in the 60+ years age group. In populations where more of the total TEQ is derived from PCDFs TEQ and mPCBs TEQ, the changes and reduction of estimates in total dioxin-like TEQ body burden could be even more pronounced than decreases reported here. For

example, the total mean TEQ for samples from Germany (Table 5) would decrease by more than 32% if the 2005 WHO TEFs were applied (data not shown).

Our findings support the use of congener specific dioxin analysis in human exposure assessment, and in the Air Force Health Study in particular. As expected, TCDD contributed a higher proportion to the total TEQ in Ranch Hand than in Comparison veterans. The total mean TEQ was similar in both groups. The use of newly released 2005 WHO TEFs decreased total mean TEQs by about 28% mainly due to an almost 90% decrease in mPCBs TEQs. These results suggests that especially in populations where mPCBs TEQ contributes substantially to total mean TEQ, a re-calculation of TEQs may lead to a substantial decrease of estimated body burdens. Measurement of PCDDs, PCDFs, and PCBs in sera collected in 2002 in 800 randomly selected participants, 400 Ranch Hands and 400 Comparisons, has recently been completed and will add further information to results observed here.

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Fig. 1. Percent contribution of PCDDs, PCDFs, cPCBs, and mPCBs TEQs to the total mean TEQ in Comparison and Ranch Hand Air Force veterans in 2002.

Table 1

Demographic characteristics of US Air Force veterans who participated at 2002 physical exam and did not have a previous TCDD measurement

	Comparisons (<i>n</i> = 94)	Ranch Hands (<i>n</i> = 12)
Age at tour, mean (SD)	31 (7.4)	30.2 (8.7)
BMI 2002, mean (SD)	28.9 (4.3)	28.7 (4.7)
Pack years of smoking, mean (SD)	16.4 (21.5)	13.8 (23.2)
Alcohol consumption (drink years), mean (SD)	46 (107)	68 (83)
White (%)	81 (86.2)	10 (83.3)
Officers	33 (35.1)	6 (50)
Flyers	20 (21.3)	2 (16.7)
Enlisted ground	41 (43.6)	4 (33.3)
Days in Vietnam, mean (SD)	246 (291)	361 (171)
Days in SEA ^a , mean (SD)	1010 (921)	47 (98)

^aSEA – Southeast Asia.

Table 2

PCDDs, PCDFs, cPCBs, and mPCBs congeners in 106 Air Force Health Study veterans in 2002

	1997 WHO TEFs	2005 WHO TEFs	Comparisons (<i>n</i> = 94)			Ranch Hands (<i>n</i> = 12)		
			>LOD% ^a	Mean	10%–90%	>LOD % ^a	Mean	10–90%
2,3,7,8-TCDD	1	1	36	1.7	0.5–3.5	42	5.5	0.4–8.8
1,2,3,7,8-PnCDD	1	1	60	5	0.8–9.8	75	5.3	0.6–8.8
1,2,3,4,7,8-HxCDD	0.1	0.1	43	3.6	0.9–8.9	50	3.9	0.9–7.8
1,2,3,6,7,8-HxCDD	0.1	0.1	99	48.2	24.8–69.3	83	37.9	21.5–63.9
F1,2,3,7,8,9-HxCDD	0.1	0.1	19	2.6	0.8–8	75	4.7	1.1–7.71
1,2,3,4,6,7,8-HpCDD	0.01	0.01	100	44.7	16.6–72	100	39.8	8.7–74.4
OCDD	0.0001	0.0003	99	369	146–655	92	261	111–529
2,3,7,8-TCDF	0.1	0.1	2	0.7	0.4–1.1	0	0.9	0.4–0.7
1,2,3,7,8-PnCDF	0.05	0.03	1	0.8	0.5–1.1	0	0.9	0.4–0.9
2,3,4,7,8-PnCDF	0.5	0.3	88	7.5	1.1–11.7	83	6.5	0.7–12.5
1,2,3,4,7,8-HxCDF	0.1	0.1	97	5.6	3–8.3	100	5.3	2.3–9.1
1,2,3,6,7,8-HxCDF	0.1	0.1	95	5.5	2.6–8.3	75	4	0.6–6.8
2,3,4,6,7,8-HxCDF	0.1	0.1	0	0.8	0.5–1.1	0	1	0.5–0.8
1,2,3,7,8,9-HxCDF	0.1	0.1	50	1.5	0.7–2.3	8.3	1.4	0.6–1.6
1,2,3,4,6,7,8-HpCDF	0.01	0.01	100	12.6	6.9–20.2	92	8.9	6.7–12.9
1,2,3,4,7,8,9-HpCDF	0.01	0.01	0	0.9	0.6–1.3	0	1.1	0.6–1
PCB 81	0.0001	0.0003	32	4.3	1.7–6.6	0	1.4	0.8–2.1
PCB 126	0.1	0.1	96	48.3	13–57.9	92	19	9–26.6
PCB 169	0.01	0.03	100	33.3	18–40.8	100	33.1	19–48.9
PCB 118 ^b	0.0001	0.00003	92	22	5.6–35.1	92	14.4	5.5–17.2
PCB 105	0.0001	0.00003	21	3.9	0.8–5.9	8	2.9	0.9–2.6
PCB 167	0.00001	0.00003	6	3.2	1.4–4.3	0	2.7	1.4–3.7
PCB 156	0.0005	0.00003	90	10.6	5.4–16.8	0	12	6.4–22
PCB 157	0.0005	0.00003	4	2.6	1.2–4.2	8	2.6	1.4–5.1
PCB 189	0.0001	0.00003	0	1.7	0.9–3.9	0	1.5	0.9–3

^a>LOD % – Percent above limit of detection.^bMono-*ortho* PCBs 118 through 189 measured levels in ng/g lipid; levels of all other congeners and TEQ levels in pg/g lipid.

Table 3

PCDDs, PCDFs, cPCBs, mPCBs, and total TEQs in 106 Air Force Health Study veterans in 2002 (pg/g lipid)

TEQ	Comparisons (<i>n</i> = 94)				Ranch Hands (<i>n</i> = 12)			
	1997 WHO TEFs		2005 WHO TEFs		1997 WHO TEFs		2005 WHO TEFs	
	Mean	10–90%	Mean	10–90%	Mean	10–90%	Mean	10–90%
PCDDs	12.6	5.9–21.9	12.7	6–21.9	15.5	6.2–25.9	15.5	6.2–25.9
PCDFs	5.4	2.3–8.1	3.8	1.9–5.7	4.6	2–8.3	3.3	1.6–3.8
cPCBs	5.2	1.4–6.1	5.8	1.8–6.8	2.2	1.2–3.1	2.9	1.8–3.9
mPCBs	9.4	4.6–12.9	1.3	0.6–1.8	9.3	5.5–15.7	1.1	0.6–1.5
Total TEQ	32.6	16.2–45.8	23.6	12.4–34.2	31.6	15.2–48.6	22.8	10.2–35.8

Table 4

90th percentiles and 95% confidence intervals of PCDDs, PCDFs, cPCBs, mPCBs, and total TEQs using 1997 WHO and 2005 WHO TEFs in 106 US Air Force veterans and reference ranges from the US general population, males (pg/g lipid)

TEQ	90th percentile (95% CI)				
	Ranch Hands		Comparisons		US population, males ^a
	Age (years)	52–87 ^b (n = 12)	40–59 (n = 32)	60+ (n = 62)	40–59 60+
1997 WHO TEFs					
PCDDs		25.9 (16.8–45.3)	16.3 (14.1–24.8)	22 (20.7–37.5)	19.5 (13.3–30.4) 39.6 (33.2–43.9)
PCDFs		8.3 (4.5–12.5)	7.2 (6.1–11.6)	8.2 (7.6–13.7)	9.3 (7.1–13.6) 11.9 (10.8–14.7)
cPCBs		3.1 (2.5–3.8)	4.9 (3.1–8.4)	6.4 (5.9–16.6)	5.1 (4.2–5.9) 10.4 (7.4–12.8)
mPCBs		15.7 (8–23.5)	10.9 (8.8–11.7)	17 (12.6–21.8)	11.1 (9.5–13.2) 20.8 (16.2–26.1)
Total TEQ		48.6 (38.2–58.6)	38.6 (31.5–45.8)	48.8 (42.2–80.3)	43.3 (33.9–52.8) 72.7 (65.2–85.3)
2005 WHO TEFs					
PCDDs		25.9 (16.8–45.4)	16.4 (14.1–24.9)	22.1 (18.9–37.6)	19.6 (13.3–30.5) 39.7 (32.6–44)
PCDFs		5.8 (3.3–8.8)	5.2 (4.3–8.1)	5.9 (5.4–9)	6.8 (5.2–9.9) 8.8 (8.1–10.4)
cPCBs		3.9 (3.4–4.2)	5.4 (3.7–9.1)	7.1 (6.7–17.3)	5.9 (4.8–6.5) 11.6 (9–14.3)
mPCBs		1.5 (1–3.6)	1.3 (0.9–2.4)	1.9 (1.8–3.2)	1.5 (1.2–1.6) 2.9 (2.2–3.6)
Total TEQ		35.8 (25.1–53.3)	29.1 (23.4–35.2)	36.3 (30.6–62)	31.5 (25.3–41.0) 58.9 (53–67.2)

^aPatterson et al. (2005).

^bMedian age 61.5 years.

Table 5

Mean levels of PCDDs, PCDFs, cPCBs, and mPCBs TEQ in Air Force Health Study Comparisons and five other populations, pg/g of lipid (year samples collected)

TEQ ^a	AFHS ^b (2002)	Vietnam vet., Michigan, US ^c (1991– 1992)	Texas, USA ^d (2002)	Germany ^e (2001)	Australia ^f (2001–2003)	USA ^g (1996–2001)
PCDDs	12.6	19.5	20.5	12.2	3.2	– ^h
PCDFs	5.4	7.2	4.6	8.1	3.5	–
cPCBs	5.2	13.5	5.4	8	4.1	–
mPCBs	9.2	50	– ^h	14.3	– ^h	–
PCDDs/Fs/cPCBs TEQ	23.2	40.2	30.5	28.4	10.8	16.8
Total TEQ	32.6	90.2	–	42.7	–	–

^a1997 WHO TEFs used to calculate TEQs unless indicated otherwise.

^bPresent study – Comparisons ($n = 94$).

^cSchecter et al. (1996), I-TEFs NATO (1988) used to calculate TEQs ($n = 50$).

^dSchecter et al. (2002) ($n = 100$).

^eFürst and Pöpke (2002) ($n = 13$).

^fHarden et al. (2004) ($n = 4696$, 50 pools).

^gPatterson et al. (2004) ($n = 588$).

^h–, not reported.