



Racial differences in levels of serum lipids and effects of exposure to persistent organic pollutants on lipid levels in residents of Anniston, Alabama



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ARTICLE INFO

Article history:

Received 27 March 2014

Accepted 24 July 2014

Available online 20 August 2014

Keywords:

PCBs

Pesticides

Cardiovascular disease

Cholesterol

Triglycerides

HDL

ABSTRACT

Serum lipid levels are major risk factors for cardiovascular disease. In addition to diet, exercise, genetics, age and race, serum concentrations of persistent organic pollutants (POPs) influence concentrations of serum lipids. We investigated associations between fasting concentrations of 35 polychlorinated biphenyl (PCB) congeners and nine organochlorine pesticides in relation to total serum lipids, total cholesterol, low-density lipoprotein (LDL) cholesterol, high density lipoprotein (HDL) cholesterol and triglycerides in 525 Caucasian and African American residents of Anniston, Alabama, who were not on any lipid-lowering medication. In Model 1, data were adjusted for age, age quadratic, gender, BMI, alcohol consumption, smoking and exercise, while in Model 2, additional adjustment was done for other POPs. As compared to Caucasians, African Americans had lower levels of total lipids and triglycerides with higher concentrations of HDL cholesterol, but higher concentrations of PCBs and pesticides. Total pesticides were more strongly associated with elevations in serum lipids than were total PCBs, and the associations were stronger in African Americans. Total DDTs were not associated with serum lipids after adjustment for other POPs in either racial group, while the strongest positive associations were seen for hexachlorobenzene (HCB) in both racial groups. Racial differences in lipid profiles, concentrations of POPs and associations between POP concentrations and serum lipids are relevant to racial differences in rates of cardiovascular disease.

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1. Introduction

Concentrations of serum lipids are known to be one of the major risk factors for cardiovascular disease, along with hypertension, smoking and diabetes (Berry et al., 2012; Prospective Studies Collaboration et al., 2007). Elevated concentrations of total cholesterol, triglycerides and especially low-density-lipoprotein (LDL) cholesterol are major risk factors for cardiovascular disease (Chapman et al., 2011), as is low high-density-lipoprotein (HDL) cholesterol (Emerging Risk Factors Collaboration et al., 2009). However, there are known racial differences

in “normal” levels of the lipid components, with African Americans having lower total/HDL cholesterol ratios and triglyceride concentrations, as well as higher HDL cholesterol levels, while Hispanics have lower LDL cholesterol, total cholesterol and HDL cholesterol as compared to Caucasians (Rodriguez et al., 2002). Willey et al. (2011) reported that levels of HDL were inversely predictive of risk of a myocardial infarction in African-Americans and Caucasians but not in Hispanics. Chang et al. (2011) have reported significant racial differences in single-nucleotide polymorphisms among the major racial groups in the Third National Health and Nutrition Examination Survey (NHANES), and Dumitrescu et al. (2011) have found racial differences in common genetic variants associated with HDL, LDL and triglycerides, which is consistent with the hypothesis that the differences reported above are at least in part due to genetic variability. However, in spite of having on average higher concentrations of HDL cholesterol, African Americans have a higher mortality from coronary heart disease as compared to either Caucasians or Hispanics (Lloyd-Jones et al., 2010; Roger et al., 2012).

Lifestyle factors, including diet (Hu and Willett, 2002), tobacco (Benowitz, 2003), binge alcohol use (Graff-Iversen et al., 2012) and frequency of exercise (Wisløff et al., 2005) are important in relation to serum levels of the various lipid components. There are significant racial

Abbreviations: AA, African Americans; ATSDR, Agency for Toxic Substances and Disease Registry; BMI, body mass index; CA, Caucasian Americans; DDE, dichlorodiphenyldichloroethylene; DDT, dichlorodiphenyltrichloroethane; HCB, hexachlorobenzene; HCCH, hexachlorocyclohexane; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; PCBs, Polychlorinated biphenyls; POPs, persistent organic pollutants; ppb, parts per billion (ng/g); ww, wet weight.

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and geographical differences in dietary intakes in black and white women (Newby et al., 2012). Smoking is more common, but heavy alcohol consumption is less common in African Americans than Caucasians in at least some studies (White et al., 2012).

The role of exposure to environmental contaminants and cardiovascular disease is often not acknowledged in large population studies, but is important. Exposure to lead (Glenn et al., 2003) and polychlorinated biphenyls (PCBs) (Goncharov et al., 2010) increases risk of hypertension, while exposure to arsenic (Chang et al., 2004) and methylmercury (Guallar et al., 2002) increases risk of coronary artery disease. Several authors have reported elevations in triglycerides (Baker et al., 1980; Chase et al., 1982) and total cholesterol (Stehr-Green et al., 1986; Takamatsu et al., 1984; Tokunaga and Kataoka, 2003) in PCB-exposed populations. Persons with occupational PCB exposures were found to have elevations in rates of cardiovascular deaths (Gustavsson and Hogstedt, 1997). In a Native American population, higher PCB levels were associated with elevations of both triglycerides and total cholesterol, as well as with self-reported hypertension and cardiovascular disease (Goncharov et al., 2008).

PCBs were manufactured in Anniston, Alabama, from 1929 until 1971. In 2003 ATSDR funded a consortium of universities to determine exposure of nearby residents and the resulting health impacts. The serum PCB levels in 758 Anniston residents ages 19–93 years ranged from 0.1 to 170.4 ng/g (ppb) with a median of 3.2 ng/g (Goncharov et al., 2010). These concentrations can be compared to the statement by ATSDR (2000) that the average PCB concentration in persons that are not unusually exposed is between 0.9 and 1.5 ng/g.

We have previously reported evidence that serum concentrations of various PCB congeners and chlorinated pesticides are associated with the alteration of the profile of serum lipid levels in Anniston residents in a study where we controlled for race (Aminov et al., 2013). The goal of the present study is to explore racial differences both among serum lipid components in a population that has nearly identical numbers of African Americans and Caucasians, and to determine how total PCBs, PCB congener groups, total pesticides and concentrations of individual pesticides or pesticide groups may alter these serum lipid associations.

2. Materials and method

Previous reports have described the study population, sampling methods, data collection techniques and laboratory analyses (Aminov et al., 2013; Goncharov et al., 2010, 2011), and so these methods will be presented only briefly here.

2.1. Study site and population

A pool of 3320 eligible addresses was randomly selected from a commercial list of all residential properties in Anniston with intentional oversampling (two thirds of all eligible) of residences in West Anniston, which is the area nearest the former PCB manufacturing facility, resulting in a stratified sample that facilitated enrollment of individuals with residences closer to the plant. An adult member of each household was invited to enroll in the study. Interviews were conducted by trained interviewers with 1110 persons (ages 18 years and older) who were enrolled in the study. The objective of the interview was to obtain information about each study participants demographics, lifestyle, and health-related variables.

A total of 774 persons provided fasting blood samples for analysis of serum PCBs and pesticides, serum lipids and fasting glucose. PCB results were missing for eight subjects failing quality control/assurance procedures, there was no medication information for one subject, no race/ethnicity information for one subject, and height and weight parameters were not available for two participants, and so these subjects were excluded. To exclude a possible influence of confounding by

lipid-lowering medication, for our study we used 575 study participants who reported that they are not taking any lipid-lowering medication.

2.2. Laboratory analyses

The Centers for Disease Control and Prevention's National Center for Environmental Health laboratory performed analyses of levels of 35 PCB congeners (PCBs 28, 44, 49, 52, 66, 74, 87, 99, 101, 105, 110, 118, 128, 146, 149, 151, 153, 156, 157, 138–158, 167, 170, 172, 177, 178, 180, 183, 187, 189, 194, 195, 199, 196–203, 206, 209) and 9 organochlorine pesticides [hexachlorobenzene (HCB), β -hexachlorocyclohexane (β -HCH), γ -HCH, oxychlorodane, trans-nonachlor, dichlorodiphenyl-trichloroethanes (p,p'-DDE, p,p'-DDT, o,p'-DDT, the sum of which will be called "total DDTs") and mirex] in serum, measured by high resolution gas chromatography/isotope dilution mass spectrometry (Sjödin et al., 2004).

The Clinical Chemistry Laboratory of the Jacksonville, Alabama Medical Center measured serum levels of different lipid fractions (triglycerides, total cholesterol, LDL cholesterol and HDL cholesterol). The formula proposed by Bernert et al. (2007) was applied to calculate total lipid levels.

2.3. Statistical analysis

All statistical analyses were conducted using SAS System 9.1.3 package (SAS Institute, Inc., Cary, NC). Descriptive statistics were calculated for outcome variables, demographic characteristics, and exposure variables. The Cochran–Mantel–Haenszel test was used to compare demographic and behavioral characteristics of the two racial groups. Student's *t*-test was used in order to assess racial differences in demographic and serum characteristics. Normality of covariates was assessed graphically and by the Kolmogorov–Smirnov test. Since serum POP concentrations were highly skewed, they were natural log transformed to achieve approximately normal distribution before including them into regression models. Serum lipid levels were less skewed but were also natural log transformed. Multiple linear regression modeling was used to evaluate relationships between five outcome variables (serum concentrations of total lipids, total cholesterol, HDL cholesterol, LDL cholesterol, and triglycerides) and exposure variables (serum levels of total PCBs and total pesticides as well as various PCB and pesticide groups) in each racial group. All regression models were adjusted for confounders defined by selected demographic and behavioral characteristics of the study population.

As previously described (Aminov et al., 2013), we used two models. In Model 1 adjustment was made only for age, age quadratic, gender, BMI, smoking, alcohol consumption and exercise. In Model 2 adjustment was made, in addition to all those variables in Model 1, for concentrations of all other POPs than the one under study. While theoretically preferable because it can assist in distinguishing actions of different contaminants that are all found in serum lipids, use of Model 2 can lead to results that are statistically significant but biologically implausible, especially if the apparent association changes sign (see Additional file 1 in Aminov et al., 2013). Thus results using Model 2 must be interpreted with caution.

Predictive models were validated by evaluating R-squared statistics. All possible interaction terms initially were in the models, including "race \times PCBs", "race \times pesticides", "age \times PCBs" and "age \times pesticides", but in final models they were removed since none of the interaction terms had significant estimates or significantly contributed to the models. To address the issue of multicollinearity between exposure variables, we have assessed the correlation between groups of POPs. The correlation between groups of PCBs organized by number of *ortho*-substituted chlorines and the various pesticides was assessed by calculation of Spearman's correlation coefficients by race. The exposure variables (concentrations of total PCBs, total pesticides, groups of PCBs, and pesticides) and hypotheses tested have been defined a priori,

consistent with our previous statistical analyses. The estimates are considered statistically significant if the p-values are less than or equal to 0.05. The data presented using Model 1 does use testing for multiple hypotheses and therefore it would be appropriate to apply the Bonferroni correction. For eight variables this would lead to a significance value of 0.0062. Application of the Bonferroni correction is not appropriate for Model 2 data. To avoid confusion all data is presented using a p value less than or equal to 0.05.

Concentrations of PCB congeners 52, 49, 44, 101, 110, 151, 149, and 128 and of γ -HCCH showed a high prevalence (more than 60%) of values below the detection limit, and were therefore excluded from analysis. For all other POPs, values below detection limits were replaced by the detection level divided by the square root of two.

Since PCB congeners and organochlorine pesticides have various molecular structures, they may have different health effects. Hence, we evaluated associations between the outcome variables and groups of PCB congeners and pesticides. Organochlorine pesticides were grouped by their molecular structure, while PCB congeners were grouped by the number of *ortho* substituted chlorines.

3. Results

Demographic characteristics of the whole study population and each racial group are presented in Table 1. The age distribution was almost the same among Caucasians and African Americans. The majority of both groups were 37 to 74 years old. In both groups females composed approximately 2/3 of the group. Prevalence of regular alcohol consumers was higher in African Americans ($p < 0.0001$), while prevalence of smokers was higher in Caucasians ($p = 0.0332$) in this population, unlike other reports (White et al., 2012). No difference was observed in numbers of study participants in each group who engaged in regular physical activity (58.0% and 53.7% for Caucasians and African Americans respectively).

The geographic residential location of the Caucasian and African American study participants is also illustrated in Fig. 1. African Americans reside primarily within the triangular area formed by the rail lines north of the former PCB production plant and the waterway running away from the plant. These areas are at lower elevation than are other parts of Anniston; areas at lower elevations often have higher soil levels of total PCBs (Chang et al., 2011; Orloff et al., 2003).

Table 1
Demographic characteristics and health behaviors of the study population (N = 575) and each racial group: Caucasian American (N = 288) and African American (N = 287).

	Total N = 575	Caucasian American N = 288	African American N = 287
Age			
18–36	106/575 (18.43%)	60/288 (20.9%)	46/287 (16.0%)
37–55	225/575 (39.13%)	98/288 (34.0%)	127/287 (44.2%)
56–74	192/575 (33.39%)	98/288 (34.0%)	94/287 (32.8%)
75–93	52/575 (9.04%)	32/288 (11.1%)	20/287 (7.0%)
Gender			
Female	407/575 (70.78%)	209/288 (72.6%)	198/287 (69.0%)
Male	168/575 (29.22%)	79/288 (27.4%)	89/287 (31.0%)
Alcohol consumption			
Yes	177/575 (30.78%)	64/288 (22.2%)	113/287 (39.4%)
No	398/575 (69.22%)	224/288 (77.8%)	174/287 (60.6%)
Smoking			
Yes	304/573 (53.05%)	165/287 (57.5%)	139/286 (48.6%)
No	269/573 (46.95%)	122/287 (42.5%)	147/286 (51.4%)
Physical activity			
Yes	319/571 (55.87%)	166/286 (58.0%)	153/285 (53.7%)
No	252/571 (44.13%)	120/286 (42.0%)	132/285 (46.3%)

Age and BMI were not significantly different in the two groups (Table 2). When mean serum concentrations of serum lipids were compared, total lipid concentrations and triglycerides were significantly lower and concentrations of HDL cholesterol were higher among African Americans. Concentrations of total cholesterol and LDL cholesterol were not significantly different between the two groups. Total serum concentrations of PCBs were significantly higher among African Americans, and the differences were similar in proportion when the concentrations of PCB congener groups were compared, i.e., values for each congener group were 2–3 times higher in African Americans. Mean total serum concentrations of chlorinated pesticides were also higher among African Americans, but when pesticides were separated into groups, summary concentrations of oxychlordane and t-nonachlordane were significantly higher among Caucasians and concentrations of HCB and HCCHs were not significantly different in the two groups. Only concentrations of mirex and total DDTs were significantly higher in African Americans. Chlorinated pesticides have never been produced in the former PCB production facility in Anniston.

In order to assess the relationship between exposure to POPs and serum concentrations of lipids, we first regressed serum concentrations of lipids with total concentrations of POPs with adjustment for demographic and behavioral variables (Supplemental Table 1). In both groups total serum concentrations of POPs on a wet weight basis (per gram of serum) were positively associated with serum total concentrations of lipids, total cholesterol and triglycerides. Associations were slightly stronger in African Americans. There was no significant association between total POPs and either LDL or HDL cholesterol.

Table 3 shows results of linear regression analysis of the relationships between serum total PCBs and chlorinated pesticides to serum lipid concentrations in Caucasians and African Americans. In Model 1 adjustment was made for age, age quadratic, gender, BMI, alcohol consumption, smoking and exercise. In Model 2 all results were adjusted for possible demographic and behavioral confounders, as well as the other contaminants. The results show some racial differences. For Caucasians, total PCBs were significantly associated only with total lipids in Model 1, but this association disappeared using Model 2. For African Americans, total serum PCBs were positively associated with total lipids and triglycerides using Model 1, but these associations also disappeared after adjustment for total pesticides. For the chlorinated pesticides, Caucasians and African Americans both showed positive correlations with total lipids and triglycerides with both models, while among African Americans in both models there was a significant positive association with serum total cholesterol as well.

Table 4 presents results obtained when total serum concentrations of PCBs are broken into groups by the number of *ortho*-substituted chlorine atoms. Among Caucasians all significant associations in Model 1 for mono- and di-*ortho* PCB congeners disappeared in Model 2 analysis, which was controlled for all remaining PCB groups and the pesticides, while the association of total lipids with tri- plus tetra-*ortho* PCBs remained significant. For African Americans, associations of mono-*ortho* PCBs with total lipids also disappeared after adjustment for other POPs, and the apparently statistically significant association with di-*ortho* PCBs with both total lipids and triglycerides changed signs, which is not biologically plausible. We attribute these several biologically implausible reversals of sign observed in Table 4, some of which are statistically significant, to excessive multicollinearity. These statistical artifacts should be treated with considerable caution (Aminov et al., 2013). Supplemental Tables 2 and 3 show Pearson's correlation coefficients for the various POPs in Caucasians and African Americans, respectively. It is clear that there is a high degree of correlation among most of these lipophilic compounds. The associations seen in Table 4 for African Americans for tri- and tetra-*ortho* PCBs with total lipids, total cholesterol and triglycerides remained significant in Model 2. There was no association with either LDL or HDL cholesterol in either racial group. These results suggest that the associations between serum lipids and PCBs are primarily due to the higher chlorinated tri- plus tetra *ortho* congeners.

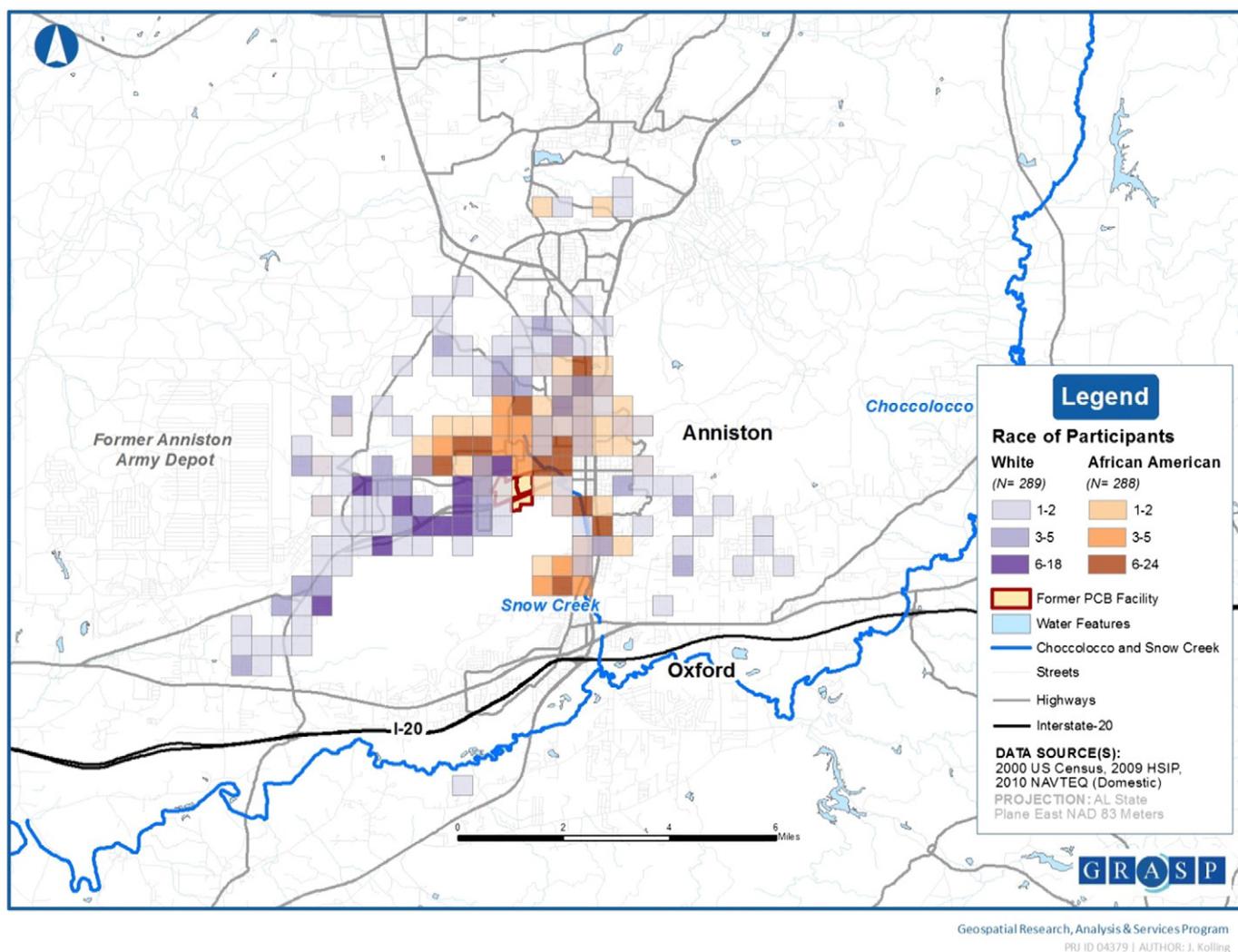


Fig. 1. Residential distribution of study participants' residences by race in relation to the site of the former Monsanto PCB production facility. Caucasian Americans are represented by purple, while African Americans are represented by orange. Each square is about 0.5 mile on each side. More detailed identification is not provided in order to avoid unique identifying information on study participants. The color of each square indicates the residential density of each racial group in that location. Areas dominated by one racial group are shown with one color more saturated than the other, while areas with a more balanced distribution are indicated by a more apparent overlap in colors.

Table 5 shows results similar to those in Table 4, but for the various groups of pesticides. In spite of the fact that total DDT was found at a much higher concentration than any of the other pesticides, there was no significant association between the levels of total DDT and any lipid component in either racial group after adjustment for other POPs. After adjustment for other POPs, serum concentrations of total chloro-danes showed significant positive associations with serum total lipids and triglycerides in African Americans, but in Caucasians there was a significant association only with triglycerides, even though the total chloro-dane concentrations were higher in Caucasians. Mirex and HCCH did not show any significant and plausible associations in either racial group after adjustment for other POPs. Although HCB was present only at background concentrations, there were strong positive associations between serum concentrations and serum lipids in both racial groups. For both Caucasians and African Americans, HCB showed positive associations with serum total lipids, total cholesterol, LDL cholesterol and triglycerides. There was even a hint of an inverse relationship between concentrations of HCB and HDL cholesterol, but most results were not significant. It is noteworthy that only HCB of all the POPs studied was associated with significant changes in LDL cholesterol.

4. Discussion

Our findings can be summarized by several points:

1. Despite similar demographic characteristics, serum lipid profiles and concentrations of POPs are significantly different in the two racial groups. African Americans had lower serum concentrations of total lipids and triglycerides, and higher concentrations of HDL cholesterol than did Caucasians, but they also had higher concentrations of total PCBs and total chlorinated pesticides.
2. Total PCBs were positively associated with elevations in total lipids in both races when results were not adjusted for total pesticides, but there was no longer a significant association after adjustment for total pesticides. Total pesticides were significantly associated with both total lipids and triglycerides before and after adjustment for other POPs in both races, and there was also a significant association with total cholesterol among African Americans. There was no significant association between levels of either total PCBs or total pesticides and either LDL or HDL cholesterol. Thus pesticides show a stronger association with serum lipid levels than PCBs.

Table 2
Means and ranges of age, BMI, serum lipid levels, total PCBs, total pesticides and PCB and pesticide groups in the study population (n = 575) with results of Student's *t*-test for differences between the means for Caucasian Americans (n = 288) and African Americans (n = 287).

	Total mean (N = 575)	Caucasian (N = 288)			African American (N = 287)			p-Value
		Mean	SD	Range	Mean	SD	Range	
Age (years)	52.15	52.69	17.43	19–92	51.61	14.60	18–93	0.4219
BMI (kg/m ²)	30.88	30.31	8.08	18–65	31.46	7.94	16–60	0.0843
Total lipids (mg/dL)	636.88	661.50	154.80	355.2–1264.6	612.09	147.40	335.8–1436.2	0.0001
Total cholesterol (mg/dL)	195.85	199.01	43.81	84.0–373.0	192.68	41.52	87.0–329.0	0.0756
HDL cholesterol (mg/dL)	48.53	45.82	12.81	20.0–95.0	51.25	18.09	19–148	< 0.0001
LDL cholesterol (mg/dL)	121.68	123.75	38.00	36.0–300.0	119.6	36.32	38–231	0.1870
Triglycerides (mg/dL)	130.14	147.31	88.63	31.0–547.0	112.85	92.49	15–929	< 0.0001
Total PCBs (ppb ww)	6.33	3.36	5.02	0.11–47.92	9.33	16.64	0.22–170.40	< 0.0001
Mono-ortho congeners (ppb ww)	0.85	0.42	0.61	0.03–5.45	1.28	2.83	0.04–34.28	< 0.0001
Di-ortho congeners (ppb ww)	3.95	2.01	2.91	0.06–32.04	5.91	10.68	0.14–108	< 0.0001
Tri- and tetra-ortho congeners (ppb ww)	1.53	0.93	1.78	0.02–19.88	2.14	3.51	0.04–28.19	< 0.0001
Tri- and tetrachloro congeners (ppb ww)	0.16	0.11	0.14	0.01–1.05	0.21	0.39	0.01–4.32	< 0.0001
Pentachloro congeners (ppb ww)	0.68	0.27	0.48	0.02–4.22	1.09	2.57	0.03–34.4	< 0.0001
Hexachloro congeners (ppb ww)	2.59	1.25	1.91	0.04–21.60	3.94	7.44	0.09–77.7	< 0.0001
Heptachloro congeners (ppb ww)	1.81	0.95	1.37	0.02–14.46	2.67	4.70	0.05–41.46	< 0.0001
Octa-, nona- and decachloro congeners (ppb ww)	1.10	0.77	1.69	0.01–21.65	1.43	2.43	0.02–1976	0.0002
Total pesticides (ppb ww)	4.31	3.44	4.35	0.24–31.61	5.19	6.31	0.15–39.07	0.0001
pp-DDE, op-DDT, pp-DDT (ppb ww)	3.65	2.73	3.77	0.03–31.38	4.59	5.91	0.10–38.51	< 0.0001
Oxychlorodane, t-nonachlorodane (ppb ww)	0.47	0.53	0.87	0.02–10.44	0.40	0.38	0.02–2.72	0.0213
Mirex (ppb ww)	0.10	0.09	0.19	0.00–2.57	0.12	0.19	0.00–2.23	0.0435
HCB (ppb ww)	0.07	0.06	0.03	0.02–0.22	0.07	0.09	0.02–1.48	0.1133
β-HCCH, γ-HCCH (ppb ww)	0.12	0.12	0.16	0.01–1.13	0.12	0.18	0.01–1.77	0.8889

Note. ppb ww = parts per billion wet weight. Results with total PCBs and total pesticides are shown in bold, as are statistically significant differences at the level $p < 0.05$.

- After adjustment for other POPs, the positive associations between PCBs and total lipids and triglycerides in African Americans were found only for the highly chlorinated tri- plus tetra-ortho PCBs. Caucasians also showed a weaker but significant association of total lipids with tri- plus tetra-ortho PCBs. Other PCB congener groups did not show any significant and plausible association in either racial group.
- The highest serum concentrations among chlorinated pesticides were observed for total DDT, but total DDT, mirex and HCCH did not show any association with serum lipids after adjustment for other POPs. HCB, present at low concentrations, had strong positive associations with total lipids, total cholesterol, LDL cholesterol and triglycerides in both racial groups after adjustment for other POPs.

Chlordane also showed a positive and significant association after adjustment for other POPs for triglycerides in Caucasians and total lipids and triglycerides in African Americans.

We have found clear differences in serum lipid profiles in our two racial groups. Previously, based on NHANES II data, Chang et al. (2011) reported that African Americans have higher HDL-cholesterol and lower LDL cholesterol as well as triglycerides than do Caucasian Americans. Similar results were published by Zatu et al. (2011) based on comparison of African and Caucasian populations in South Africa after stratification by smoking status. Another study on weight loss in obese African American and Caucasian adolescents (Budd et al., 2007) reported a higher serum HDL-cholesterol as well as lower LDL-cholesterol and

Table 3
Results of multiple linear regression analysis of the associations between serum concentrations of PCBs and chlorinated pesticides with lipid fractions in Caucasian Americans (CA) and African Americans (AA). Statistically significant values are shown in bold.

		Total PCBs				Total pesticides			
		CA		AA		CA		AA	
		Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Total lipids	β	0.05	0.03	0.05	0.02	0.06	0.04	0.08	0.07
	SE	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	p-Value	0.0100	0.1312	0.0016	0.2391	0.0028	0.0322	< 0.0001	0.0009
Total cholesterol	β	0.04	0.03	0.03	0.01	0.03	0.02	0.05	0.04
	SE	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	p-Value	0.0553	0.1885	0.0801	0.5654	0.0771	0.2765	0.0099	0.0478
HDL cholesterol	β	−0.02	−0.00	0.01	0.00	−0.04	−0.04	0.03	0.02
	SE	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03
	p-Value	0.4085	0.9688	0.5429	0.8703	0.0502	0.0763	0.3384	0.4499
LDL cholesterol	β	0.04	0.03	0.02	0.01	0.03	0.02	0.03	0.02
	SE	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03
	p-Value	0.2003	0.3399	0.3493	0.5972	0.3140	0.5922	0.3074	0.5049
Triglycerides	β	0.10	0.04	0.10	0.05	0.14	0.12	0.16	0.14
	SE	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.06
	p-Value	0.0517	0.4320	0.0128	0.3143	0.0022	0.0126	0.0009	0.0150

Notes: Separate models were used to assess the relationships between total serum PCBs, pesticides and lipid fractions for Caucasian Americans and African Americans. Model 1 – Estimates adjusted for age (as well as age quadratic), gender, BMI, alcohol consumption, smoking and exercising status, but estimates for total PCBs are not adjusted for total pesticides and estimates for serum total pesticides not adjusted for total PCBs; note that the Bonferroni correction has not been applied to Model 1 results. Model 2 – Estimates adjusted for age (as well as age quadratic), gender, BMI, alcohol consumption, smoking and exercising status and in addition total PCB results adjusted for total pesticides, and total pesticides results adjusted for total PCBs.

Table 4

Results of multiple linear regression analysis of associations between serum concentrations of PCB congener groups (number of *ortho* chlorines) and lipid fractions by racial group.

		Mono- <i>ortho</i> PCBs				Di- <i>ortho</i> PCBs				Tri-/tetra- <i>ortho</i> PCBs			
		CA		AA		CA		AA		CA		AA	
		Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Total lipids	β	0.05	-0.03	0.04	-0.05	0.05	-0.05	0.05	-0.18	0.05	0.07	0.06	0.20
	SE	0.02	0.04	0.02	0.05	0.02	0.05	0.02	0.08	0.02	0.04	0.01	0.05
	p-Value	0.0165	<i>0.3482</i>	0.0123	<i>0.3069</i>	0.0151	<i>0.3963</i>	0.0034	0.0240	0.0054	0.0443	<0.0001	0.0002
Total cholesterol	β	0.04	0.00	0.02	-0.04	0.03	-0.05	0.02	-0.12	0.04	0.06	0.03	0.14
	SE	0.02	0.04	0.02	0.05	0.02	0.06	0.01	0.08	0.02	0.04	0.02	0.05
	p-Value	0.0486	<i>0.9426</i>	<i>0.2167</i>	<i>0.4852</i>	<i>0.0763</i>	<i>0.3473</i>	<i>0.1153</i>	<i>0.1235</i>	0.0320	<i>0.1079</i>	0.0206	0.0105
HDL cholesterol	β	-0.01	0.07	0.02	0.09	-0.02	-0.01	0.01	-0.08	-0.02	-0.03	0.01	0.01
	SE	0.02	0.05	0.02	0.07	0.02	0.07	0.02	0.12	0.02	0.05	0.02	0.08
	p-Value	0.7011	<i>0.1431</i>	<i>0.3064</i>	<i>0.2096</i>	<i>0.4086</i>	<i>0.8331</i>	<i>0.5794</i>	<i>0.4745</i>	<i>0.4236</i>	<i>0.5197</i>	<i>0.7208</i>	<i>0.9285</i>
LDL cholesterol	β	0.04	0.01	0.01	-0.08	0.03	-0.10	0.02	-0.08	0.04	0.10	0.03	0.15
	SE	0.03	0.06	0.02	0.07	0.03	0.09	0.02	0.12	0.03	0.06	0.02	0.08
	p-Value	0.2009	<i>0.7987</i>	<i>0.7874</i>	<i>0.2423</i>	<i>0.2619</i>	<i>0.2685</i>	<i>0.4225</i>	<i>0.4962</i>	<i>0.1018</i>	<i>0.0879</i>	<i>0.1346</i>	<i>0.0557</i>
Triglycerides	β	0.07	-0.16	0.08	-0.12	0.09	-0.07	0.09	-0.44	0.09	0.16	0.13	0.51
	SE	0.05	0.09	0.04	0.12	0.05	0.13	0.04	0.21	0.04	0.09	0.04	0.14
	p-Value	0.1191	<i>0.0637</i>	<i>0.0584</i>	<i>0.3194</i>	<i>0.0671</i>	<i>0.5718</i>	0.0222	0.0338	0.0309	<i>0.0709</i>	0.0010	0.0002

Model 1 – Estimates adjusted for age (as well as age quadratic), gender, BMI, alcohol consumption, smoking and exercising status, but estimates for each PCB groups are not adjusted for other PCB groups or for chlorinated pesticides. Bonferroni correction has not been applied; Model 2 – Estimates adjusted for all covariates as in Model 1 and in addition adjusted for the remaining two PCB groups and all chlorinated pesticides. Statistically significant values are shown in bold. p-Values that reversed sign in Model 2, which reflect excessive multicollinearity, are shown in italics.

triglycerides among African American adolescents. Our study, in addition to these studies, shows that differences in serum lipid fractions in African American and Caucasians exist and that these differences are not dependent upon differences in age or BMI.

It is likely that genetic factors play an important role in these racial differences, although behaviors like smoking and alcohol consumption may also contribute (Chang et al., 2011). African Americans have higher activity levels of lipoprotein lipase, which leads to lower triglyceride

Table 5

Results of multiple linear regression analysis of the associations between serum concentrations of chlorinated pesticides and lipid fractions by racial groups.

		DDT				Chlordane			
		CA		AA		CA		AA	
		Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Total lipids	β	0.03	-0.03	0.07	0.03	0.08	0.03	0.14	0.09
	SE	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
	p-Value	0.0474	<i>0.2144</i>	<0.0001	<i>0.1909</i>	<0.0001	<i>0.2144</i>	<0.0001	0.0056
Total cholesterol	β	0.02	-0.02	0.04	0.02	0.05	0.00	0.07	0.03
	SE	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03
	p-Value	0.2702	<i>0.3158</i>	0.0168	<i>0.3931</i>	0.0074	<i>0.8355</i>	0.0005	<i>0.4310</i>
HDL cholesterol	β	-0.03	-0.01	0.02	0.03	-0.04	-0.02	-0.01	-0.04
	SE	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.05
	p-Value	0.0693	<i>0.5197</i>	<i>0.3453</i>	<i>0.3691</i>	<i>0.0618</i>	<i>0.5124</i>	<i>0.8313</i>	<i>0.3517</i>
LDL cholesterol	β	0.01	-0.01	0.02	0.02	0.04	-0.01	0.05	-0.00
	SE	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.05
	p-Value	0.5208	<i>0.7195</i>	<i>0.3307</i>	<i>0.6216</i>	<i>0.1451</i>	<i>0.8314</i>	<i>0.1130</i>	<i>0.9794</i>
Triglycerides	β	0.07	-0.07	0.14	0.03	0.22	0.12	0.32	0.28
	SE	0.04	0.04	0.04	0.06	0.04	0.05	0.06	0.08
	p-Value	0.0457	<i>0.1098</i>	0.0020	<i>0.5628</i>	<0.0001	0.0183	<0.0001	0.0009

		Mirex				HCB				HCCH			
		CA		AA		CA		AA		CA		AA	
		Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Total lipids	β	0.03	0.01	0.06	0.03	0.26	0.33	0.19	0.12	0.07	-0.05	0.08	-0.02
	SE	0.02	0.02	0.02	0.02	0.03	0.04	0.03	0.04	0.02	0.03	0.02	0.03
	p-Value	0.1104	<i>0.6039</i>	0.0004	<i>0.2531</i>	<0.0001	<0.0001	<0.0001	0.0011	0.0007	<i>0.0780</i>	<0.0001	<i>0.4073</i>
Total cholesterol	β	0.02	0.01	0.04	0.02	0.20	0.28	0.13	0.11	0.04	-0.07	0.05	-0.01
	SE	0.02	0.02	0.02	0.02	0.03	0.04	0.03	0.04	0.02	0.03	0.02	0.03
	p-Value	0.2784	<i>0.7163</i>	<i>0.0177</i>	<i>0.3030</i>	<0.0001	<0.0001	<0.0001	0.0049	<i>0.0698</i>	0.0163	0.0120	<i>0.5860</i>
HDL cholesterol	β	-0.00	0.01	0.02	0.02	-0.10	-0.06	0.04	-0.11	-0.06	-0.04	0.03	0.07
	SE	0.02	0.03	0.02	0.03	0.04	0.05	0.04	0.06	0.02	0.03	0.03	0.04
	p-Value	0.9576	<i>0.6730</i>	<i>0.5254</i>	<i>0.5433</i>	0.0111	<i>0.2889</i>	<i>0.3250</i>	<i>0.0501</i>	0.0133	<i>0.2661</i>	<i>0.2984</i>	<i>0.806</i>
LDL cholesterol	β	0.01	0.00	0.03	0.01	0.21	0.33	0.15	0.18	0.03	-0.09	0.03	-0.05
	SE	0.03	0.03	0.03	0.03	0.05	0.07	0.04	0.06	0.03	0.04	0.03	0.04
	p-Value	0.6010	<i>0.9208</i>	<i>0.3097</i>	<i>0.8050</i>	<0.0001	<0.0001	0.0005	0.0012	<i>0.3705</i>	0.0287	<i>0.4116</i>	<i>0.2431</i>
Triglycerides	β	0.05	-0.00	0.11	0.02	0.56	0.62	0.39	0.22	0.19	-0.01	0.18	-0.05
	SE	0.04	0.04	0.04	0.06	0.07	0.10	0.07	0.10	0.05	0.06	0.05	0.07
	p-Value	0.2815	<i>0.9895</i>	0.0125	<i>0.7878</i>	<0.0001	<0.0001	<0.0001	0.0226	<0.0001	<i>0.9303</i>	0.0009	<i>0.4817</i>

Model 1 – Estimates adjusted for age (as well as age quadratic), gender, BMI, alcohol consumption, smoking and exercising status; Model 2 – Estimates adjusted for all covariates as in Model 1 and in addition adjusted for all PCB groups and all remaining pesticide groups. Statistically significant values are shown in bold. p-Values that reversed sign in Model 2, which reflect excessive multicollinearity, are shown in italics.

levels (Sumner et al., 2005), whereas Caucasians have a higher activity of hepatic lipase, which favors lower levels of HDL cholesterol (Vega et al., 1998). There are well known racial differences in apolipoprotein E polymorphisms (Eichner et al., 2002). In a literature review, Hubacek and Vrablik (2001) suggest that 40–60% of the variation in cholesterol concentrations and up to 70% of differences in effectiveness of statin therapy are due to genetic factors. However, in spite of having a “healthier” lipid profile, rates of cardiovascular disease are generally higher in African Americans than Caucasian Americans (Roger et al., 2012). There may also be significant dietary differences between the races that impact serum lipid concentrations, but we did not have sufficient information in our dataset to examine such differences.

In our study, the African American population had a significantly higher concentration of PCBs in serum. One of the reasons could be that African Americans live nearer to the Monsanto plant (Fig. 1), although the map does not show a striking difference. There may also be cultural differences in the consumption of local livestock, fish and clay which contribute as a source of greater PCB exposure in African Americans (Pavuk et al., 2010). Vapor-phase PCBs have been shown to be elevated near the plant and decrease over distance from the Monsanto facility (Hermanson et al., 2003). Spread of vapor-phase PCBs would be influenced by wind direction. Children in Anniston show a congener pattern that indicates inhalation as an important route of exposure (Hermanson et al., 2006). The same volatile congeners are present in adults, but the relative levels are less because of the time-dependent accumulation of higher chlorinated congeners. Thus, it seems likely that significantly higher serum PCB concentrations in African Americans are due to a combination of differences in residential proximity to the plant and areas of higher PCB contamination, dietary intake of POPs and potentially genetic differences in the rates of PCB metabolism and excretion.

Because there is no specific local site that is a source of the pesticides we have studied, it is more likely that the difference in exposure between the races is a function of diet and eating habits. There may also be racial differences in rates of metabolism of organochlorine pesticides. Winoto et al. (2011) studied frequencies of certain polymorphisms of cytochromes P450 2B6 and 2C19, and found the 2B6 polymorphism more common in Caucasians, but the 2C19 polymorphism more common in African Americans. Since various P450s are the class of enzymes responsible for xenobiotic metabolism, genetic differences could explain some of the variation in concentrations by race. Smoking results in induction of cytochrome P450 1A2 that metabolizes PCBs (Kalow and Tang, 1991), and thus smokers may have lower serum PCB concentrations than non-smokers. In our study, prevalence of smokers was higher among Caucasian Americans, which can partially explain lower serum concentrations of POPs.

Our study shows that not all PCBs have the same relationship to serum lipid fractions, nor do all chlorinated pesticides act the same. This is important because reports often provide information only on total PCBs, frequently after measuring only a limited number of congeners. Clearly, considering only the total concentration may obscure important relationships with various congener groups. With regard to the serum lipids it appears that only the more heavily *ortho*-substituted congeners influence lipid levels, and that this relationship is stronger among African Americans than Caucasians. Among the chlorinated pesticides, HCB—present at much lower concentrations than some of the others like DDT—showed strong associations with serum lipids and the relationships were, if anything, stronger among Caucasians.

4.1. Strengths and weaknesses

This study has the strength of relatively large numbers and approximately equal numbers of African Americans and Caucasians. Exposure status was evaluated objectively and comprehensively. We had control over residential address, medication status and high quality measurement of serum lipid components.

However, it also has some major limitations. The cross-sectional design does not allow for assessing causality. There may remain some confounding due to the fact that POPs are found in the lipid layers and migrate together, and because of this it is difficult to clearly distinguish relative influences on the lipid synthesis. We have attempted to control for this multicollinearity by adjusting for all of the contaminants except the one under examination in all of our models, but this raises the risk of overadjustment (Chapman et al., 2011). The dangers of overadjustment are apparent in a few places where negative associations were found that make no sense, while positive associations were found provided we did not adjust for other contaminants. We also have no comprehensive information on possible dietary differences as a function of race.

5. Conclusions

While our study shows that concentrations of PCBs and chlorinated pesticides are associated with changes in levels of serum lipids, we also found evidence that groups of POPs vary in their associations with serum lipid fractions. In light of this finding, the common practice of reporting only on total PCB concentration may conceal important relationships, such as how heavily *ortho*-substituted PCB congeners may influence lipid levels, and how these relationships may vary based on demographics or other factors. Measurement of specific pesticides revealed that, in this sample, HCB concentration was strongly associated with serum lipids, despite being present at lower concentrations than some of the other pesticides.

Conflict of interest

Dr. Carpenter has served as an expert witness for the plaintiffs in legal actions relating to exposure of residents of Anniston, Alabama to PCBs with all reimbursements going into a Research Foundation of SUNY account. Dr. Olson was also an expert witness in this legal action.

Acknowledgments

Supported by a grant from the Passport Foundation to the Institute for Health and the Environment of the University at Albany (reference #56052) and a grant from the Agency for Toxic Substances and Disease Registry to Jacksonville State University, #5U50TS473215. The contents of this publication are solely the responsibility of the authors and do not necessarily represent ATSDR's official views. GIS analysis was conducted by HoeHun Ha, Department of Geography, Central Michigan University. The Anniston Environmental Health Research Consortium Steering Committee members include Shirley Baker, community representative; Scott Bartell, UC Irvine; James Olson, University at Buffalo; Russell Foushee and Alan Percy, University of Alabama at Birmingham; David O. Carpenter, University at Albany; Jane Cash; Martha Lavender and Christie Shelton, Jacksonville State University; Howard Frumkin, University of Washington; Marian Pavuk ATSCR/CDC; Paula Rosenbaum, Allen Silverstone and Ruth Weinstock, Upstate Medical University; and Kirsten Moysich, Roswell Park Cancer Institute. The map showing the geographic distribution of ACHS participants by race was created by Jessica Kolling of the Geospatial Research, Analysis, and Services Program (GRASP) at the Agency for Toxic Substances and Disease Registry.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.envint.2014.07.022>.

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