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Predictors for dioxin accumulation in residents living in Da Nang and Bien Hoa, Vietnam, many years after Agent Orange use

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HIGHLIGHTS

- Blood dioxin levels were measured from residents in Bien Hoa and Da Nang, Vietnam.
- Blood dioxin levels were related to individual and environmental risk factors.
- Fish farming was associated with higher blood dioxin levels at both locations.
- Blood dioxin levels were positively correlated with living on flooded property.
- Da Nang dioxin sites are being cleaned up so exposure should decrease.

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ABSTRACT

Agent Orange (AO) was the main defoliant used by the US in Vietnam from 1961 to 1971; AO was contaminated with dioxin (2,3,7,8-tetrachlorodibenzo-*p*-dioxin, or TCDD). Three major dioxin "hot spots" remain from previous AO storage and use at former US bases at Bien Hoa, Da Nang, and Phu Cat, posing potential health risks for Vietnamese living on or near these hot spots. We evaluated potential risk factors contributing to serum TCDD levels in Vietnamese residents at and near contaminated sites in Da Nang and Bien Hoa, Vietnam. We used multiple linear regression to analyze possible associations of blood dioxin concentrations with demographic, socioeconomic, lifestyle, and dietary risk factors for residents living on or near these hot spots. For the Da Nang study, fish farming on the site, living on property flooded from monsoon rains, and age were among the factors showing significant positive associations with serum TCDD concentrations. For the Bien Hoa study, fish farmers working at this site and their immediate family members had significantly higher serum TCDD concentrations. Our results suggest that water-related activities, especially fish-farming, at the hot spots increased the risk of exposure to dioxin.
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1. Introduction

High levels of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) have been found in soils and aquatic sediments in several areas of southern Vietnam that were contaminated during the Vietnam War in 1961–1971 via spraying, handling and/or spillage of herbicides, mainly Agent Orange (Dwernychuk et al., 2002; Mai et al., 2007; Nhu et al., 2009). Agent Orange herbicide used by the US military in Vietnam was a 50:50 mixture of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), which was contaminated with TCDD during the manufacturing process. TCDD is a member of a class of chemicals known commonly as "dioxins", and it is considered to be the most toxic compound in this chemical group (Van den Berg et al., 2006). TCDD (hereafter sometimes referred to as dioxin) is associated with numerous health effects in adults including soft-tissue sarcoma, non-Hodgkin's lymphoma, chronic lymphocytic leukemia and also birth defects such as spina bifida in newborns (IOM, 2009).

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Additionally, elevated dioxin levels in food items collected near contaminated sites have also been reported (Hatfield Consultants, 1998; Schecter et al., 2003; Hatfield Consultants and Office 33, 2009, 2011). Even more worrisome, high levels of dioxin in blood and breast milk samples have also been found in Vietnamese residents living on or near these contaminated sites (Schecter et al., 1995; Dwernychuk et al., 2002; Hatfield Consultants and Office 33, 2009, 2011; Saito et al., 2010). Despite the elevated dioxin levels measured in human blood, breast milk, and environmental media in Vietnam, little research has been conducted to study specific risk factors contributing to dioxin exposure. A study by Saito et al. (2010) found that previous exposure was the major contributor to high levels of breast milk dioxin in females living in sprayed areas of Quang Tri Province, Vietnam. However, dioxin found on surface soils in sprayed areas is degraded by ultraviolet light; sprayed areas are, therefore, no longer a main concern for dioxin contamination (NRC, 2003; Dwernychuk, 2005). Compared to the sprayed areas, the areas where quantities of Agent Orange were stored, handled, and spilled have much higher dioxin concentrations in soils and in nearby aquatic sediments and are referred to as dioxin "hot spots" (Dwernychuk, 2005). Among these dioxin hot spots, the former US military bases at Bien Hoa, Da Nang, and Phu Cat are sites of major concern (Dwernychuk, 2005). Thus, it is important to investigate potential risk factors contributing to dioxin accumulation in residents living on or near these hot spots, so as to manage and remediate these and other dioxin contaminated sites to reduce human exposure.

The current study is part of an extensive reassessment of dioxin contamination and human exposure at Da Nang and Bien Hoa recently completed by Hatfield Consultants and the Vietnam Office of National Steering Committee 33 (Office 33) (Hatfield Consultants and Office 33, 2009, 2011). Although Hatfield Consultants and Office 33 (2009, 2011) and Boivin et al. (2011) already presented and partially analyzed serum dioxin data from the Da Nang and Bien Hoa studies, we extend their analyses using multiple linear regression. The objective of the current study is to evaluate potential demographic, socioeconomic, health, lifestyle, and dietary risk factors contributing to dioxin exposure and accumulation in residents who are living on or near the Da Nang and Bien Hoa dioxin hot spots.

2. Materials and methods

2.1. Study populations

This study is a part of three investigations conducted by Hatfield Consultants and the Government of Vietnam to determine the extent and level of dioxin contamination in the environment and the exposed human populations on and around former US military bases in Da Nang and Bien Hoa. Details of the 2006 and 2009 studies in Da Nang and the 2010 study in Bien Hoa are reported by Hatfield Consultants and Office 33 (2009, 2011).

Individuals participating in these studies were all at least 18 years old. Eligible individuals were selected from the population living on or around the former US military bases at Da Nang (now the Da Nang International Airport) and Bien Hoa (now a Vietnamese Military Airbase). For the Da Nang studies conducted in 2006 and 2009, the sub-populations included in the study were selected either randomly or non-randomly as follows. Sub-populations from which samples were selected randomly included: (1) An Khe Ward, Thanh Khe District (2009 study) located near the west side of the Da Nang Airport and also close to the Pacer Ivy Area, where Agent Orange drums were cleaned, re-labeled, and repacked for shipping the Agent Orange out of Vietnam in 1972 (Young, 2009); (2) Khue Trung Ward, Cam Le District (2009 study) is a low-lying wetland located south of the Da Nang Airport; (3) Thuan Tay Ward, Hai Chau District (2009 study) is near the eastern boundary of the Da Nang Airport; (4) Chinh Gian Ward, Thanh Khe District (2006 study) is a former wetland connected to Sen Lake near the north boundary of the Airport; and (5) Thuan Phuoc Ward, Hai Chau District (2006 study) was the control area located 5 km away from the Airport. Sub-populations from which samples were selected non-randomly included (1) Sen Lake workers and their family members (2006 and 2009 studies) who were chosen non-randomly because they had been in contact with the contaminated Sen Lakes inside the Airport; and (2) West Airbase workers and their family members (2006 and 2009 studies) who were chosen non-randomly because they had been in contact with lakes in the western perimeter of the Airport. The total sample size for these studies was 186 participants. For the Bien Hoa study conducted in 2010, Bien Hoa Airbase workers were chosen randomly and resulted in 42 total participants.

2.2. Questionnaires

All individuals participating in the survey and who provided blood samples did so voluntarily, and signed consent forms prior to sampling. Questionnaires and consent forms were in the Vietnamese language. Staff members from Office 33, the Ministry of Health and the local health department interviewed each volunteer donor in Vietnamese with guidance from Hatfield personnel. Surveys included information on participants' age, sex, smoking habits, general health, residency, work history, food consumption patterns, and general awareness about dioxins.

Demographic and socioeconomic variables including age, gender, and education were collected from questionnaire surveys and used in both the Da Nang and Bien Hoa analyses presented here. Age was determined in years at the time of sampling. Education levels were self-reported using multiple grade categories, but since the sample sizes for both Bien Hoa and Da Nang were small, this education variable was combined into 2 categories of "high school graduate and below" and "any postsecondary education".

Additionally, weight, height, current smoking status, and residency were included in this study. Weight (in kilograms) and height (in centimeters) information were self-reported, and were combined to calculate body mass index (BMI) as weight (kg) divided by height in meters squared (m^2), to obtain an estimate of participants' body fat. Current smoking status was recoded as a dichotomous (yes/no) categorical variable and residency information was collected by asking participants about their duration (in years) of living at current ward addresses.

2.3. Measurement of serum dioxin concentrations

To measure the blood serum dioxin concentration, each respondent was asked to donate his or her blood sample, with signed consent forms obtained in advance. Under the supervision of Hatfield personnel, trained medical staff from the local health departments in Da Nang and in medical clinics at the Bien Hoa Airbase collected participants' blood samples. The samples were then shipped to AXYS Analytical Services in Sidney, British Columbia, Canada for analysis using High Resolution Gas Chromatography Mass Spectrometry (HR GC/MS) (Hatfield Consultants and Office 33, 2009, 2011). These analyses provided concentrations of 17 PCDD and PCDF compounds in pg/g or parts per trillion (ppt) (lipid weight basis) and also the dioxin Toxicity Equivalent Quotients (TEQ) using Toxic Equivalency Factor (TEF) values from the WHO 2005 scale (WHO, 2011). The 2006 Da Nang dioxin concentrations were measured from whole blood samples and the 2009 Da Nang and 2010 Bien Hoa dioxin concentrations were measured from serum samples as reported by Hatfield Consultants and Office 33 (2009,

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