Polychlorinated Biphenyls in Malibu Schools

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Date Completed: 03/21/2016

Background: Polychlorinated biphenyls (PCBs) are carcinogenic pollutants that have been banned nationally and which have been found in state governed Malibu public schools Juan Cabrillo Elementary (JCES), Malibu Middle (MMS), and Malibu High School (MHS). Exposure to PCBs increases the risk of heart disease, thyroid disease, Hashimoto's disease, and several forms of cancer. We tested whether the levels of PCBs at Malibu schools correlate with increased incidences of PCB-related diseases, and thus are putatively causing diseases in staff members working at the schools. Hence, we tested our hypothesis that there would be a higher than average persistence of PCB-related diseases in individuals working at these schools.

Methods: We conducted a pilot study that analyzes enrichments in the incidence of PCB-related diseases in staff members at the Malibu schools. In order to test our hypothesis, we administered an online survey to teachers at JCES, MMS, and MHS (n = 146). The survey collected information on the prevalence and severity of PCB-related diseases, along with work hours, and work-site specific information, such as buildings that the teachers work in. In order to draw a comparison, we also administered the same survey to teachers at Oaks Christian School (OCS), a negative control (n= 195). We used binomial tests to assess increased prevalence of PCB-related diseases at the Malibu schools and OCS from our responses (n_{Malibu}= 41; n_{Oaks}= 23). We then used a Fisher's exact test to identify enrichment in disease prevalence in Malibu schools compared to OCS disease rates. Furthermore, we calculated the chance of having a PCB-related disease due to working in buildings with high levels of PCBs using odds ratio. Finally, we conducted a Fisher's exact test to assess the relationship between exposure time and disease status.

Results: The binomial test found a significantly larger prevalence of thyroid cancer ($p = 3.175 \times 10^{-14}$) and Hashimoto's disease ($p = 1.34 \times 10^{-12}$) at the Malibu schools compared to rates in the US. We found no significantly enriched diseases at OCS. The Fisher's exact test comparing disease rates between Malibu schools and OCS found significant enrichment in thyroid disease ($p = 2.110 \times 10^{-4}$), Hashimoto's disease ($p = 0.0216$), and fertility issues ($p = 0.0362$); while thyroid cancer ($p = 0.0983$) showed marginal significance. We could not find any significance when comparing location or length of exposure with disease occurrence.

Solutions: It is important that the public and especially the teachers working at Malibu schools are aware of the significantly increased prevalence of PCB-related diseases. Therefore, we designed a brochure for teachers and students attending the Malibu schools in order to spread awareness. The brochure aims to provide information about PCBs, their health risks, the current state of PCBs in Malibu Schools, and details of non-profit, America Unites for Kids.

The Problem

Polychlorinated biphenyls (PCBs) are a group of man-made organic chemicals and persistent environmental pollutants with a well-known potential toxicity (Domingo and Bocio, 2007). Because of their beneficial properties in thermal insulation, waterproofing, and fire resistance, beginning in 1929, an estimated 1.5 billion pounds of PCBs were commercially manufactured in the United States for use in products such as microscope oils, electrical insulators, capacitors, and electric appliances (National Oceanic and Atmospheric Administration, 2014 and U.S. Environmental Protection Agency (EPA), 2016). Also functional in construction materials like adhesives, paint, and caulk (used to seal components of a building envelope), PCBs were commonly used in many types of buildings, including homes and schools. However, the use of PCBs was banned by Congress in 1976 after they were found to pose unreasonable risk to the environment and public health (EPA, 2016). There are no known natural sources of PCBs. Because PCBs do not readily break down in the environment, they may cycle between air, water, and soil for long periods of time, allowing for their widespread dissemination throughout the world (Agency for Toxic Substances and Disease Registry, 2014). Furthermore, because PCBs are highly stable, they tend not to evaporate or dissolve easily in water, causing them to persist in the environment for long periods of time (World Health Organization, 2003).

In 2013, when three teachers were diagnosed with thyroid cancer within months of one another, discussions of health concerns at the Malibu schools began to mount. PCB exposure in Malibu schools has since been thought to be associated with at least thirty combined cases of self-reported thyroid disease, thyroid cancer, and melanoma. Other self-reported disease incidences include a pre-melanoma case and diabetes in current students and soft tissue cancer in alumni. Further, approximately 75 students and teachers have suffered from unexplained rashes, typically found on the face around the mouth that lasted more than 24 hours. One teacher at Juan Cabrillo Elementary experienced symptoms so severe that he/she required hospitalization (America Unites, 2016).

The problem seems to have been discovered in November 2006 when voters passed the Measure BB bond, entitled "Santa Monica-Malibu Schools Safety and Repair Measure," which required several safety and environmental reports (America Unites), later leading to the discovery of what the Arcadis Removal Action Workplan stated in August 2010 was an "unacceptable health risk" of PCB concentration in the soil at Malibu High School (Arcadis Removal Action Workplan, 2010, pg.1). Soil remediation took place from July 11, 2011 to August 4, 2011 at Malibu High School. On November 2-3 2013, the Phylmar Group conducted initial air, wipe, and bulk (caulk and paint) tests at Malibu Middle and High School, which found four wipe samples exceeding the 10 μg/100 cm2 criterion in Rooms 1, 5, 301 and the Library, as well as a bulk sample exceeding the 50 parts per million (ppm) criterion in Room 8 (Phylmar Group, Inc., 2014). Furthermore, a report from BC Laboratories, Inc. on July 7, 2014 showed results of independent caulk testing conducted by parents and teachers with PCB levels of 340,000 ppm in Juan Cabrillo's Room 19 and 370,000 ppm in the interior doorframe of Malibu High School's woodshop (Room 506), numbers that are much greater than the highest level previously reported by the district of 1,870 ppm in the library at Malibu High and as much as 7,400 times higher than legal limits (CBS, 2014). Later caulk tests conducted in March 2015 by the Malibu school district (Table 1) and independent tests conducted from June to October 2015 (Table 2) confirmed that the levels of PCBs in Juan Cabrillo Elementary School and Malibu High School far exceed what federal regulation claims is safe or legal (Map 1, America Unites, 2016). Although the legal regulatory limit for PCBs is 50 ppm, as required by CFR 40 761.20 of

the Toxic Substances Control Act (TSCA) (Code of Federal Regulations, 2016), the results from one classroom was at 570,000 ppm, up to 11,000 times the 50 ppm limit (America Unites, 2016). Such strikingly high PCB levels have only been matched by schools on the East Coast, such as Public School 45 in Bushwick, Brooklyn, sparking a sense of urgency in New York City to take action to lower the risk of long-term exposure, and, consequently, the risk of illness (The New York Times, 2011). Additionally, all ten areas of window caulking that were examined at Juan Cabrillo Elementary School and Malibu High School in March 2015 tested positive for PCBs (America Unites, 2016). The non-profits America Unites for Kids and Public Employees for Environmental Responsibility (PEER have advocated for PCB removal. On March 23rd, 2015, they filed a citizen suit in the in the United States District Court, Central District of California seeking an order that the SMMUSD to comply with federal law and remove the PCBs.

Literature Review

PCBs are toxic compounds that have chemical stability, insulating properties, and high dermal resistance, which make PCBs very persistent in the environment. The lipophilic stability of PCBs allows them to bioaccumulate and biomagnify through the food chain, and PCBs' metabolites may have biological activity and may be persistent in living organisms for a period of time (Connor et al., 1997; Sandau et al., 2000).

PCBs have been shown to be correlated with an extensive range of adverse health effects. They are associated with severe damage to the immune system, reproductive system, nervous system, and endocrine system. According to the EPA (2012), which conducted a thorough and comprehensive review of the existing scientific literature, "the literature presents overwhelming evidence that PCBs cause cancer in animals." Evidence of the damaging health effects of PCBs has also been found from studies of humans. Developing fetuses and young children are the most vulnerable to PCBs, which may subject them to developmental health effects (EPA, 2016).

PCBs act as general cancer promoters, and they are expected to increase the risk of every kind of cancer (Carpenter, 2006; Tharappel, 2002). Pre- and early post-natal exposure to PCBs are associated with deficit or retardation of mental and/or motor development, even after adjusting for maternal intelligence and developmental effects of the qualify of the home environment (Winneke, 2011). Aside from age, total serum PCB concentration is the strongest determinant of whether or not a person will develop hypertension (Goncharov et al., 2010; Yorita Christensen, 2011), and high levels of PCBs cause the liver to make more cholesterol and lipids, which then increases the risk of cardiovascular disease (Goncharov et al., 2008). Even low-level prenatal exposure to PCBs may affect thyroid hormone homeostasis (Chevrier, 2007). Moreover, adults and children have an increased risk of asthma and infectious respiratory diseases when exposed to PCBs (Carpenter, 2008; Ma, 2007), and studies have illustrated that children with higher PCB levels in their blood were more prone to coughing, chest congestion, and phlegm (Weisglas-Kuperus, 2000; Carpenter, 2006; Nakanishi, 1985). Furthermore, damage to one biological system may interfere with the functioning of other interrelated systems, indicating the extremely volatile nature of the issue of PCB-related illness (EPA, 2016). Skin conditions, such as acne and rashes, are well-documented effects that may occur in people exposed to high levels of PCBs, in addition to irritation of the nose and lungs, gastrointestinal discomfort, changes in the blood and liver, and depression and fatigue (ATSDR, 2015).

In addition to ingestion, inhalation and dermal absorption are also major routes of exposure to PCBs. Compared to ingestion in animal studies, inhalation of the vapor phase of PCBs is a more efficient exposure pathway, and inhaled vapor phase PCBs can bioaccumulate and cause

pathological changes (Casey et al., 1999). Close to PCB-contaminated hazardous waste sites, the concentration of vapor phase PCBs significantly increases (Chiarenzelli et al., 2000; Hermanson et al., 2003), and individuals living in close proximity to such contaminated sites are inclined to have health effects caused by PCBs (Baibergenova et al., 2003; Kudyakov et al., 2004; Seergev and Carpenter, 2005; Shcherbatykh et al., 2005; Huang et al., 2006). Results from various studies motivate us to investigate the relationship between PCB exposure and reported serious illnesses among teachers, students, and alumni at Malibu Schools. According to Herrick (2011), teachers in PCB-containing schools had elevated levels of PCB congeners in their blood. In particular, they exhibited higher-concentrations of lighter PCB congeners, which are more likely to come from non-dietary endocrine-disrupting developmental toxins (Herrick, 2011). Additionally, workers distributing PCB caulk had elevated PCB concentrations in their blood (Kontsas, 2003; Wingfors, 2006; Herrick et al., 2007). Since the high concentration of PCBs in caulking has been detected, we want to look for the evidence that those diseases that Malibu schools' teachers have are possibly due to the PCB contaminated environment they work in.

Methodology

Rationale to our approach:

The existence of high levels of PCBs at these schools, coinciding with a high incidence of self-reported, rare, chronic diseases and side effects linked to PCB exposure, prompted us to further investigate the issue. We decided to conduct a survey of staff members at Malibu schools in order to identify the rate of PCB-related diseases and then to investigate whether they differ significantly from that observed in the general population and in a control school population. We administered the survey to staff members because their long hours of work result in higher levels of PCB exposure; because many of them have been working at Malibu schools for a long period of time; and because their email addresses are freely accessible on staff directories. Diseases resulting from mutagenic chemicals, such as PCBs, have a typical latency period from a few months to a couple of years between exposure and disease diagnosis. Thus, it is essential to evaluate individuals that have been exposed repeatedly over time.

Study design:

We administered an online survey to 146 teachers using MailChimp, an email service. The survey, created as a seven-section questionnaire through Google Forms, was sent as an email to all teachers at JCES, MMS, and MHS, requesting that they complete a health survey administered by UCLA undergraduate students for an Honors Collegium (HC 41) course. We asked questions about the demographics of the participants in order to take covariates like ethnic, age range age (specified by 10-year increments), and gender into consideration. We probed into the medical history of participants by inquiring about physician diagnosed diseases, common symptoms of disease and their severity, and the period of incidence of the symptoms (during school breaks, or when the school is in session). We queried the following diseases known to be associated with PCBs: thyroid and other cancers, diabetes, heart disease and hypertension, Hashimoto's disease, asthma, fertility issues, attention deficiency disorder and attention deficiency hyperactivity disorder, cardiovascular disease, respiratory disease, thyroid disease, melanoma, and autoimmune disease. The symptoms we analyzed included: persistent headaches, skin irritations, and respiratory issues. In order to make sure we received honest responses, we decided to add positive controls for each disease inquiring question. A positive control is a dependent variable whose response to changing independent variables is known and, thus,

expected if the responses are truly representative of reality. Firstly, when inquiring about physician diagnosed diseases, we added meningitis and HIV/AIDS as controls since they are caused independently from PCB exposure. Likewise, we also included the common cold and stomach cramping as answers to common disease symptoms felt by participants. The participants were strictly asked to report their diseases based on a doctor's diagnosis, while the incidence, frequency, and severity of the symptoms were self-reported. To ascertain the role of PCB exposure in causing the diseases, we gathered information on the incidence of the diseases in the participants' families, in order to separate out genetically predisposed participants and focus on individuals that would have developed the disease due to sporadic mutations caused by PCB exposure.

The staff members' levels of PCB exposure were measured by collecting information on the number of hours of work, the buildings where the teachers worked, and whether the teachers had attended the Malibu schools as a student prior to teaching there. Knowledge of prior exposure to PCBs, such as if the teacher was a student at the same school previously, would be important to show enrichment of diseased individuals in the group of participants exposed over this long a time period.

Control school:

To compare the results we obtained at the Malibu schools, we administered the same exact survey at Oaks Christian School (OCS), a negative control (n = 195). Because OCS was built after the national ban on PCBs, there would not be any PCBs used in the construction and thus present in the school's infrastructure, making it a good negative control. However, since OCS is a private Christian school rather than a district public school, the comparison is not a perfect match.

Binomial distribution:

We used a binomial test to compare the deviation of the observed number of disease incidences at the Malibu schools and at OCS with the binomial expected value derived from the rates of incidence in the US population, which is published by various government organizations. We used R studio to perform the statistical test and derived p-values for the probability of observing the given number of diseased individuals in the total population of the Malibu schools (n_{Malibu} = 163). The rate of disease from our surveys accounted for only the non-genetic incidences of the disease, obtained by subtracting the number of individuals that are possibly genetically predisposed, measured in our survey by asking the status of close relatives. At Malibu, we excluded one person for ADD/ADHD and one person for Heart disease and hypertension. While at OCS, we excluded one person for asthma.

At OCS, however, we calculated the statistic with n = 23. The binomial test was performed with OCS responses to show that while the Malibu schools have significantly more diseased individuals, the control school of OCS does not. This validated it as a good control by showing its agreement with published literature. The OCS statistic is calculated with n = 23 to avoid the errors from approximating the population incidences from a biased response group, especially since the population (n = 195) is almost 10 times the size of the response group. The significance of this test is tested at the 95% confidence level and thus p-values of lower than 0.05 are significant.

Fisher's Exact Test:

To compare the number of affected individuals for each disease between the two response sets (OCS and Malibu), we conducted a Fisher's exact test. Fisher's exact test is independent of sample size, and hence allows us to accurately test small sample sizes (n_{Malibu}=41, and n_{Oaks}=23). Significant p values are lower than 0.05 for this statistic.

To measure the influence of the length of exposure on disease status, we first had to decide how to define low exposure and high exposure. We divided our responses by choosing the median score of 600 hours as the threshold of exposure that defines anything lesser than it as low and anything greater than it as high. The length of exposure was measured as the number of hours of work the staff members have performed at Malibu, and thus the hours of potential exposure. Since the fisher statistic categorizes the continuous variable of exposure time, minor calculation errors due to information not captured in the survey, such as vacation time, is allowed. The statistic was adjusted for previous exposure due to being a student at the Malibu schools prior to working there as a teacher by adding the hours of exposure as a student to the total exposure time. We defined disease status as a binary variable of either having or not having one or more of thyroid cancer, and Hashimoto's disease.

Odds ratio:

We used an odds ratio to assess the likelihood or the odds of having a disease given whether teachers worked at a building with low PCB levels or at a building with high PCB levels. We divided the buildings into two groups based on the levels of PCB found during previously conducted tests on caulking from windows and doors, dust samples, and soil. The PCB detection tests were performed in suspected areas only and not all parts of the school equally. Hence, this statistic may be confounded due to the categorization of buildings as having low PCB when in fact they have not been tested. During remediation of the physical education office at the Malibu schools, our clients noticed that the same caulking contaminated with PCBs was used in multiple rooms within the same building. Thus we categorized any building with a room that has PCB levels well above EPA limits (>1,000ppm) under high PCB. Supplementary figure 1 has a map that indicates PCB levels, EPA limits, and building layout. Low PCB: New high school, H, K, D, M, N, O, Q, R, J, L; high PCB: Old gym, I, G, B, C, A, E, F, P. Two individuals were removed from the calculations since they did not provide information on the buildings they worked in.

Results and Discussion

Survey

We received 41 responses to the online survey sent out to 146 staff members from JCES, MMS, and MHS staff directory (response rate of 28.1%). Seventeen staff members of JCES did not receive the survey. The staff was also sent an email by the principal to not fill out the survey, which could have lowered the number of responses we received. Given the large proportion of missing responses, we decided to collapse the data from JCES, MMS, and MHS into a single group. We could group the data and thus increase statistical power because the three schools were well matched owing to staff members that teach in multiple divisions (elementary, middle, and high) of the school.

The Malibu schools have a very charged environment on the issue of PCBs, and so the survey links were shared multiple times. We advised participants to fill out the survey only once, and we kept track of any multiple responses using a unique code system. In order to address the

possibility that teachers with diseases were more likely to fill out the survey, thus biasing the sample population (i.e., surveys we received), we decided to apply conservative statistical methods that provided the minimum significance that could be derived from this dataset. We did this by equating the frequency of diseases found in the response set to the minimum frequency in the total school population, rather than conserving disease frequency between the sample of responses and the population of total staff members. In other words, we calculated the probability of finding the number of diseases reported in the survey out of the total school population (n=163) instead of the survey sample population (n=41). The level of significance that we observed is therefore the least amount of significance that is possibly obtained in the population of 163 individuals at Malibu.

Control Comparability

We collected 23 surveys from OCS staff members (n = 195) because we were blocked by the IT officials a day after survey administration. Thus, we had a very small proportion of the control population represented from which we derived the control rates of incidences of the diseases. In order to establish the value of the control, we conducted tests of proportion (student's t-test) to show that there was no significant variation between the leading parameters, e.g. female for sex, between the responses from Malibu and OCS (**Table 1**).

Of the 41 responses from the Malibu Schools, 78.1% were female (n = 32), 14.6% were male (n = 6), and 7.3% would rather not disclose (n = 3). While of the surveys from OCS (n = 23), 69.6% were female (n = 16), and 30.4% were male (n = 7). Both datasets had more females than males. Table 1 further describes other demographic parameters (age, sex, and ethnicity) at each of the two schools and shows that the p-values for the proportion of the variable with the most individuals (leading parameter) is not significantly different between the two schools. Since we did not find a significant p-value; therefore, the responses were well matched and a strong comparison can be made between the Malibu and OCS responses (n = 41, and n = 23 respectively).

Table #1: Proportion of each demographic parameter in the two school population. The fraction left out of the table are responses that would not like their demographic to be disclosed. Results of a two tailed student's t-test performed to measure differences between the proportion of students in the leading parameter under the covariates - age, sex, ethnicity.

Parameter		Malibu Schools (n = 41)	Oaks Christian School (n = 23)	Student's t-test (p-value at 95% confidence level)
Sex	Female	0.781	0.696	0.4511
	Male	0.146	0.304	-
Age group	21 to 30	0	0.130	-
	31 to 40	0.073	0.304	-
	41 to 50	0.415	0.261	0.2179
	51 to 60	0.195	0.217	-
	61 and above	0.171	0.087	-
Ethnicity	Native American	0.024	0	-
	Hispanic or Latino	0.024	0.174	-
	White or Caucasian	0.854	0.739	0.2581
	Asian	0	0.043	-

Disease prevalence

We performed primary literature searches, cited in Table 2, to identify the rate of incidence of the diseases in the US population. The rates in the US population were well suited to our study because our responses show that the school encompasses a largely Caucasian population of staff members with some minorities, typical of the US population. Since the ban on PCBs was a national effort, the US as a whole makes up the population that we are studying.

Table 2 shows the results of a binomial test performed for the two schools against the rate of incidence found from primary literature searches. A significant result indicates higher than expected prevalence of the disease in our datasets. We assumed the lowest frequency for the disease in the population at Malibu must be the absolute number of diseased individuals from our responses thus; we calculated our statistic out of 163 individuals to avoid inferring from a small biased response group. We found thyroid cancer and Hashimoto's disease to have a significantly

increased prevalence at Malibu schools, compared to published background rates in the U.S. We found five cases of thyroid cancer at Malibu, compared to 0.31 cases expected ($p = 3.175 \times 10^{-14}$), and we found eight cases of Hashimoto's disease at Malibu, compared to 0.90 cases expected ($p = 1.34 \times 10^{-12}$). We also observed that no disease had a significantly larger prevalence in our responses from OCS (n = 23), thus supporting its validity as a negative control. The diseases with no incidences and low frequency at OCS were given a 0.5 probability due to the lack of power from having no incidence of the disease and not due to marginal significance.

Having established the legitimacy of our control responses and showing that the case group (Malibu) is enriched in some PCB-related diseases, we conducted Fisher's exact test on the number of affected and unaffected individuals between the case group (Malibu schools) and control group (OCS) for each disease. We found significantly more cases of thyroid disease, Hashimoto's disease, and fertility issues in Malibu when compared to OCS. The prevalence of thyroid cancer was also marginally enriched. Cases of HIV and meningitis, the negative control diseases, did not vary significantly between the two school groups, thus establishing the legitimacy of our comparison. Hence, we found a very significant enrichment in PCB-related diseases (thyroid disease, Hashimoto's disease, and fertility issues) at the Malibu schools.

Table #2: The significance observed from conducting binomial tests for physician diagnosed diseases in the total population of Malibu schools and response sample from OCS. The p-values for each disease are listed in columns 4 (Malibu) and 6 (OCS). The binomial tests compare the incidences at the schools with background rates of diseases (column 2). Fisher's exact tests were also performed in column 7, which lists p-values generated from comparing between Malibu responses (n = 41) and OCS responses (n = 23) as case and control respectively.

Disease	Rate of disease in US (literature searches)	Number of disease incidences in Malibu Schools (n = 163)	Significance observed from binomial tests (p-values at 95% confidence level)	Number of disease incidences in Oaks Christian School (n = 23)	Significance observed from binomial tests (p-values at 95% confidence level)	Fisher exact test p-values at 95% confidence level (one tailed test)
Thyroid disease	12% (ATA website)	16	0.7696	0	0.9265	2.110×10^{-4} (significant)
Thyroid Cancer	0.1916% (SEER website)	5	3.175×10^{-14} (significant)	0	0.5000	0.0983 (marginally significant)
Diabetes	9.3% (CDC Website)	1	0.9999	1	0.6768	0.4678
Heart Disease/ Hypertension	26.4% (Johns Hopkins Medicine Website)	8	1.0000	2	0.9545	0.1596
Hashimoto's Disease	0.55% (RightDiagnosis Website)	8	1.34×10^{-12} (significant)	0	0.5000	0.0216 (significant)

Cardiovascular disease	26.4% (Johns Hopkins Medicine Website)	2	1.0000	2	0.9545	0.3265
Asthma	8.4% (CDC Website)	3	0.9980	0	0.8591	0.2559
Fertility issues	6% women 12% men (CDC Website)	7*	Female: 0.6022 Male: 0.9431	0	Female: 0.6859 Male: 0.6537	0.0362 (significant)
ADD/ADHD	11% (CDC Website)	1	1.0000	0	0.9119	0.6406
Autoimmune disease	7.4% (AARDA Website)	8	0.8567	2	0.5000	0.1596
Melanoma	2.1% (SEER Website)	4	0.4832	0	0.5000	0.1594
Other cancers	4.35% (ACS Website)	4	0.8401	1	0.5000	0.3055
HIV (control)	0.376% (CDC Website)	1	0.5000	0	0.5000	0.6406
Meningitis (control)	0.00138% (CDC Website)	1	1.380×10^{-5}**	0	0.5000	0.6406

*All women, statistic performed out of n = 137 (proportion of women in responses x 163)
** Meningitis is a sporadic, contagious disease that is either fatal or is cured through treatment. Hence, the response for meningitis must have meant that he had meningitis at some point in time. Therefore, it is valid to see a significant p-value for it in the binomial test.

Influence of location on disease

The Malibu Schools had previously been examined for PCB levels by testing caulking and other fragments from the building's construction materials in a fraction of the rooms within each building. Based on the levels of PCBs in these rooms, we have classified the buildings (Supplementary Figure 1) from the Malibu schools into two groups: low PCB or high PCB. By doing this, we were able to calculate odds ratios to show the influence of the levels of PCB on disease status.

In order to measure the likelihood of having a disease given that you work in a high or a low PCB building, we decided to calculate the odds ratio by defining disease state based on the diseases that either showed significantly increased prevalence in our responses compared to the US rate of incidences (Hashimoto's disease and thyroid cancer), or compared to the control school (thyroid disease, Hashimoto's disease, and fertility issues). We also added the marginally significant thyroid cancer in a second test against the control Oaks Christian School.

Although the odds ratios we found supported our hypothesis, we did not reach the significance level ($p < 0.05$), and so we could not conclude that there was a significant a relationship between an increased likelihood for disease given whether you work at a low PCB

level building or high (Table 3). We also noticed that adding thyroid cancer to the union of thyroid disease, Hashimoto's disease and fertility issues does not change the number of individuals in the contingency tables and thus results in the same p-value as only using thyroid disease, Hashimoto's disease, and fertility issues (Table 4). This is explained by the fact that thyroid cancer is a secondary disease that occurs in the individuals who have thyroid disease.

The large confidence interval highlights the lack of power in our statistic, and thus in order to accurately answer this question, we must collect more responses so we could gain power by increasing the sample size (n).

Table #3: Odds ratios and Z statistic derived p-values for the combination of significantly associated diseases in low PCB and high PCB buildings.

Disease	Odds ratio	95% confidence interval for odds ratio	P-value derived from Z statistic
Thyroid cancer ∪ Hashimoto's disease	1.6800	0.1724 to 16.3742	0.6552
Thyroid disease ∪ Hashimoto's disease ∪ fertility issues	1.3725	0.2780 to 6.7754	0.6975
Thyroid cancer ∪ Hashimoto's disease ∪ fertility issues ∪ thyroid disease	1.3725	0.2780 to 6.7754	0.6975

Table #4: Fisher's exact test p-values for the different significantly associated disease combinations used to define disease status.

Disease	Fisher's exact test p-value (one tailed test)
Thyroid cancer ∪ Hashimoto's disease	0.469
Thyroid disease ∪ Hashimoto's disease ∪ fertility issues	0.444
Thyroid cancer ∪ Hashimoto's disease ∪ fertility issues ∪ thyroid disease	0.444

Influence of length of exposure on disease

We then decided to see whether there existed a difference in the incidences of disease (similarly defined as in the odds ratio) and the reported length of exposure. The exposure was calculated as the number of hours of work at the schools. The group with greater than or equal to 600 hours, the median, of PCB exposure has 20 individuals, while the group exposed to less than 600 hours of PCBs has 19 individuals.

We found no significant association in our tests. Hence, we could not conclude that individuals who have worked there longer, thus exposed longer, are worse affected by the influence of PCB from the school's environment. However, we propose that this statistical method is confounded by the nature of our definition of disease. Perhaps thyroid cancer, Hashimoto's disease, and fertility issues are not a full representation of the population of diseases that individuals get. Moreover, it would be advisable to include the length of exposure

based on the location of exposure, suggesting that not only exposure but the kind of exposure (in high PCB area vs low PCB area) matters.

The Proposed Solution

The statistical evidence collected in this report shows the enriched prevalence of PCB-related diseases in individuals attending the Malibu schools compared to published literature and the control school, OCS. Our highly significant findings support the claim against SMMUSD that not removing all PCBs from classrooms exposes teachers (and students) to a health risk. Collecting a comprehensive and scientific dataset that could be used in rigorous statistical analysis is crucial to solving the problem; hence, our survey is only an initial attempt at collecting such data. Moreover, since we cannot perform experimental studies in humans that gather evidence for causality of PCB exposure with thyroid disease or cancer incidence, we can use statistical methods on observations to find correlations that may underlie causal relations. Furthermore, the correlations become especially interesting when they exist in Malibu Schools (case) and not OCS (control).

We hope that the information disbursed through our report will increase awareness in parents and students attending the Malibu Schools. Some ways to elicit awareness are through brochures, the news, and social media (such as Facebook and Twitter). We created brochures (supplementary figure 2), which can be distributed to staff and students at Malibu. Since the majority of individuals do not know the health hazards associated with PCBs, the brochure educates the public about the toxic nature of PCBs and brings attention to the situation at Malibu Schools.

In the future, we advise collecting all the information from the remaining participants and those that were missed in this survey. It would be essential to study student populations at these schools too in the future. We advise future surveys to be performed in person or over the phone rather than online. The client could use other media outlets, such as Facebook, which are ideal for disbursing news to a large audience at once. In addition to our statistical evidence, a blood test for total serum concentration can be use to confirm the amount of exposure to PCB in these individuals and thus perform statistics with a more accurate variable.

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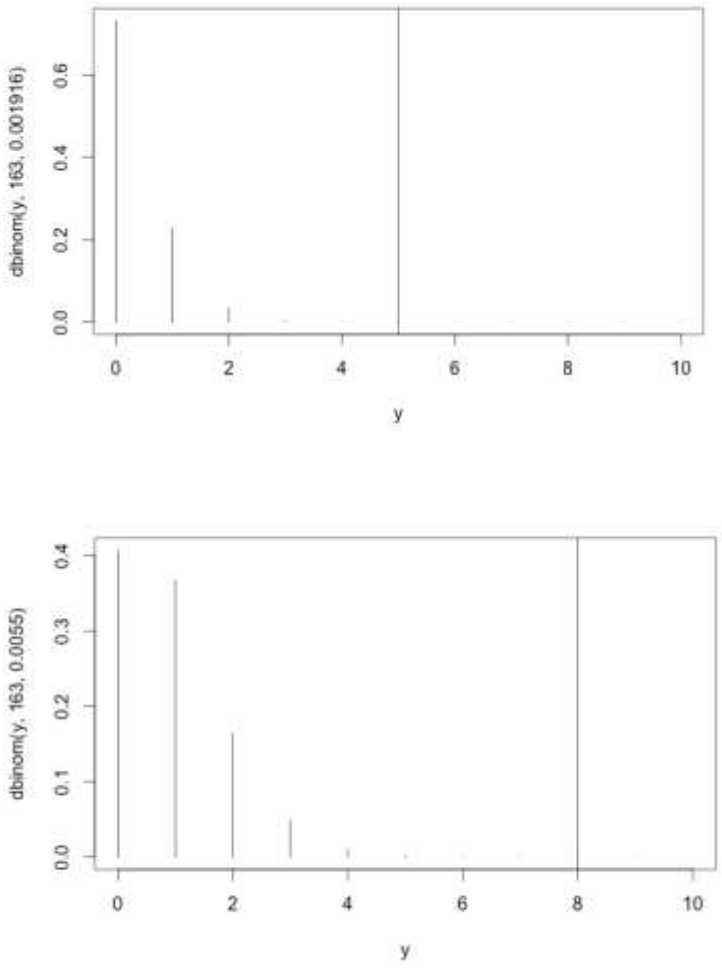
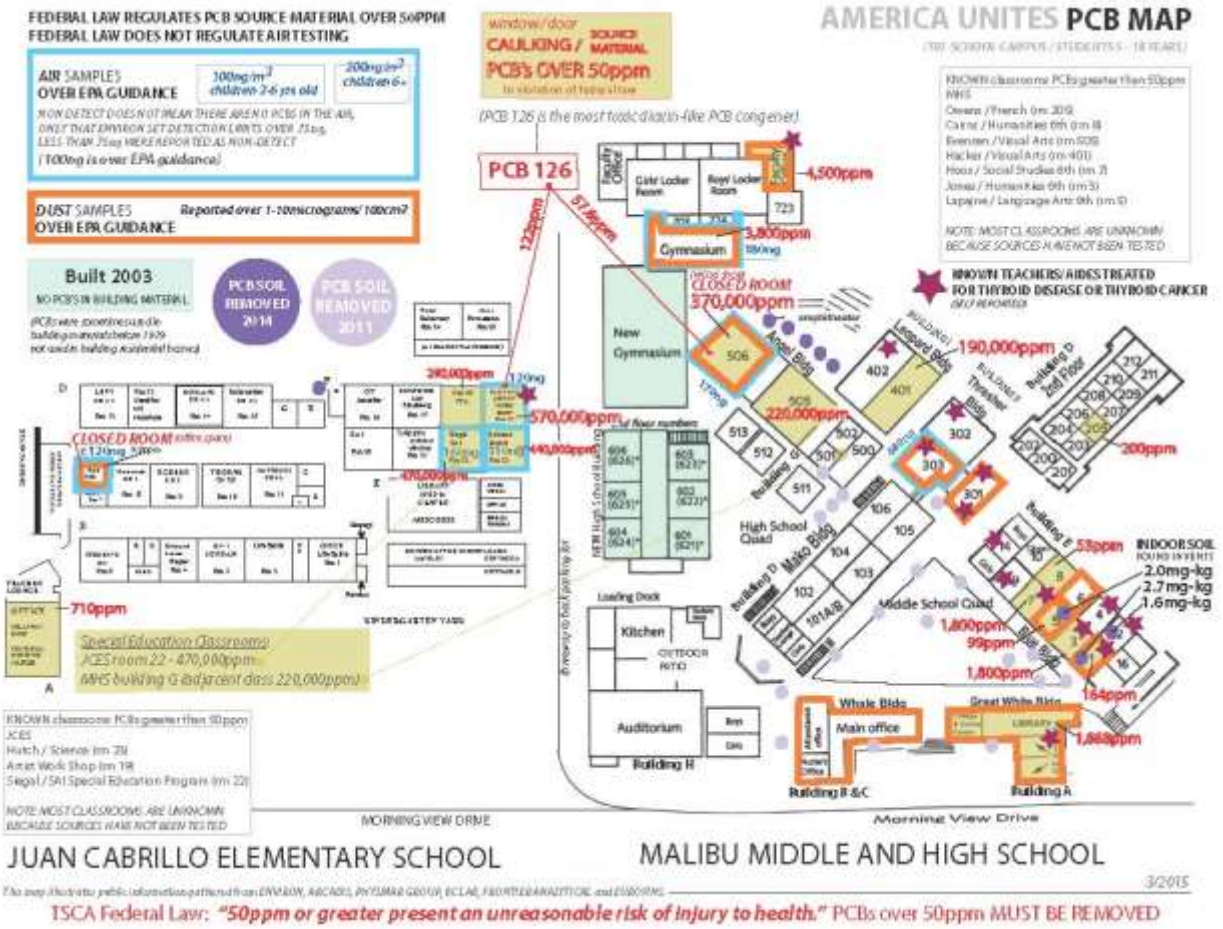
Supplemental Materials

Figure 1: Binomial test graphs showing the binomial distribution in US of the incidence of disease. A vertical line indicating the number of affected individuals in our survey responses from the Malibu schools is drawn at 5 (top left), 8 (top right) and compared to the binomial curve made according to primary literature rates of disease incidences. Top: Thyroid Cancer; Bottom: Hashimoto's diseases



Supplementary Figure 1: Top: Map of JCES, MMS, and MHS with PCB levels from caulking and dust testing. Bottom two pictures are maps of JCES, MMS, and MHS as divided into buildings in our survey. The buildings were grouped by low PCB level or high PCB level based on previous research done by America Unites for Kids (Top map is summary of that research found published on their website).



Brochure (Additional final product)

Our team developed an educational tri-fold brochure that can be used by America Unites for Kids to raise awareness of the current PCB issue at the Malibu Schools. The brochure was designed to provide information on who America Unites for Kids is, their mission, the current state of PCBs in Malibu Schools, what the school district has done to address the issue, background information of PCBs, the health risks PCBs pose to humans, and where they are generally located in the classrooms. We tried to limit the amount of text while also ensuring that all of the necessary information was presented. We also included a variety of pictures to add appeal to the brochure. Ideally, we hope that the brochure can be distributed (with the permission of the school and teachers) to the students in their classes so they can bring it home to their parents and family members. The brochure could also be distributed publicly at future events where America Unites for Kids will be in attendance.