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Pulmonary Function Alternations after Vog Exposure in Hawaii Island Schoolchildren

YANJUE WU

PULMONARY FUNCTION ALTERNATIONS AFTER VOG EXPOSURE IN HAWAII ISLAND SCHOOLCHILDREN

By

YANJUE. WU

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30303

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PULMONARY FUNCTION ALTERNATIONS AFTER VOG EXPOSURE IN HAWAII ISLAND SCHOOLCHILDREN

By

YANJUE WU

Approved:

Ruiyan Luo, Ph.D.________________________________
Committee Chair

Xiaoting Qin, Ph.D.______________________________
Committee Member

10/21/2014_______________________________________
Date

ABSTRACT

INTRODUCTION: Kilauea volcano on Hawaii Island has emitted as much as 6,000 tons of sulfa dioxide (SO_2) daily more than 20 years. In 2008. Kilauea's emissions from its summit and its east rift increased dramatically. SO_2 reacts with water vapor to generate "vog", a mixture of SO_2 and sulfate particles which induces respiratory symptoms. Wind patterns and the island's terrain produce zones of chronic vog exposure. Respiratory health of island's school children could be affected by "vog".

AIM: In this project, we will analyze the relationship between air pollutants from volcano emission and pulmonary function alternations in local school children. The effects of air pollutants as environmental risks on children's respiratory health will be addressed. Results and recommendations will be given to the local public health department and residents on Hawaii Island to prevent further respiratory problems caused by volcano emissions.

METHODS: In 2002-2003, we recruited 1,986 children, born 1992-1994, who attended 29 Hawai'i Island schools in all 4 vog exposure zones. Questionnaires of home environment, family and personal medical history, and respiratory health were administered. Height, weight, and spirometric lung function were measured in 2008 – 2009. We conduct multivariate analyses to identify the significant risk factors which affects children's pulmonary functions.

RESULTS: Our results suggest that pulmonary function of local children in Hawaii Island are affected by race distribution and asthma condition adjusted by height, weight and age. Smoking and vog exposure are not significant risk factors.

CONCLUSION: In summary, pulmonary functions of Hawaii Island schoolchildren are associated with their body growth, race or asthma conditions. Vog exposure doesn't affect children's respiratory system though asthma and smoking prevalence are higher than those of other areas

INDEX: Volcano, Hawaii Island, Vog, Pulmonary function, Asthma

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Yanjue Wu

Yanjue Wu

12610 Morningpark Cir • Alpharetta, GA 30004
Yj_w2000@yahoo.com
(443) 823-9717

Education

8/2013 – 10/2014 Master of Public Health (Biostatistics)

Georgia State University, Atlanta, GA

2007 Ph.D. Pharmaceutical Sciences

University of Maryland School of Pharmacy, Baltimore, MD

1996 Medical Bachelor, Clinical Medicine

Capital University of Medical Sciences, Beijing, China

Experience

5/2014-9/2014 Contractor in CDC/ONDIEH/NCEH, Air Pollution and Respiratory Health

Project: Vog exposure associated with asthma in Hawaii Island children

- Identify the association between vog exposure and public health issues
- Develop and perform data management and data analyses with SAS
- Provide Interpretation of statistical results to support clinical study
- Collaborate with other team members on project plans and investigations
- Assisted in writing manuscripts and grant applications

5/2011 – 6/2013 Research Assistant, Critical Care Division of Pulmonary, Allergy and Critical Care Emory University School of Medicine and Grady Memorial Hospital

Research Projects: Epidemiology and pathogenesis of Acute Lung Injury and ARDS

- Conduct epidemic study of ARDS, data collection and analysis
- Evaluate interventions to determine the cause of disease
- Provides advice and assistance in the development and implementation of procedures, methods and strategies when obtaining and using clinical data

2007 – 2009 Postdoctoral Fellow

Department of Neurology in Johns Hopkins University

School of Medicine and Kennedy Krieger Institute

- Conduct research of cancer stem cell of brain tumor development

1996 – 2002 Resident/Attending Physician of Infectious Disease and Critical Care, Beijing Friendship Hospital, Beijing, China

- Conduct infectious diseases treatment and studies

Awards and Honor

2008 The Honor Society of Phi Kappa Phi Chapter University of Maryland

2007 Rho Chi Pharmacy Honor Society

2006 Dr. Jerome and Mitzie Holen Schwartz Fellowship for Alzheimer's Research

Publications

Wu Y, Sircar K, Yip F, Tam E. Association of vog exposure with asthma in schoolchildren on Hawaii Island. In draft 2014.

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All these deposited in the Georgia State University Library must be used in accordance with the stipulations prescribed by the author in the preceding statement.

The author of this thesis is:

Yanjue Wu
12610 Morningpark Cir
Alpharetta, Georgia 30004

The Chair of the committee for this thesis is:

Ruiyan Luo, Ph.D.
Division of Epidemiology and Biostatistics
School of Public Health
Georgia State University
P.O. Box 3995
Atlanta, Georgia 30302-3995

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CHAPTER 1

INTRODUCTION

1.1 Background

Volcanism is not a new issue for Earth. Volcanoes have been providing pathways for degassing and cooling the inside of the planet Volcanism plays an important role in how the formation of the early atmosphere, oceans, and continents (Longo & Longo, 2013). It is also likely that it was a part of the formation of life. Throughout the times, many volcanoes have erupted, and today, many are still active. Over 450 million people worldwide live within an area where they could be exposed to a volcano. Volcanoes and geothermal areas are related to emissions of many gases that are together. Emissions can occur with eruptions of all sizes. Although emissions may only affect small amount people, they can create severe environmental problems as well (Hansell & Oppenheimer, 2004).

Volcano eruptions happen around the world and impact on health locally and global as a result of airborne dispersion of gases and ash or as impact on climate. This was shown in a recent volcano eruption that occurred in Iceland where air traffic was ceased for several days in large areas of Europe causing an economic impact. Although eruptions have a short life span, the ash fall deposits remain in the environment for many years, being blown around by wind and by human activity (Gudmundsson, 2011)

Hawaii is a state that is known for volcanoes. It is built around volcanoes and its surrounding areas can be affected whenever one erupts. For example, the Kālu district of Hawaii gets volcanic activities frequently and has been exposed to ongoing eruptions of Kilauea Volcano. Kilauea has one of the largest point source of sulfur dioxide (SO_2) gas in the United States. The gaseous emissions have increased dramatically due to the opening of the vent at the volcanoes summit after March, 2008. The SO_2 reacts with water vapor generating "vog", a mixture of SO_2 and sulfate particulates. There have been many studies ongoing to understand the health effects from the exposure to vog and develop evidence-based health interventions for the communities that are affected (Longo & Longo, 2013; Longo, Yang, Green, Crosby, & Crosby, 2010). Due to increased activity in 2008, an indoor air quality assessment was done on the area hospitals and schools. Efforts are underway to help improve indoor air quality and respond to those that are suffering from vog exposure (Longo et al., 2010). The first assessment was done in June 2008 to priority people in the community such as Ka'u District's hospital, schools, and community library.

There have been studies that showed that volcanoes can have a direct effect on people's health. Epidemiological studies show that there is an association because air pollution and cardiovascular causes. Air pollution can cause cardiovascular distress due to lung inflammation and oxidative stress. SO_2 can be harmful to asthmatic adults because it reduces vagal tone. In elderly people, there is an association between the respirable particles of diameter and changes in autonomic nervous system control which can be brought on by heart-rate variability (HRV) (Chow et al., 2010). However, the association between volcanic air pollution and changes in HRV are not studied as much.

1.2 Purpose of Study

Kilauea volcano has been active for more than 20 years. Continuous SO_2 emission, characteristic Island wind patterns and Hawaii Island's towering mountains create a nature environment in which some communities are almost chronically exposed to SO_2 or acid aerosols. .

In this essay, by using questionnaires and measuring lung function, we will analyze the relationship between air pollutants from volcano emission and respiratory health in local areas. The effects of volcano ashes as environmental risks on people's health will be addressed. Results and recommendations are given to the local public health department and residents on Hawaii Island to prevent further respiratory problems caused by volcano emissions.

1.3 Research Questions

(1) Is there any relation between pulmonary function FEV1 and environmental risk factors?

(2) Is there any relation between pulmonary function FVC and environmental risk factors?

(3) Is there any relation between pulmonary function FEV1/FVC ration and environmental risk factors?

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Active Volcano on Hawaii Island

Over 450 million people worldwide live within an area where they could be exposed to a volcano (Hansell & Oppenheimer, 2004). In the state of Hawaii in U.S, Hawaii Island is the southernmost and newest in the chain of Hawaii Islands. Its Kilauea volcano has erupted almost continuously for 28 years. Volcanoes, the surrounding ocean and island wind patterns produce more than 200 of the world's microclimates on this island. Distinctive variations in local weather can contribute significantly to difference in air quality and respiratory health. In addition, the demographics of the island provide a complex and varied background of racial, culture and social economic variations that are possibly to influence respiratory responses to the volcanic air pollution.

Since 1986 Kilauea's east rift has erupted without stopping, releasing each day 300 to 6000 tons of sulfur dioxide (SO_2). This is far in excess of any mainland source. SO_2 emission interact with water vapor to form an acidic haze of respirable particles, known as "vog" (Sutton, Elias, Gerlach, & Stokes, 2001). Local wind and weather patterns are major determinants of widespread human exposure to vog. Kilauea also emits water vapor, carbon dioxide and less amount of hydrogen chloride, hydrogen fluoride, hydrogen sulfide, carbon monoxide, radon, and heavy metals including lead and mercury (Hansell & Oppenheimer, 2004) , however, its major emission by far is SO_2.

2.2 Volcanic air pollution

SO_2 and acid aerosols are major components of vog. Prevailing wind patterns and Island demographics affect vog distribution. Inhaled SO_2 readily reacts with the moisture of mucous membrane to form sulfurous acid, a type of severe irritant. Its effects in the lower airway appear to depend on bronchial responsiveness. Non-asthmatic subjects experience increased airway resistance at 5,000 ppb, sneezing and cough at 10,000 ppb and bronchospasm at $> 20,000$ ppb. It was reported that exposure to

100,000 ppb has been tolerated for up to 60 minutes in non-asthmatic persons (Bethel, Epstein, Sheppard, Nadel, & Boushey, 1983). In asthmatic subjects, however, exposure to SO_2 500 ppb during eucapnic ventilation 30 -50 LPM, can induce small but significant increase in specific airway resistance when delivered in cold, dry air, but not when delivered in humidified air (a more common condition in Hawaii). In freely breathing, heavily exercising asthmatics, an even lower concentration of SO_2 (250 ppb) can induce a small but severe increase in airway resistance that eclipsed by exercise along (Bethel et al., 1983). Based on such findings, the National Ambient Air Quality Standard (NAAQS) issued by the U.S. Environmental Protection Agency (EPA) includes SO_2 as one of its criteria air pollutants and recommends that the annual mean level of SO_2 not exceed 30 ppb and that its 24hr maximum concentration not exceed 140 ppb (Lockey et al., 1988). The State Hawaii adds a 3-hr limit of 500 ppb.

Similarity, acid aerosols that have been the subject of epidemic studies to date were derived from fuel burning. The acid aerosols were thus mixed with other combustion products. It has been postulated that the acidity of the sulfate particles may be responsible for the respiratory health effects of fine particles (Lippmann & Schlesinger, 1984). In contrast, volcanic sulfur aerosols is more acidic and has a much narrow range of cations and may have stronger effects on respiratory health of the local population.

There would be little concern about vog's health effects if vog did not travel to populated areas. Local wind and weather patterns are major determinants of widespread human exposure to vog. Vog is generally trapped below the first temperature inversion layer at ~ 6,000 ft (Longo & Longo, 2013), where it is carried by the low-level trade winds (brisk winds from the northeast) toward the southeast. Regional wind patterns wrap around the southern tip of the island and send vog up the populated leeward coast. Here, vog becomes trapped by daytime (onshore) breezes, and is usually swept to sea by nighttime (offshore) breezes. In contrast, when there are no trade winds or when there are light winds from the south (Kona winds), vog becomes more concentrated on the east side of the island (Longo et al., 2010). During prolong Kona wind conditions, vog is carried as far north as Oahu. Thus, wind direction and speed largely determine the distribution and density of vog on the island of Hawaii.

In addition to weather conditions, geological and meteorological considerations are factors introduced by the population and its distribution. The island is extraordinarily diverse in its people. As is true of the entire state, there is no racial majority on the island and the overall racial composition differs significantly from the population studied in the mainland. Furthermore, a community that differs in its vog exposure may also differ in its racial composition, and hence, may differ in susceptibility to vog. This is in fact statewide data to suggest racial disparities in the prevalence and severity of asthma. Filipno and part Hawaiians, in particular, are more likely to report symptoms of asthma (Sutton et al., 2001). By July 2006, the Hawaii County population had increased by more than 40% since the 1990 census to a resident population of more than 171,000. Approximately 26% are children under the age 18. Nearly 32% on the island’s 53,000 households claim children under the age of 18 living with them. Overall, 13-14% of these children below the poverty line, but a closer look at data from designated places in census 2000 reveals marked disparities between Hawaii County communities in socioeconomic status, another likely determinant of respiratory health (Wing, Brender, Sanderson, Perrotta, & Beauchamp, 1991).

2.3 Health effects of volcanic air pollution

Epidemiological studies that indicate association between SO_2 concentrations and pulmonary symptoms, hospital admissions and mortality. The Harvard Six Cities study demonstrated an association between sulfates and bronchitis, chronic cough and chest illness (Dockery et al., 1989). Similarly, the Twenty-four Cities Study confirmed an association between sulfate and bronchitis in children (Dockery et al., 1996). Bates and Sizto also reported connection between temperatures, SO_2, ozone, and sulfate with hospital admission rates for respiratory illness during the summer (Bates & Sizto, 1983, 1987). SO_2 levels have also been associated with total mortality (Schwartz et al., 1994; Ware et al., 1986). In Philadelphia, total mortality was estimated to increase by 5% for each $100ug/m^3$ increase in SO_2 (Schwartz et al., 1994). In all these studies, however, it should be noted that the SO_2 resulted from fuel-burning and, unlike volcanic SO_2, was mixed with combustion products. In a recent study of volcanic air pollution on Hawaii Island, Longo describes associations between SO_2 concentrations and fine sulfate aerosols with increased cough, phlegm, rhinorrhea, sore/dry throat, sinus congestion, wheezing, eye irritation and bronchitis. Quantitative measures of blood pressure and heart rate suggested correlation with air pollution only in subsets group (younger than 25, non-smoking, non-medicated, and Body Mass Index less than 25) (Longo & Yang, 2008).

The Kilauea Volcano is the most studied because it continuously releases huge amounts SO_2. It is currently still in eruptive stages, with few breaks in between eruptions. Since 1986, Kilauea Volcano has been releasing tons of SO_2 gas into the air daily. Due to the amounts of SO_2, it has been posing a health concern that people with preexisting respiratory issues can go into distress. Relationships have developed between air pollutants from volcano emission and asthma. Local areas in Hawaii are experiencing pollution and health issues. The effects of volcano ashes as environmental risks on people's health are a big problem in Hawaii. There are many people that are affected by vog including children and elderly people. However, volcanoes are known to cause air pollution and emission in the air. There are many studies that examine this issue. Analyzing the relationship will help verify the amount of health and environmental problems that volcanoes can cause, especially in Hawaii.

From January 1997 to May 2001, Michaud et al analyzed the emergency department visiting in Hilo, Hawaii. Subjects were examined for amounts of vog, SO_2, and particle matter (PM). Four groups were classified as asthma/COPD; cardiac; flu, cold, and pneumonia; and gastroenteritis. This study was motivated by the 20 years of volcano eruptions, the local public, and the government who were concerned about the possible health issues that vog can cause in Hawaii (J.-P. Michaud, Grove, & Krupitsky, 2004).

On the other hand, Hawaii has experienced high mortality rates due to asthma for more than 20 years. These high numbers are compared to the rest of the United States and internationally. The methods used to investigate this were to monitor ambient aerosol and SO_2 levels. The daily air quality was measured as well. The interaction between levels of particulate matter concentration and SO_2 were tested. As a result, a significant relationship was found between air quality and asthma/ chronic obstructive pulmonary disease (COPD) (Hansell & Oppenheimer, 2004). The other groups tested did not have a consistent significant association with SO_2 being exposed into the air (Longo & Yang, 2008). The results in the emergency room visits expressed that the effect from vog in Hilo could vary depending on the monthly variations and if the season changes (J.-P. Michaud et al., 2004).

Henceforth, there have also been studies that showed that volcanoes can have a direct effect on people's cardiovascular health. Epidemiological studies show that there is a positive correlation between air pollution and increased mortality and morbidity attributable to cardiovascular causes (Chow et al., 2010). Air pollution can cause cardiovascular distress due to lung inflammation and oxidative stress. The study that was done determined whether or not volcanic air pollution and heart-rate variability (HRV) had an association. The monitoring began for Kona in 1997 and Ka'u in August 2008 (Chow et al., 2010).

The study was done in four different exposures zones, Kohala; Volcano Village; Ka'u; and Kona. Kohala is a vog-free area that is northernmost tip of the island. Volcano Village is located slightly north of the Kilauea volcano's summit and has episodes of high vog. Ka'u is located southwest and downward from Kilauea's degassing vents. This location makes the area extremely exposed to sulfur dioxide and acid aerosol. Kona is west of Kilauea volcano and is also exposed to high amounts of acid aerosol (Chow et al., 2010).

The four exposure zones were being measured for HRV. The HRV was measured while the subject was resting, paced breathing, or actively standing. Results suggested that exposure to volcanic pollution between April 2006 and July 2008 was not associated with autonomic imbalance in health adults. Also, the study suggested that the influence of volcanic air pollution does not affect the autonomic nervous system (Chow et al., 2010).

However, populations have been increasing around the volcanic areas in Hawaii. Volcanic eruptions are also being associated with physical trauma as well as asphyxiation from direct blast of volcanic particles, heated gases, mudflows, avalanches, or tsunamis (Longo et al., 2010). Sulfurous volcanic gases and aerosols are surfacing into the stratosphere, which is affecting agriculture and resulting in human starvation. Although, most studies will suggest that a mass amount of volcanic activities are causes to cardiovascular and nervous systems, a least amount of volcanic activities can cause problems such as physiological effects as well (Longo et al., 2010).

Another study conducted at the Hawaii Volcanoes National Park, showed that workers complained about having symptoms such as headaches, coughing, eye irritation, and throat irritation. The method used was visiting clinics located in a vog-exposed area downwind from the Ka'u District. SO_2, particle matters (PM), and air quality data was reviewed. The air quality study that occurred between May and June of 2008 showed that there is a positive correlation between ambient concentrations of SO_2 and PM during Pacific trade wind conditions. Therefore, SO_2 was considered the root for vog exposure in this study. The results revealed that headaches were among the highest issue with high vog exposure. Acute pharyngitis was also associated with vog exposure whether it was high or low. The main concern was the amount of acute airways problems that were associated with vog and the Pacific Island patients and children living in the rural areas. This study has suggested that health promotion effects are needed and early health screens need to be done to catch the early warnings on health risk associated with Kilauea's vog (Longo et al., 2010).

In the same year of 2008, one indoor study was done at the Kilauea Volcano. For more than 25 years, the gaseous emissions have increased dramatically due to the opening of the vent at the volcanoes summit. Due to increased activity in 2008, an indoor air quality assessment was done on the area hospitals and schools. The first assessment was done in June 2008 to priority people in the community such as Ka'u District's hospital, schools, and community library. The assessment showed that signs and symptoms were being associated with low levels of sulfur dioxide exposure. Meanwhile, high blood pressure, faster pulse, and respiratory rates were identified in residents of Ka'u. Ka'u falls in the district of the Kilauea Volcano (Longo et al., 2010).

The results revealed the highest concentration levels were in the patient rooms on the windward side of the hospital. 83% of the SO_2 was mixed in with air inside the hospital because of the air condition units and the doors were left open (Longo & Yang, 2008). In the schools, 57% to 85% of the outdoor concentration was floating onto the inside with the air conditioner going. The highest concentration rates were in the high schools because their doors and windows were open constantly. The middle school rates were much lower because their doors and windows were not open as much as the high school. Ironically, the high school band room had only 10% penetration of ambient levels. The library had the air condition going and the levels were low because the direct wind was blocked due to the location of the library. Recommendations can include making assessments that lead to evidence-based prevention efforts to help control the sulfur dioxide levels inside places such as schools, hospitals, and libraries (Longo & Yang, 2008).

Subsequently, volcanic ashes cause as many problems as SO_2. Ash fall is very hazardous to the environment. It can affect the population as well as create an economic chaos. The particles are a fine size shaped object and are formed during a volcanic eruption. Volcanic ashes are created by the release of gases from magma, which develops large bubbles causing fragmentation, and the bubbles explosively propel upward. The air becomes exposed to the ashes and particles from the eruption which causes health risk. Even after the eruption is complete, health risk still are vulnerable. The alveolar region of the lungs can be exposed to the small particles and the lung tissue can also be severely damaged (Longo & Longo, 2013). In 1987 Speizer et al suggested that the rate of bronchitic symptoms among children in the Harvard Six Cities study increased most consistently with city-specific concentrations of aerosol strong acidit, that is a measure of sulfuric acid and partially neutralized sulfates suspended in the air (Speizer, 1989). In a large cross sectional study of school children in 24 suburban and rural communities across the U.S. and Canada, bronchitis symptoms were more prevalent and lung function more comprised in communities with higher strong acidity concentrations (Dockery et al., 1996). No association were found with the prevalence of asthmatic symptoms. Separately, a series of epidemiologic studies investigated the effect of episodes of acidic sulfate air pollution and other respiratory endpoints. The studies indicated that the acidic sulfate aerosols were associated with increased asthmatic emergency room visits, increased asthmatic symptoms and medication use, and decreased lung function (Raizenne et al., 1996).

In conclusion, volcano eruptions happen around the world and impact on health locally and global as a result of airborne dispersion of gases and ash or as impact on climate. Although eruptions have a short life span, it has been recognized that the ash fall deposits remain in the environment for many years, being blown around by wind and by human activity. Water supplies, animals, and land can be contaminated by toxin amounts of fluorine. People are mostly affected by inhalation, abrasion of the skin, and mucus membranes. The size and amount of concentration of the ashes enters the lungs and can deeply affect the airways in the lungs. The chest, nose, and throat of an individual can be affected also. Asthmatic and COPD patients notice increase health risk as well (Gudmundsson, 2011).

Recommendations for the future include making sure there are good studies for volcanic activities. The assessments should be done close to the people that it is affecting as well as when the activity actual happens. Observing the volcanic activity is also a good recommendation so that researchers can get a better observation of how it flows and what actually is happening during that time period (Hansell & Oppenheimer, 2004). The community should be involved in the planning of the studies. Lastly, epidemiologic surveillance should be placed to help epidemiologist understand the studies of volcanoes (Longo & Longo, 2013).

CHAPTER 3

METHODS

3.1 Research design and participants

In this cross-section study, all participants were recruited from schools at different locations on the Hawaii Island. During 2002-2003, 1986 schoolchildren participated the Hawaii Island Children's Lung Assessment Scientific Study (HICLASS) which aimed to evaluate effects of air pollutants from active eruption of Kilauea volcano on the local children respiratory health. Totally 1096 schoolchildren were involved in the final study from 2008 to 2009. For better assessing chronic exposure of vog, HICCLASS researchers divide the Hawaii Island into four regions based on wind patterns and geographical characters. There are four zones in the island with different levels of SO_2: low exposure zone - northeast of the island, intermittent exposure zone – southeast of the island, high exposure zone – southwest of the island and high acidity zone- northwest of the island. This division may not be perfect. U.S. Geological Survey (USGS) already has environmental monitoring data in processing which can be used to modify the division criteria in the future.

Figure 3.1 Wind Patterns and Geography of the Hawaii Island

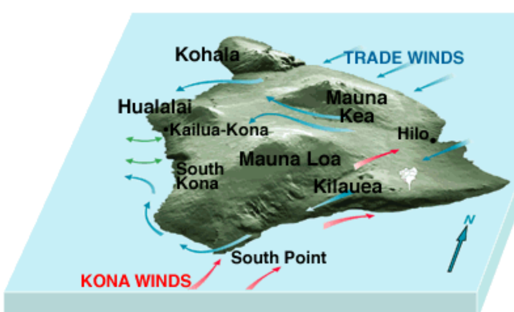

Figure 3.1 Wind Directions and Geography of the Hawaii Island. Adapted from "Is vog exposure associated with airway obstruction in Hawaii Island schoolchildren" by E.K. Tam, K. Sircar, R. Miike, F. Yip, T. Divinski, 2014 ATS.

3.2 Data collection

Before staring pulmonary function tests (PFTs), HICCLASS researchers gave all schoolchildren a classroom presentation about anatomy structure of the respiratory system, influence of air pollutants in the volcano emission and procedures of PFTs. PFTs was conducted with ndd EasyOne spirometers (ndd Medizintechnik AG) which can provide real-time parameters of flow-volume. Every child did a practice of PFTs while the technician helped the student to keep correct performance. With a sitting position and nose clip, the students performed tidal breathing, full inspiratory and forced expiratory movements under technician's instructions and computer display, which allowed the students to improve their maneuvers instantly. Test results were examined by the related programs followed American Thoracic Society (ATS) criteria (Miller et al., 2005). Each student can try no more than eight times and analysis of Forced Expiratory Volume in 1^{st} second (FEV1), Forced Vital Capacity (FVC) and FEV1/FVC were based on the blow results of three times among which the difference is less than 5% or 100 cc.

Anthropometric information, such as weight, height and age, and health history of respiratory system, such as asthma diagnosis, medication, smoking history and associated respiratory symptoms, were collected by a designed baseline questionnaire. Students answered these questions privately before conducting PFTs. Informed consents were also obtained from guardians. All information were saved in spirometer computers. Ethical Committee of University of Hawaii approved this study.

3.3 Data analysis

In order to check the relationship of respiratory disease episodes and changes of PFTs in Hawaii Island schoolchildren with different SO_2 levels, parameters of PFTs will be adjusted for individual risk factors and environmental risk factors. Previous studies indicated PFT parameters are related with height or age (Hankinson, Odencrantz, & Fedan, 1999; Wang, Dockery, Wypij, Fay, & Ferris, 1993). In the linear regression models used for statistics, weight, height, age were treated as continuous independent variables; gender, asthma conditions, vog exposure and smoking status were treated as independent categorical variables. FEV1, FVC and FEV1/FVC were treated as dependent variables. Models fitted best are selected. Mean and Stand Division (SD) were used in descriptive statistical results. Parameter estimates, P value with significance < 0.05 or 0.01 and partial correlation were also used to explain some variables when necessary. All statistical analyses were conducted with Statistical Analysis System (SAS), version 9.3.

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CHAPTER 4

RESULTS

4.1 Demographic data of the study

During the academic year 2008 – 2009, 1096 students participated the HICLASS which was to evaluate respiratory effects of vog exposure and their anthropometric data are reported in Table1. For the students involved in this study, their average age was 16.2 years old. Student's average height and weight were about 166 cm and 147 lb. Child's Body Mass Index (BMI) was applied to evaluate student's development (Kuczmarski et al., 2000). BMI of 64% students were normal but still 34% students were overweight or obese, which have been considered as an important risk factor for child asthma occurrence (Ding, Ji, & Bao, 2014). Gender distribution was almost equal for male (51%) and female (49%). Compared with U.S. continent, Hawaii Island has its unique race composition, Asian and mixed groups are more than 80%, white is only 13% which is much less than the continent. HICLASS researchers used environmental tobacco smoke to count the students exposed to direct and secondary smoking and result showed that 67% students in this study was exposed to smoking. Similarly asthma prevalence (32%) is also higher than the average level of U.S.(Kann et al., 2014). For the environmental risk factor, vog exposure, the statistical results showed 24.6% students exposed to low level SO_2, 31.5% students exposed to intermittent level SO_2, 5.3% students exposed to high level SO_2, and 38.6% students exposed to acid which is produced by SO_2 and water vapor.

4.2 Results of PFTs

Spirometry is the most common method to assess the effects of asthma on respiratory functions. FEV1, FVC and FEV1/FVC are used to monitor asthma activity and airway obstruction. Results of schoolchildren PFTs are reported in Table 2.

Table 1: Demography of the HICLASS population, Hawaii Island, 2008-2009 (N=1096)

		N (%)	Mean ± SD	Min	Max
Total		1,096 (100%)			
Age			16.2 ± 0.7	14	19
Standing Height in cm			166.2 ± 9.4	140	197
Weight in lb			147.4 ± 37.0	83	336
Race					
	Asian	187 (17.24)			
	Pacific Is.	44 (4.06)			
	White	138 (12.72)			
	Mixed	693 (63.87)			
	Other	23 (2.12)			
Sex					
	Male	561 (51.19)			
	Female	535 (48.81)			
Environmental Tobacco Smoke					
	Yes	728 (66.73)			
	No	363 (33.27)			
Asthma					
	Yes	353 (32.39)			
	No	737 (67.61)			
BMI (Body Mass Index)					
	Underweight	19 (1.74)			
	Normal Weight	700 (63.93)			
	Overweight	197 (17.99)			
	Obese	179 (16.35)			
Vog Exposure					
	"Clean"	268 (24.61)			
	Low Intermittent	343 (31.50)			
	SO_2	58 (5.33)			
	Acid	420 (38.57)			

Note: N= number of students; %= proportion of students; SD= standard deviation

In our study, mean volume of FVC is 4.0 ± 0.9 and mean volume FEV1 is 3.4 ± 0.7. To better interpret FEV1, lower limit of normal (LLN) FEV1 is calculated as FEV1/reference value, which is usually above 80% for normal pulmonary function (Miller, Quanjer, Swanney, Ruppel, & Enright, 2011). 78% students had normal pulmonary function while testing. Ratio of FEV1/FVC is important to asthma diagnosis (Johnson & Theurer, 2014) and our result suggested about 80% student pulmonary functions were in the normal range (≥80%).

Table 2: PFT results of HICLASS population, Hawaii Island, 2008-2009 (N=1,096)

	Mean (SD)	N(%)	Range (Min – Max)
FVC in liter	4.0 ± 0.9		2.2 – 7.0
FEV1 in liter	3.4 ± 0.7		1.2 – 5.8
FEV1 (percent predicted)	0.9 ± 0.1		0.3 – 1.4
≥80%		857 (78.19%)	
80% - 70%		138 (12.59%)	
70% - 60%		56 (5.11%)	
<60%		45 (4.11%)	
FEV1/FVC	0.9 ± 0.1		0.4 – 1.1
FEV1/FVC Range			
≥80%		884 (80.66%)	
80% - 70%		148 (13.50%)	
70% - 60%		20 (1.82%)	
<60%		44 (4.01%)	

Note: N= number of students; %= proportion of students; SD= standard deviation

FVC: Forced Vital Capacity, FEV1: Forced Exhaled Volume in the 1st second

As a common respiratory disease, asthma is not only associated with environmental risk factors but also has a long-term effect of obstruction on respiratory airway. In questionnaire several questions were designed to check asthma and asthma related information including history and medication. Table 3 showed 20% students with positive asthma history had an episode within two weeks of PFTs. 70% asthma students admitted that they used inhaler before but only 8% asthma students used inhalers in the same day they did PFTs.

Table 3: Asthma History and Drug using, HICLASS population, Hawaii Island, 2008-2009 (N=1,090)

		Asthma 'Y'(%)	Total
Asthma History			
	Today/Yesterday	20 (5.67)	21
	2-3 days ago	17 (4.82)	17
	4-7 days ago	17 (4.82)	17
	8-14 days ago	15 (4.25)	15
	All others	284 (80.45)	1020
Inhaler ever used	Y	233 (69.14)	235
	N	104 (30.86)	121
Inhaler using today	Y	26 (8.07)	26
	N	269 (91.93)	279

Note: Asthma 'Y' represents students who answered "yes" to the question " Do you have asthma?"

Today is the date measuring PFTs.

4.3 Risk factors associated with PFTs

Spirometry reflects pulmonary function and is sensitive to airway obstruction caused by acute respiratory diseases such as asthma, and chronic obstructive pulmonary diseases (COPD). Compared with other parameters of spirometry, FEV1, FVC and FEV1/FVC are more commonly used to diagnose respiratory diseases. If FEV1/FVC is less than lower limit of normal (LLN), it is very likely for a patient to have obstruction in airway (Johnson & Theurer, 2014). Previous studies and above results suggest spirometry parameters may be associate with anthropometric factors and environmental risk factors (Wang et al., 1993). For better understanding, linear regression analyses for FVC, FEV1 and FEV1/FVC were conducted individually to find best fit models. Before model selection data's normal distribution assumptions were examined. Selections of variants and covariates were performed by Glmselect and genmode procedures. After model selection, multicollinearity of explanatory variables were also checked. Regression models, estimates, standard errors and P-value are reported.

Table 4: FEV1 Multivariate Regression Analysis of HICLASS 2008-2009, Hawaii island (N=1096)

Variable	Estimate	Standard Error	P-value
Intercept	-4.2156	0.5086	<.0001**
Height	0.0397	0.0023	<.0001**
Weight	0.0027	0.0004	<.0001**
Age	0.0515	0.0219	0.0187*
Female	-0.3810	0.0372	<.0001**
Male	control		
Asthma - No	control		
Asthma - Yes	-0.0634	0.02985	0.0339*
Vog exposure			
Low	control		
Intermittent	0.0004	0.0371	0.9921
High SO_2	-0.0267	0.0662	0.6862
High acidity	-0.0031	0.0356	0.9314

Note: Regression model:

FEV1 = -4.2156 + 0.0397*height + 0.0027*weight + 0.0515*age – 0.3810*female - 0.0634*Asthma-Yes Sex, Asthma and Vog exposure are catagorical variables. Female = female students; Male = male students. Asthma-No = students without asthma history; Asthma-Yes = students with positive asthma history. Low = low vog exposure area; intermittent = intermittent vog exposure area; High SO_2 = high SO_2 exposure area; High acidity = high acidity exposure area. *P<0.05, **P<0.01 for the significance of each independent variable in the regression model considering all other variables.

Table 4 summarized the regression model for FEV1 which is positively related with student's height, weight and age. Since there is a narrow range of student's age in HICLASS population, we consider the age as a continuous variable. Compared with male students, female students have lower FEV1. Students with asthma also have lower FEV1 than those without asthma. Above results indicate gender and asthma history affect student's FEV1 when controlling the height, weight and age. Student FEV1 are not affected by vog exposure areas.

Table 5: FVC Multivariate Regression Analysis of HICLASS 2008-2009, Hawaii island (N=1096)

Variable	Estimate	Standard Error	P-value
Intercept	-4.8892	0.5459	<.0001**
Height	0.0451	0.0024	<.0001**
Weight	0.0054	0.0005	<.0001**
Age	0.0638	0.0234	0.0064**
Race			
Asian	-0.2082	0.0587	0.0004**
Mixed	-0.1105	0.0474	0.0200*
PI	-0.2657	0.0854	0.0019**
White	control		
Female	-0.5080	0.0398	<.0001**
Male	control		
Vog exposure			
Low	control		
Intermittent	0.0286	0.0402	0.4762
High SO_2	0.0011	0.0718	0.9880
High acidity	0.0501	0.0389	0.1982

Note: Regression model:

FVC = -4.8892 + 0.0451*height + 0.0054*weight + 0.0638*age – 0.5080*female - 0. 2082*Asian – 0.1105* Mixed – 0.2657*PI

Race, Sex and Vog exposure are categorical variables. Asian = student's race is Asian, Mixed = Student's Race is mixed, PI = Student's race is pacific island, White = Student's race is white. Female = female students; Male = male students. Low = low vog exposure area; intermittent = intermittent vog exposure area; High SO_2 = high SO_2 exposure area; High acidity = high acidity exposure area. *P<0.05, **P<0.01 for the significance of each independent variable in the regression model considering all other variables.

Table 5 summarized the regression model for FVC which is positively related with student's height, weight and age. Female students have lower FVC than male. White students usually have a higher FVC value than other students. Asthma history is not an important explanatory variable to FVC. Student FVC are not affected by vog exposure areas either.

Table 6: FEV1/FVC Multivariate Regression Analysis of HICLASS 2008-2009, Hawaii Island (N=1096)

Variable	Estimate	Standard Error	P-value
Intercept	0.8137	0.0805	<.0001**
Height	0.0003	0.0004	0.3291
Weight	-0.0042	0.0001	<.0001**
Age	0.0003	0.0035	0.9255
Race			
Asian	0.0331	0.0087	0.0001**
Mixed	0.0168	0.0070	0.0168*
PI	0.02116	0.0128	0.0974
White	control		
Female	0.0158	0.0059	0.0075**
Male	control		
Asthma - No	control		
Asthma -Yes	-0.0196	0.0047	<.0001**
Vog exposure			
Low	control		
Intermittent	-0.0033	0.0054	0.5505
High SO_2	-0.0146	0.0104	0.1585
High acidity	-0.0097	0.0058	0.0924

Note: Regression model:

FEV1/FVC = 0.8137 - 0.0042*weight + 0. 0331*Asian + 0.0168* Mixed + 0.0158*female - 0.0196*Asthma – Yes

Race, Sex, Asthma and Vog exposure are categorical variables. Asian = student's race is Asian, Mixed = Student's Race is mixed, PI = Student's race is pacific island, White = Student's race is white. Female = female students; Male = male students. Asthma-No = students without asthma history. Asthma-Yes = students with positive asthma history. Low = low vog exposure area; intermittent = intermittent vog exposure area; High SO_2 = high SO_2 exposure area; High acidity = high acidity exposure area. *P<0.05, **P<0.01 for the significance of each independent variable in the regression model considering all other variables.

Regression model of FEV1/FVC ratio is reported in Table 6. Different from FEV1 and FVC models, height and age are not significant in this regression model, weight has a negative liner relation with the ratio. Asian and mixed students have greater ratio than white students. Female students and negative asthma history students also have greater ratio. Same as the previous results, vog exposure are not significant in the model, however, there is still a trend that students in lower SO_2 area have higher ratio

Above all, our results indicates that schoolchildren pulmonary functions have positive linear relationships with height, weight, age and are effected by student's race and asthma conditions. Environmental risk factors, vog exposure and smoking status, don't have significant effects on the PFTs.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion of Results

The Kilauea volcano has been active for 30 years on Hawaii Island, especially after the vent open in March 2008. Under the local climate and geographic conditions, major gas components of the volcano emission react with water vapor to generate vog which is believed as an important environmental risk factor to local people's health (J. P. Michaud, Krupitsky, Grove, & Anderson, 2005). However, this point of view needs more support from epidemiology researches which focus on effects of adult's respiratory and cardiovascular systems (Mannino et al., 1996; J.-P. Michaud et al., 2004).

HICLASS was initiated in 2002 to investigate health effects of chronic vog exposure on local schoolchildren. The sudden eruption of Kilauea in 2008 gave scientists a good opportunity to inspect student reactions to the unique exposure pattern. The pattern showed a slow exposure to low amount vog, followed by a quick exposure to high amount vog, which might be different from either acute or chronic effects of vog in the schoolchildren. Another advantage is the cross section data collected during 2008 to 2009 was originated from HICLASS longitudinal study in which student's information and spirometry parameters were gathered by the same procedures. Questionnaire design in the HICLASS was followed the previous study (Speizer, 1989). Only lung growth rate and asthma occurrence were recorded during the whole study period because they were more sensitive and specific than other parameters. Firsthand or secondhand smoking history were also collected due to high smoking prevalence in adolescents on the island (L. T. Wu, Swartz, Burchett, Workgroup, & Blazer, 2013) and close association between asthma and smoking cigarettes (Boychuk et al., 2006).

Before constructing regression models, distributions of the data were investigated. Although some outliers were found, all data were considered approximate normal distributions which is fit for liner regression analysis. In the demography summery report, range of student age is quite narrow, mostly from 15-year-old to 17-year-old, and analyzed as a continuous explanatory variable. Ethnicity in Hawaii Island is different from mainland. Mixed and Asian are more than 80% in our samples, which is difficult for the HICLASS research team to find proper reference values to adjust spirometry parameters (FVC, FEV1, FEV1/FVC) since these values are not from the similar population (Hankinson et al., 1999). Unique race composition is also believed to relate with high prevalence of smoking, obesity and asthma (Brown, Gotshalk, Katzmarzyk, & Allen, 2011; B. H. Wu, Cabana, Hilton, & Ly, 2010; L. T. Wu et al., 2013). For the division of vog exposure, HICLASS research team followed the observation results of regional wind patterns because vog distribution is mainly decided by the wind direction and speed. Among the four regions, high SO_2 exposure area has much less students than the other three, which might be caused by several reasons, such as students moved to other regions or dropped off the study during that period.

In constructing FVC, FEV1 and FEV1/FVC prediction models, GLMSELECT procedure is applied which is a new developed procedure in SAS and covers GLM and REG type models (www.*support.sas.com).* For the prediction models of FVC and FEV1, height, weight and age are significant independent variables and have positive liner relationship with dependent variables which indicates FEV1 and FVC alternations of the Hawaii Island schoolchildren are associated with their growth (Dockery, Berkey, Ware, Speizer, & Ferris, 1983; Wang et al., 1993; B. H. Wu et al., 2010). Controlling for height, weight and age, sex difference is also significant. Female students have less FEV1 and FVC values than those of the male students because boys and girls have different growth rates of lung, which may be related with their trunk heights (Schwartz, Katz, Fegley, & Tockman, 1988; Wang et al., 1993). Variable race or asthma condition enters into FVC or FEV1 prediction model respectively. FVC value can be influenced by lung capacity, truck size and thorax muscle (DeGroodt, van Pelt, Borsboom, Quanjer, &

van Zomeren, 1988; Grivas, Burwell, Purdue, Webb, & Moulton, 1991). White students have higher FVC value, which might be caused by anatomic, nutritional and social economic factors, mostly related with races. Unlike FVC, FEV1 also affected by elasticity of lung and respiratory airway. Airway obstruction, like asthma, can easily reduce FEV1 value than other factors (Quanjer et al., 2010; B. H. Wu et al., 2010). In clinic FEV1/FVC less than 80 percent is a sensitive diagnostic criteria for asthma (Oei et al., 2011). Our FEV1/FVC prediction model suggests less weight and female are related with higher FEV1/FVC, which is supported by other team's study (Schwartz et al., 1988; Ware et al., 1986). Controlling weight and sex, effect of race on the ratio might be explained by the trunk size of Asian or mixed students (Schwartz et al., 1988). For FVC and FEV1 prediction models, both R^2_{FVC} (0.71) and R^2_{FEV1} (0.62) are greater than 0.5, which suggest two models include most effective variant and covariant. $R^2_{FEV1/FVC}$ (0.10) indicates some explanatory variables are missing, such as social economy situation.

Although smoking cigarettes and vog exposure are two important environmental risk factors believed to affect the schoolchildren PFTs (Longo & Yang, 2008; Longo et al., 2010), our prediction models can't prove this assumptions. Results showed that the percentage of students' exposure to firsthand and secondhand smoking is pretty high. However, effects of smoking on respiratory system may need a longer time to appear. Vog effects on people's health have been researchers' interest for some time (Longo & Longo, 2013; J. P. Michaud et al., 2005; Raizenne et al., 1996). Recently, Michaud et al reported emergency visits due to attacks of acute respiratory diseases which were believed being induced by vog in Hawaii Island (J.-P. Michaud et al., 2004). Results of their analysis displayed that factor of season is more responsible for the visits than vog. Their conclusion is supported by other group's result (Mannino et al., 1996).

In our study, multiple reasons can be accounted for vog's effect "loss". Wind patterns and geographic features are major determinants for the HICLASS researchers to divide vog exposure regions but activity of Kilauea volcano is different daily. The accuracy of division method is questionable. USGS have monitors to record SO_2 level during the eruption. However, this data is still in processing. Vog has multiple components including different chemicals, metals or particulate matters (PM). Some of them like $PM_{2.5}$ can induce respiratory diseases as well (Longo & Longo, 2013). Indoor air quality is also important when researchers evaluate risk factors of students' asthma occurrence.

5.2 Study Strengths and Limitations

Strengths of this study include relatively synchronized sample subjects, collecting data with standardized questionnaire, measuring PFTs by authorized equipment and protocols and building up important relationships between spirometry parameters and risk factors. Data of 1096 qualified students was collected, which make data distribution approximately normal. Active Kilauea volcano, specific weather conditions, and geography of Hawaii Island compose exclusive environment for researchers to inspect chronic vog (natural SO_2) effects on students' health. Race composition in the island is different from other regions of the U.S.

Several limitations to this study also exist. Although all the data were collected from relatively restrictive subpopulation in Hawaii Island, about 40 percent (887/1983) of the students either moved between regions of vog exposure or dropped off the study, which may have affected final results.

Model of vog exposure area was not based on measured environmental data, which lacks accuracy of SO_2 level and need further confirmation. Not like longitudinal study, cross section study only shows association but not causality. Race distribution is different from other regions and difficult for the researchers to find appropriate reference values to adjust PFT data. Multivariate analysis can select risk factors and examine confounders. However, some risk factors or confounders may be missed from the beginning of the study. Respiratory symptoms reported were assumed to induce by asthma. However, other diseases, such as swine flu, can cause the similar symptoms which can lead to incorrect clinical diagnosis.

5.3 Implications of Findings

Kilauea volcano eruption on Hawaii Island has been active for 30 years. Sulfurous air pollution may affect local people's health. Race distribution and high asthma prevalence are associated with the schoolchildren's PFTs. From our results, pulmonary function changes of adolescents on the island are mainly decided by growth. Environmental risk factors don't play an important role.

5.4 Recommendations for Future Research

For the future study, more environmental risk factors could be included, like PM_{10}, $PM_{2.5.}$ Air pollution models should be constructed on the real measured data from environmental surveillance department. Besides outdoor air quality, indoor air quality also needs to be investigated since people spend more time doing indoor activities. Asthma and smoking prevalence in local children is related with race distribution, which indicates social economic risk factors have important effects on people's health.

5.5 Conclusion

In summary, pulmonary functions of Hawaii Island schoolchildren are associated with their body growth, race or asthma conditions. Vog exposure doesn't affect children's respiratory system though asthma and smoking prevalence are higher than those of other areas in U.S.

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