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The Association of Dust Events with Asthma Exacerbation in the U.S.-Mexico Border Children: A Pilot Study

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Abstract

Background. Asthma is one of the most prevalent chronic pediatric illnesses in the U.S. and a major cause of childhood disability, hospitalization, and missed schooldays. Air pollution is one of a number of known environmental triggers known to exacerbate pediatric asthma. Emerging evidence also suggests that exposure to dust aerosols associated with dust storm events may trigger asthmatic symptoms. The Paso del Norte (PDN) region is the single most dust-prone major metropolitan area in the U.S., averaging 14.5 major dust events/yr. The annual peak in dust event activity occurs during March to May where there is a 42% chance of blowing dust on any day. Pediatric asthma is common in the PDN. Published and unpublished studies estimate asthma prevalence in El Paso children at 5-15%. In Ciudad Juarez, the prevalence of medically diagnosed asthma has been estimated at 6.8% and wheezing at 20%.

Objectives and Hypotheses. A panel pilot study was conducted to explore the association between dust aerosol exposure and symptom exacerbation in asthmatic El Paso children. It was hypothesized that exposure to high ambient PM concentrations produced during dust events (especially finer particulates in the < 2.5-0.09 nm diameter range) will be associated with symptom exacerbation in asthmatic children because of ability of particles in this size range to readily penetrate to lower airways where they initiate the Type 2 immune response inflammatory process.

Methods. Medically diagnosed asthmatic children were identified from the original UTEP ARCH Cohort study and recruited for participation. The inclusion criteria were age 5-17 years, medically diagnosed asthma, current asthma sufferer, and El Paso area resident. Subjects and their parents/guardians who elected to participate went through the informed consent & assent

process (UTEP IRB #94578-2). Detailed dust aerosol data (size and elemental composition) were collected over a consecutive 42 day period (April 1-May15, 2009) by the ARCH companion project using an 8-Stage DRUM sampler. Sampling was performed by upwind-downwind transect in four geographical sites. Additional data on $PM_{2.5}$ and PM_{10} concentrations were obtained from TECQ central air monitors. Subjects/parents used a 16-question asthma diary (Juniper et al., 2000) to record daily symptoms during the 42-day study period (e.g., wheezing, persistent cough, chest tightness, shortness of breath, activity limitations, asthma medications, asthma-related outpatient visits/hospitalizations). Three unannounced telephone calls to verify the previous day's diary entries were made to each home over the 5.5-week study period as a quality control check.

Results. The 24 study participants ranged in age from 7-17 years (x=11.8 $\pm$ 3.0 yrs). The majority were female (58.3%), Hispanic (83.3%), and had lived in El Paso since birth (91.7%). During the study period, recorded 24-hour average of $PM_{2.5}$ that ranged from 5 $\pm$ 1.9 $\mu g/m^3$ to 16 $\pm$ 9.1 $\mu g/m^3$ while that of PM_{10} ranged from 16 $\pm$ 5.6 $\mu g/m^3$ to 92 $\pm$ 77.2 $\mu g/m^3$. The concentration of elements such as silicion, sulfur, and lead was elevated on high dust days. On the high compared to low $PM_{2.5}$ days, there was a statistically significant increase in the proportion of the asthmatic subjects who experienced moderate-severe shortness of breath, wheezing, and chest pain. A statistically significant increase also was identified regarding the proportion of children reporting moderate-severe chest pain and persistent coughing during the high compared to low PM_{10} days. In addition, the number of children who experienced moderate-severe limitations in their overall daily activities and who received emergency medical treatment for their asthma was significantly increased on high compared to low PM_{10} days.

Conclusions. The preliminary evidence from this pilot study suggests that exposure to high PM_{10} as well as $PM_{2.5}$ from dust, fire and other sources may exacerbate pediatric asthma. However, future studies are needed which employ a larger sample size and a longer observation period in order to improve statistical contrast of maximal and minimal dust aerosol periods for the data analyses.

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Chapter 1

Background and Significance

Overview of Clinical Asthma

Asthma is a chronic disease that affects the lungs (CDC, 2008). The airways of asthmatic patients become inflamed in contact to an allergen resulting in vasodilation and reversible episodes of obstruction (Fireman, 2003; American Lung Association [ALA], 2007; Passalacqua and Ciprandi, 2008). Airway inflammation is an immune response that is under the control of a type of T-lymphocyte, the T helper type 2 (Th-2) cell (Marieb, 2004). By secreting certain cytokines (IL-4, IL-5, and IL-13), Th2 cells stimulate the production of IgE (immunoglobulin E) by plasma cells or effector B cells, therefore activating and surviving inflammatory cells (eosinophils) to the site (Marieb, 2004; Passalacqua and Ciprandi, 2008). The airways of asthmatics are very sensitive and tend to react strongly to allergic or irritating triggers (NHLBI, 2008). In asthmatic persons, inflammation causes an increased reaction of the airways to various stimuli. When a non-asthmatic has a reaction to a substance, e.g., peanut butter, the "allergic" reaction they experience may be dermatological compared to an asthmatic whose allergic reaction is more likely to affect the lungs (allergic lung disease).

Persons experiencing an asthma episode experience swelling of the airway lining (edema), tightening of the bronchial muscles (bronchospasm), and increased bronchial secretion of airway mucus (hyper-secretion) (ALA, 2007; COMPEDIA, 2008). The most common symptoms of an asthma attack are wheezing, coughing, chest tightness and difficulty in breathing, particularly at night or early in the morning (NHLBI, 2008; CDC, 2008). There are four clinically defined levels: 1) mild intermittent symptoms that come and go, 2) mild persistent symptoms that occur more than twice a week, 3) moderate persistent symptoms that occur most days, and 4) severe persistent daily symptoms (NHLBI, 2008).

Epidemiology of Asthma

Asthma is a major worldwide health problem that affects every age, gender and socioeconomic group. It is estimated that approximately 3% of the global population has experienced this disease sometime in their lives (Urbina, 2001). The World Health Organization (2006) estimated that in 2005, approximately 300 million people suffered from asthma, and 225,000 people died from it. Asthma is on the increase globally. It has been estimated that asthma deaths will increase by approximately 20% in the next 10 years if immediate action is not taken (WHO, 2006). According to the International Study of Asthma and Allergies in Childhood (ISAAC), the highest prevalence of asthma symptoms (> 30%) has been reported for United Kingdom, New Zealand, Australia, and Ireland (Respirar, 2008).

Asthma is the single most prevalent chronic illness among U.S. children (CDC, 2008). It is a major cause of disability among this age group (CDC 2008) accounting for an estimated 14 million missed schooldays each year. It is the third leading cause of hospitalization among children <15 years, and costs approximately $3.2 billion annually to treat (CDC 2008). The prevalence of this childhood illness has been steadily increasing in the U.S. during the past 30 years. For example, between 1980-1996, asthma prevalence doubled from 3.6% to 6.2% (CDC 2008). Economically disadvantaged, minority racial/ethnic groups, and inner city children are at much higher risk for developing asthma and when they do, they have more likely to have poorly controlled disease and mortality rates compared to the general child population.

Childhood asthma is more common among boys and they also are more likely to die from an asthma attack compared to girls. However, after puberty the risk is higher for girls (AAFA, 2005). The prevalence of asthma and asthma-related mortality also varies by ethnic group. African-Americans and Hispanics, especially those of Puerto Rican or Cuban origin are at great risk for the disease and asthma-related mortality (CDC, 2008). According to the Asthma and Allergy Foundation of American (2005), genetically inherited allergies can predispose people to developing asthma. For example, of one parent has allergic disease, the potential risk that in their offspring is 40%. If both patents suffer from allergies, this risk could be as high as 70% (COMPEDIA, 2008).

Potentially modifiable risk factors for asthma include early childhood exposure to allergens acting as asthma triggers (Ho et al., 2007). Substances documented as common asthma triggers include allergens such as certain foods, dust mites, animal dander, pollen, and cockroaches; irritants, such as cigarette smoke, air pollution, dust storms, excitement and stress; and others triggers such as aspirin, wine, dried fruit, exercise, and weather changes especially during the summer and winter (ALA, 2007; NHLBI, 2008). In addition, an estimated 5-20% of asthmatics have medication sensitivity or allergies which can trigger attacks (COMPEDIA, 2008). Residence in an urban area also has consistently been reported as a risk factor for asthma and asthma exacerbation, presumably because of environmental triggers (Ho et al., 2007).

Air Pollution Exposure and Asthma Exacerbation

Although often viewed by the general public as a childhood nuisance, an asthma attack can be life-threatening. Failure to promptly treat a severe asthma attack can lead to oxygen deprivation resulting from airway constriction and death within minutes (Joseph, et al., 1996). As reported in a previous section, a number of diverse dietary and other environmental triggers have been identified for asthma attacks. The evidence indicates that exposure to ambient air pollutants can trigger asthma attacks and exacerbate the severity of respiratory symptoms. New evidences also associate near-road exposure with asthma development.

The two major types of air pollutants are gases and particulate matter (PM) (Environmental Protection Agency [EPA], 2006). Particle pollutants are made up of a number of components, which include acids, organic chemicals, metals, soil or dust particles, and allergens (EPA, 2006). U.S. National Ambient Air Quality Standards for ozone and PM have become more stringent since the Clean Air Act was signed into law in 1970 (Koenig, 1996; AAP, 2004; Trasande and Thurston, 2005). However, the 1997 National Ambient Quality Standards estimated that around 146 million Americans were living in areas where monitored air failed to meet their standards for having at least 1 of the 6 regulated ambient air pollutants: ozone, PM, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead (AAP, 2004; Trasande and Thurston, 2005).

Exposure to air pollutants has been linked with a number of adverse health effects in persons with pre-existing asthma (Koenig, 1996). These include: increased production of pro-inflammatory immune response indicators, bronchial hyperresponsiveness, airway inflammation, and decreased pulmonary function. Asthmatics exposed to high ambient air pollutant levels also are more likely to visit emergency departments for their symptoms and be admitted to the hospital (Koenig, 1996).

Villeneuve and associates (2007) reported finding a robust positive association between ozone exposure and the exacerbation of asthma symptoms in Canadian children aged 5-14 years. The results from a study conducted by Shildcrout and associates (2006) linked carbon monoxide and nitrogen dioxide present in air pollution to an increased asthma exacerbation. They suggested that these gases can initiate adverse reactions with inhaled allergens leading to the onset of asthma symptoms in children with the disease (Schildcrout et al., 2006). Delfino and colleagues (2008) also reported that schoolchildren with persistent asthma showed evidence of lung function deficits due to air pollutant exposure, especially PM and nitrogen dioxide.

Particulate Matter and Asthma Exacerbation

Particulate Matter (PM) is a type of air pollutant that includes both solid and liquid particles that are suspended in the air. These vary in size, composition and origin. PM characteristically contains a mixture of soot, acid condensates, and sulfates and nitrate particles (Yang et al., 2005). Ultrafine PM (UFP) consists of particles with an aerodynamic diameter of <0.1 µm. Fine particulate matter ($PM_{2.5}$) is comprised of particles having an aerodynamic diameter of <2.5 µm. In contrast, coarse PM ranges from 2.5 to 10 µm or larger in diameter. It originates predominantly from geological sources such as soil and other crustal materials resulting from the breakdown of rocks, soil, and dust (Yang et al., 2005; Trasande and Thurston, 2005). These coarse particles can become airborne as a result of high wind speeds, which simultaneously reduce the concentration of fine particles and other combustion-related pollutants (Yang et al., 2005).

Particulate matter is taken into the upper and/or lower respiratory system when inhaled during breathing. However, where the particles are ultimately deposited in the respiratory tract varies with particle size (Trasande and Thurston, 2005; Lei et al. 2004). Children are more likely to be exposed to the adverse health effects of PM and other air pollutants than adults because of their anatomical, physiological and behavioral characteristics. For example, children have smaller, less well developed lungs that are more easily damaged by pollutants than those of adults (Bateson & Schwartz 2008). They also have higher baseline ventilation rates and tend to mouth breathe more often than adults. This allows PM and other pollutants to be deposited deeper into their lungs resulting in decreased rates of clearance and healing. In addition, children tend to spend a greater number of hours outdoors engaged in aerobic activities which causes them to breathe in a larger amount of air pollutants per kg/body weight compared to most adults (Bateson and Swartz 2008; Kleinman 2000; Transande & Thurston 2005). The volume and anatomical location of PM deposition in children's respiratory tracts and the resultant respiratory effects also depend on the size of the particles that they inhale. It has been reported that fine ($PM_{2.5}$) and ultrafine particles are more easily deposited deeper into children's lungs than those of adults (ibid). Larger sized PM_{10} or very coarse PM ($\geq$ 10 μm) usually do not pass much beyond the larynx in most persons. However, because of the tendency of children to mouth-breathe, these particles often deposit deeper down into the airway (ibid).

A comprehensive review conducted by Wilson and associates (2004) indicated that exposure to high PM levels present in outdoor air pollution was a significant predictor of hospital admission for respiratory problems including asthma and chronic-obstructive pulmonary disease (COPD) across diverse European population groups. Another comprehensive review of the epidemiological evidence published on populations in the United Kingdom, Netherlands, and Italy concluded that residence close to areas of high traffic density (with ostensibly high PM) was linked with increased wheezing, chronic cough, and other indicators of asthma exacerbation (Trasande & Thurston, 2005). In addition, a study conducted by Lin and associates (2002) in Toronto covering the period 1981-1993 examined the association between size-fractioned particulate matter and hospitalizations of asthma in children aged 6-12 years old. The authors were able to identify any significant association of exposure levels of $PM_{10-2.5}$ particulate matter and asthma hospitalizations.

In contrast to the above reports, a systematic review of the literature found a negative association between PM exposure and cough symptoms in children (Ward & Ayres, 2003). Likewise, the results of a prospective investigation (Children's Health Study) carried out in southern California found no association between coarse PM and increased bronchitis symptoms in children with asthma (Brunekreef and Forsberg, 2005).

Dust Storm Events

Dust storms, which are a major source of particulate matter, occur in all continents. Over the last 20 years, Asian dust activity has been incrementing (Griffin and Kellogg, 2004), ostensibly due to climatic changes associated with global warming. The regions of North Africa, the Sahara and Sahel, are known to serve as significant sources of dust in the Earth's atmosphere. These are documented to have a negative impact on air quality not only in the Middle East and Europe but as far away as the Caribbean, and the Americas (Griffin and Kellogg, 2004).

According to Griffin and Kellogg (2004) some of the highest incidence rates of asthma in the world are due to areas heavily impacted by desert dust, such as the Aral Sea and the Caribbean. Emerging evidence generally supports the notion that dust events may be an asthma trigger in children. For example, a prevalence study from the United Arab Emirates reported that 13.6% of the 850 schoolchildren examined had asthma; 72.9% also showed evidence of allergy (Bener et al. 1996). The results also identified exposure to dust storms as a significant risk factor for both conditions (Bener et al. 1996). However, another study carried out in the nearby desert nation of Kuwait was unable to identify any association between dust storm activity and the frequency of attendances/admissions to hospital for asthma in children (Strannegard & Strannegard 1990).

A study conducted by Yoo et al. (2008), examined the exposure of Asian dust events on respiratory symptoms in children with mild asthma in the Seoul, Korea metropolitan area. They found associations with an altered respiratory outcome but were unable to identify the exact mechanism by which the dust causes adverse respiratory health effects. This could be due to the fact that during Asian dust events there is an enormous increase in the concentration of fine or ultrafine particles (Yoo et al., 2008). Furthermore, aerosol properties during these dust events have been shown to be different from those of the general atmospheric conditions by having chemical components in the atmosphere, such as NO_2, SO_2, and $O_{3,}$ further comprises the respiratory system from asthmatic and normal people (Yoo et al., 2008).

Results from the few studies that have investigated the potential role of dust aerosols and childhood asthma exacerbation conducted in North American populations are mostly supportive but vary as to reported exposure levels, PM size fractions, and estimated effect size. For example, Romieu and co-authors (1996) reported that respective increases of 10 $\mu g/m^3$ and 20 $\mu g/m^3$ in weekly mean $PM_{2.5}$ and PM_{10} levels was associated with robust 21% and 8% increases in the risk for lower respiratory illness symptoms among children living in Mexico City. Gordian and colleagues (1996) noted a 3-6% increase in outpatient visits for asthma in an urban Alaskan city for each 10 $\mu g/m^3$ increase in PM_{10} concentration. This study was one of the few where the PM primarily came from dust, not anthropogenic pollutants.

Mar and colleagues (2004) carried out a longitudinal study in Spokane that evaluated the effect of four different PM size fractions (i.e., very coarse PM, PM_{10}, $PM_{2.5}$, $PM_{1.0}$) on respiratory symptoms in asthmatic children. The main PM sources identified were dust storms, re-suspended road dust, motor vehicles, agricultural burning and woodstoves. The study results confirmed a significant positive association between cough in asthmatic children and all of the four PM fractions analyzed. In contrast, PM_{10} and PM coarse fraction were the only predictors of increased sputum production and rhinitis. Their findings suggest that both larger and smaller fraction PM can aggravate asthma symptoms in children but not adults.

A study conducted by Gent and associates (2003) examined the simultaneous effects of O_3 and $PM_{2.5}$ exposure and respiratory symptoms and use of a rescue inhaler in children living in southern New England. However, the authors were unable to identify a significant independent effect for $PM_{2.5}$ although estimated mean exposure levels were exceedingly low, only 13 ± 8 $\mu g/m^3$ for daily 24-hour average/total which is well below average background levels reported for many sites including El Paso.

Although the emerging epidemiologic evidence suggests that exposure to aerosolized dust may exacerbate asthma in children, it remains uncertain whether PM concentration, size, composition (e.g., mineral, organic), and/or their interactions is most responsible. The toxic effects of PM on human respiratory tissue may result from the direct action of $PM_{2.5}$ on the respiratory tissue but particle composition varies extensively by source and any toxicological effects may also be mediated by compounds present in or associated with $PM_{2.5}$ (Lei et al. 2005). Ultrafine PM or UFP's, which consists of particles with an aerodynamic diameter of <0.1 µm, may contribute to the adverse health effects of PM because of their large surface area, oxidant capacity, ability to evade macrophage phagocytosis, and propensity for inducing pulmonary inflammation. It has been reported that peak ventilation flow in asthmatic subjects was more closely associated with UFP than $PM_{2.5}$ concentration (Peters et al. 1997). The results from this study also suggested that the UFP component of fine particle pollution may have the greatest adverse effect on the respiratory airways of asthmatics. However, as noted in a previous section, larger size fractions also may be able to penetrate deeper down into airways because of children's tendency to mouth-breathe (Bateson and Swartz 2008; Kleinman 2000; Transande & Thurston 2005).

The mineralogy of fine particles in the urban atmosphere is reported to change during dust storm events. The crystalline polymorphs of silica, which are the primary constituents of dust storms, are known to be lung irritants (Rutherford et al. 1999). Metals such as beryllium, cobalt, nickel, chromium, iron, and aluminum identified using PM elemental analysis have been linked with asthma (Merget 2000; Fedan & Cutler 2001; Kusaka et al. 1986; Bernstein et al. 1999; Mandervelt et al. 1997). The metallic elements and inorganic particles that constitute some PM species have a propensity to attach themselves to the alveoli and other types of respiratory tract surfaces. The attachment of minerals such as asbestos can adversely affect lung function and the mucocilliary escalators are important mechanisms for clearing inhaled particles (Allison 1974). Ichinose et al. (2008a) identified distinct differences in the allergic inflammatory potential of sand dusts from Arizona and China that appear to be associated with differences in their mineral composition especially SiO_2. Specifically, Arizona sand dust and SiO_2 were shown to synergistically increase eosinophil-relevant cytokines and chemokines (e.g., IL-5, monocyte chemotactic protein-3) in mice. In contrast, the sand dust from China showed lower immunogenicity.

Paso del Norte Border Region: Asthma and Dust

The population prevalence of child asthma in the El Paso metropolitan area has been reported to range from 5-13% (Neas et al. 2002; Alexander et al. 2000). However, new data from the UTEP ARCH core cohort study conducted by Dr. Maria Amaya and co-investigators suggests that the true prevalence in children appears to be as much as 15% (unpublished data). Less is known about the prevalence on the Mexican side of the border. However, the results of a survey conducted by Barraza-Villareal and co-authors (2001) in Cd. Juarez reported that the prevalence of medically diagnosed asthma was 6.8%. The prevalence of wheezing was estimated at 20% (ibid). Asthma-related hospitalization rate for the state of Texas averaged 29.0/10,000 and for the border was 21.2 per 10,000 (Grineski, 2007). It was also found that hospitalized border children who were much younger and had less severe asthma were hospitalized at 36% higher rate, had 30% more probability to enter the hospital through a clinic or physician, and 28% less likely to be admitted directly from the emergency room (Grineski, 2007).

El Paso is believed to be the single most dust-prone major metropolitan area in the United States averaging around 14.5 major dust events annually (Novlan et al., 2007). Dust events occur throughout the year but are most frequent during the dry, windy season. The peak in dust event activity occurs from March to May when there is a 42% chance of blowing dust on any day (ibid). Although the geological sources and meteorological conditions associated with blowing dust in El Paso are well documented, less is known about how dust event characteristics (particle size, spatio-temporal distribution, elemental and organic composition) exacerbate symptoms in asthmatic children.

Chapter 2

Study Aims and Hypotheses

The major objective of the pilot study was to investigate the association of dust storm events with the exacerbation of asthma symptoms in asthmatic children residing on the U.S.-Mexico border. Two working hypotheses were examined.

Hypothesis 1*. Exposure to high ambient PM concentrations produced during dust events is associated with the exacerbation of asthma in children with existing disease.*

Specific Aim 1. To analyze the association between ambient PM concentrations produced during dust events and exacerbation of asthma. Data obtained from the companion pilot project and the TEQC central air monitors were used to model subject exposures. Subject exposures were correlated with indicators of asthma exacerbation recorded during the same time period with a daily asthma diary which collected data on respiratory symptoms (type, severity, timing), use of maintenance, rescue and other medications, and emergency visits to outpatient health providers and hospitals.

Hypothesis 2*. Exposure to aerosols containing a high proportion of fine and ultrafine PM particles (< 2.5-0.09* nm/m^3 *diameter range) produced during dust events is associated with symptom exacerbation in asthmatic children because of the ability of particles in this size range to more readily penetrate to lower airways where they initiate the Th2 immune response inflammatory process.*

Specific Aim 2. To determine whether exposure to aerosols containing a high proportion of fine and ultrafine PM (< 2.5-0.09 nm/m^3 diameter range) produced during dust events is associated with indicators of asthma exacerbation in children with pre-existing disease. Accomplishment of this aim was through analysis of the distribution of PM fractions in the fine, ultrafine and coarse particle size ranges to construct subject exposure models during dust event and non-dust event periods (baseline). Subject exposures were assessed for their relationship with asthma exacerbation (i.e., respiratory symptoms, maintenance and rescue medication use, outpatient health provider visits and hospitalizations using the aforementioned daily asthma diary).

Chapter 3

Methods and Materials

Description of the Study Population and Site.

The pilot study was conducted in the El Paso metropolitan area. This site is situated on the U.S.-Mexico border adjacent with New Mexico and the northern Mexican border state of Chihuahua. The major metropolitan area is inhabited by approximately 800,000 persons. According to the most recent American Community Survey (U.S. Census Bureau, 2007), the median age of the El Paso population is 30.6 years. Family size averages 3.67 persons. The *per capita* income for families averages only $14,752 per year and 24.9% of all families live below the poverty line. Eighty-two percent of El Paso residents classify themselves as either Hispanic or Latino, 27.5% reported being foreign-born, most of these in Mexico. Three-fourths (75.9%) of persons over the age of five years speak a language other than English in the home.

Study Design

The major goal of the panel study was to examine the association of aerosols produced during dust events with the exacerbation of asthma in 5-17 year old children. The subjects were previous participants in the ARCH core study cohort who were previously medically diagnosed with asthma. Data on ambient PM was obtained from a companion pilot project undertaken by Dr. Tom Gill in the UTEP Department of Geology during a 5.5-week sampling period using an 8-Stage DRUM (Davis Rotating Universal size-cut Monitoring) sampler. The DRUM sampler collected detailed data on size and time-resolved aerosol samples. The samples were collected from an upwind-downwind transect at several sites across the El Paso metropolitan area during early spring 2009. The spring is one of two yearly temporal periods when major dust events are most likely to occur in the Paso del Norte region.

Data concurrent with the DRUM and TEQC central air monitors were collected on indicators of asthma exacerbation. Specifically, daily logs filled out by the child participants and their parents included the occurrence of any respiratory symptoms (type, severity, timing), use of maintenance and rescue medications, and visits to outpatient health providers, asthma-related emergency room visits and hospitalizations.

Subject Recruitment

The study protocol received formal approval by the University of Texas at El Paso Institutional Review Board (#94578-2). Children previously enrolled as subjects in the current ARCH cohort core study were selected for participation in the pilot project. The original ARCH cohort consisted of children 5-17 years of age. The ethnic and other sociodemographic characteristics of the sample reflect those of the larger El Paso population. A total of 81 potential subjects were identified as possible participants from a list provided by the ARCH study (Dr. Maria Amaya, P.I.). Figure 1 shows the outcome of the recruitment process.

Prospective subjects who could be contacted were recruited by telephone from the ARCH study list to confirm their eligibility and interest in participating in the current study. Meetings with the children and their parents/guardians were conducted to explain the purpose of the study, its requirements, potential risks and benefits, and address any questions or concerns. A total of 24 children and parents of children who agreed to participate went through the informed assent and consent processes, respectively.

Data Collection Procedures and Instruments

Subject Characteristics and Health History Data

Data on sociodemographic characteristics, health history and other characteristics were abstracted from available data previously collected on the subjects in the ARCH cohort study.

Asthma Exacerbation Indicators

Prospective data on asthma symptoms and severity were timed to be collected simultaneously with the air sample data collected by the ARCH companion project during the continuous 5.5 week time period (April-May, 2009). Data on the type (e.g., wheezing, persistent cough, chest tightness, shortness of breath), severity, and timing of respiratory symptoms were recorded by the parent/guardian or child, as appropriate, onto a daily 24-hour diary form (Juniper et al., 2000). The diary also noted the use of bronchodilator use or asthma-related emergency visits/hospitalizations. It employed a Likert-like scale for items where subjects/parents were asked to rank the child's symptoms from 0-6 with zero designating a lack of any symptoms and six, very severe symptoms. The others were (1) very mild symptoms, (2) mild symptoms, (3) moderate symptoms, (4) quite severe symptoms, (5) severe symptoms, and (6) very severe symptoms. The other items included bronchodilator and other medication use (frequency), and activity limitations (yes/no answers). Participants were able to choose English or Spanish language versions of the diary depending upon their preference. All but two of the 24 study subjects elected to have English-language diaries.

The symptom diaries were collected every two weeks during scheduled home visits by the study coordinator (M. Gaytan). As a quality control check, unannounced telephone calls were made to each participating household three times during the 5.5-week study period to check on the respiratory symptom status of the child subjects, ask specific questions about the log entries for that day (to use to later verify with the recorded log entries), and to answer any questions that the parents/guardians or children may have regarding the study protocol. Each subject household received an incentive of $60 at the end of the data collection period.

Dust Aerosol Collection and Analysis

As previously noted, DRUM sampler technology (Cahill et al. 1985) was used to collect highly detailed data on the size and time-resolved aerosol samples. Air samples were collected from an upwind-downwind (generally west-east) transect across the El Paso metropolitan area during April-May 2009, which corresponds with high wind/dust season in the El Paso area (Novlan et al. 2007). These were located on the far western edge of the El Paso metropolitan area (Sta Teresa), two across the central city area, and another on the far eastern fringe of the city (Socorro). Additional observational data on dust, visibility, wind, fires, and other ambient conditions were recorded daily during the study period by the ARCH companion project conducted by Dr. Gill of the UTEP Department of Geology.

Publically available data on ambient air quality routinely collected from central monitoring stations in the El Paso metropolitan area by the Texas Commission on Environmental Quality (TCEQ) were used to supplement the DRUM sampler aerosol data. Specifically, data from the Continuous Ambient Monitoring Stations (CAMS)-UTEP. The CAMS measure the amount of pollutants in the environment, such as ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and $PM_{2.5}$ and PM_{10} (TCEQ, 2009). They also measure meteorological conditions during the sampling period (temperature, rainfall, humidity, visibility) and wind speed (Figure 2). The UTEP CAM (TCEQ) and the Sta. Teresa Drum sampler sites were used for estimating subject exposures since the large majority of subjects resided closest to these as compared to Socorro or other sites.

Data Analyses

Subject PM exposures were analyzed for their associations with the exacerbation of asthma symptoms in the asthmatic study children. Data collection and construction of the exposure models were shaped by three unplanned occurrences. First, different from prior years and expectations, no major dust storm events were recorded during the April-early May 2009 study period according to the national and international definition of dust, i.e., sufficient dust aerosols that would reduce visibility under 10 kilometers (Dr. Tom Gill, UTEP Dept. of Geology, personal communication). Different from the dust storm event pattern observed during the past several decades, the first officially registered dust storm of the season occurred after the conclusion of the air and asthma data collection period, i.e., on May 28, 2009. However, detailed daily weather observations carried out by Dr. Gill during the study period indicated a number of days in which winds had sufficient force to create dust that could be observed with the naked eye (local and intermittent) despite not being strong enough to reduce visibility so as to become an official dust storm event. The second unplanned occurrence was that smoke from industrial and forest fires intruded into the El Paso area during the study period on nine days. This made it difficult to separate out the potential putative respiratory effects of exposure from PM from smoke versus dust or the possible interactive effects/burden of both dust and smoke-derived PM. The third unplanned event was that the DRUM sampler size resolved dust aerosol data were not available as planned from due to a technical malfunction with an analyzer (Dr. Tom Gill, personal communication).

Particulate Matter ($PM_{2.5}$, PM_{10})

The association of $PM_{2.5}$ or PM_{10} concentrations with indicators of asthma exacerbation were examined using UTEP CAM daily data published by the TCEQ for the 42-day study period due to the unfortunate lack of dust aerosol data from the DRUM sampler as had been planned. The published daily $PM_{2.5}$ and PM_{10} values were divided into quartiles. Fine particulate matter values falling into the upper quartile were classified as high (≥ 10 µg/m^3). The other study days were classified as low $PM_{2.5}$ days (< 10 µg/m^3). Likewise, mean coarse PM values falling into the upper quartile were designated as either high ($\geq$ 36.25 µg/m^3) or low PM_{10} days (< 36.25 µg/m^3).

Air Pollutants and Asthma Exacerbation

Subject categorical descriptive data are reported as frequencies and percent and continuous data as means $\pm$ standard deviation (S.D.). The association of subject air pollutant exposures (high vs. low) with indicators of asthma exacerbation during the 42-day study period were analyzed using contingency table analysis with X^2 or Fisher's exact test, as appropriate. *P*-values $\geq$ 0.05 were considered significant. The small sample size (24) precluded the use of stratification to examine the effects of exposure on the outcomes of sub-groups.

Chapter 4

Results

Subject Characteristics

Table 4.1 displays the sociodemographic and residence characteristics of the 24 asthmatic children who participated in the study. The average age of the children was 12 years of age (range 7-17 years), almost 60% were female, 80% were Mexican-American and over 90% had lived in the El Paso metropolitan area since birth. Ten children had furred mammal pets (dogs), cats, or guinea pigs. Fifty-four percent had a history of respiratory infections, and about three-fourths, croup and seasonal allergies.

The proportion of children who experienced any moderate-severe symptoms on one or more of the 42 study days were as follows: shortness of breath (23.8%), wheezing (21.4%), cough (40.5%), chest tightness (21.4%), chest pain (19%), night waking (11.9%), and early morning symptoms (23.8%). Only six children (11.9%) had well-controlled asthma and were symptom-free during the entire study period. Twenty-nine percent reported that asthma symptoms had imposed a moderate-severe limitation on their general activities; 31% were forced to limit their outdoor activities at school because of poor air quality and 11.9% said they had missed at least one school day due to asthma. In addition to their bronchodilators and nebulizers, subjects used a variety of both prescribed and over the counter asthma and allergy medications such as Singulair, Flovent, Loratadine, Zyrtex, Albuterol, Prednisone, Ventolin, Pulmicort, Sambutamol, Claritin, Xopenex, Tassir, Aldex, Allegra, Nasonex, and Dephenhydramine.

Ambient PM Characteristics

Mean daily $PM_{2.5}$ values obtained from the UTEP CAM during the 42-day study period ranged from 5.0 $\pm$ 1.9 $\mu g/m^3$ to 16.0 $\pm$ 9.1 $\mu g/m^3$ while those of PM_{10} ranged from 16 $\pm$ 5.6 $\mu g/m^3$ to 92 $\pm$77.2 $\mu g/m^3$. The data were examined for the $PM_{2.5}/PM_{10}$ ratio. This ratio is used as an indicator of PM sources (anthropogenic vs. geologic). The median value obtained during the 42 day study period was 0.2764. The 42 study observation days were categorized by ratio values falling into the upper quartile ($\geq$ 0.3128) indicating PM likely to have a more anthropogenic origin compared to those values in the lower three quartiles. A total of 10 days fell into the upper quartile of the $PM_{2.5}/PM_{10}$ ratio. These were April 5,13, 27-28, and May 1,3,6,9,10, and 11). The 42 observation days also were classified by lowest quartile ($\leq$ 0.2381) indicating PM likely to be of a more geologic origin was contrasted with the highest three quartiles. A total of 11 days fell into the bottom $PM_{2.5}/PM_{10}$ ratio quartile (April 1-4, 8-9, 11, 14-15, 19, and May 2).

Figures 4.3-4.7 show the graphical results of the initial XRF analyses that examined several different elements in ambient air collected that were by the DRUM sampler during April 2009. The majority of the ambient silicon concentrations were coarse (5.0-10 nm) particles [840 ng/m^3] followed by smaller particle concentrations in the 2.5-5.0 nm [455 ng/m^3] and 2.5-1.15 nm ranges [450 ng/m^3]. Sulfur and lead constituted the other major elemental components. The five days on which mean silicon particles in the 5-10 nm/m^3 range were recorded at concentrations of $\geq$ 500 nm/m^3 were classified as high coarse silicon days. Those that were in the lower concentration range were grouped as low coarse silicon days. The four days on which fine silicon (1.5-2.5 nm/m^3 range) particle mean concentrations were $\geq$ 400 ng/m^3 were categorized as high fine silicon days. Low fine silicon days were those where mean concentrations were < 400 ng/m^3. Fine sulfur particle days (0.26-0.56 ng/m^3 range) were classified as high where ambient mean concentrations were $\geq$ 80 ng/m^3 and low where they were < 80 ng/m^3**.** Days on which coarse lead particles in the 2.5-10 nm/m^3 range reached ambient concentration levels that were $\geq$ 20 ng/m^3 and < 20 ng/m^3 were respectively classified as high and low coarse lead days.

Air Pollutants and Asthma Symptom Exacerbation

Particulate Matter ($PM_{2.5}$ and PM_{10})

Table 4.2 displays the results of the analyses that compared the proportion of children who experienced asthma-related events on high versus low $PM_{2.5}$ days and other analyses that compared those on high versus low PM_{10} days. As the table indicates, on the high compared to low $PM_{2.5}$ days, there was a statistically significant increase in the proportion of the asthmatic subjects who experienced moderate-severe shortness of breath, wheezing, and chest pain. For some unknown reason, the proportion of children who administered prescription and/or non-prescription allergy and asthma medications on the low $PM_{2.5}$ days was higher than on the high $PM_{2.5}$ days.

Table 4.2 also shows that there was a statistically significant increase identified in the proportion of children reporting moderate-severe chest pain and persistent coughing during the high compared to low PM_{10} days. In addition, the number of children who experienced moderate-severe limitations in their overall daily activities and who received emergency medical treatment for their asthma was significantly increased on high compared to low PM_{10} days.

Chapter 5

Discussion and Conclusions

Asthma is a serious chronic disease of global public health importance (IUATLD, 2005). The World Health Organization (2006) estimates that the condition affects approximately 300 million people globally with annual treatment, hospitalization, and other economic costs that are in the billions of dollars. Asthma is a major disease that especially affects children with dust and other allergies (INER, 2008).

It has been reported that that finer PM ($PM_{2.5}$) is more likely to cause lower respiratory symptoms in children than coarse PM_{10} exposure such as that caused by dust (Schwartz and Neas, 2000). However, the findings of this pilot panel study suggest that higher levels of both types of outdoor PM fractions such as coarse PM, derived from predominantly geologic (dust) as well as finer PM fractions ($PM_{2.5}$) more commonly from anthropogenic sources (e.g., smoke, car emissions) are associated with increased severity of certain asthma symptoms, asthma-related limitations in daily activities, and increased emergency hospitalizations for asthma among medically diagnosed asthmatic children living in the Paso del Norte, a border region located in the northern Chihuahua Desert.

The study results are consistent with those of recent studies linking outdoor PM exposure with asthma hospitalizations (Wilson et al., 2004) and severe bronchospasms which force asthmatics to limit their daily activities (Chetty, 2009). The results also generally concur with findings from Schwartz and Neas (2000) who linked increased cough in children with coarse particle exposure. Our study results are consistent with those from extensive article reviews from different locations in the world (Wilson et al., 2004), such as in Canada, where a study was carried out in an urban setting (Montreal) which found that both $PM_{2.5}$ and PM_{10} exacerbated asthma, albeit in children of different ethnicity and much younger age (< 2 years) than those in the current study. The results are also consistent with a comprehensive review on European populations (United Kingdom, Netherlands, and Italy) that found linkage with asthma exacerbations and PM exposure (Trasande & Thurston, 2005).

Lee and associates (2006) have reported that in Hong Kong, ambient level of both PM_{10} and $PM_{2.5}$ were associated with increased childhood asthma hospital admissions. The results of a study conducted in Toronto found associations between size-fractioned PM and childhood asthma hospitalizations (Lin et al., 2002). Our results are in agreement with these findings as they identified a modest but significant increase in asthma-related emergency medical treatment on high PM_{10} exposure days. In our study, emergency medical treatment for asthma also was increased on high compared to low $PM_{2.5}$ days, but this difference did not achieve statistical significance.

Exacerbation of asthma symptoms such as coughing, wheezing, chest problems, and night wakening, limitations on normal daily activity, and emergency medical treatment were more likely made worse by the heavy smoke from a large industrial fire, other local fires, and smoke drift from other parts of Texas that affected the Paso del Norte area during the study period. The results of studies conducted in Sydney, Australia and California found that decreased air quality caused by smoke from fires was associated with a significant increase in emergency department visits for asthma (Etzel, 2003).

The possible limitations and strengths of this study should be taken into consideration when interpreting its results. For example, the sample size of this initial pilot study was small, only 24. However, repeated daily measurements over a 42-day period resulting in 1,008 observations which increased study power.

Self-reports of health events are subject to systematic error. However, the use of the daily standardized asthma diary in which parents/older children received detailed instruction on how to fill out coupled with their easy access to the study investigators for having their study questions and concerns at any hour by phone or email answered strengthened the study quality. In addition, the use of multiple unannounced phone calls to subject homes to check on the reliability of the diary data entries.

Another possible limitation was the fact different from past weather patterns, no major dust storm events were recorded during the study. This resulted in lower than expected statistical contrast in high versus low dust days, as measured by proxy PM indicators. Another possible limitation was the unexpected incursions of smoke from industrial and forest fires during nine of the 42 study days which made it more difficult to separate out the potential putative respiratory effects of exposure from PM from smoke versus dust or the possible interactive effects/burden of both dust and smoke-derived PM. We also were unable to use DRUM sampler size resolved dust aerosol data at the time of the data analyses due to a technical malfunction. Thus, we could not directly measure the fine gradations in size-and time-resolved dust aerosols as planned and were forced to use published TECQ CAM-UTEP data as our primary data source. The forced reliance on the TECQ CAMs to estimate subject exposure is another possible limitation. Although most subjects lived in the general area of the UTEP CAM sampler, some lived in Horizon City. Thus, exposure classification could have been less accurate for these subjects.

The preliminary evidence from this pilot study suggests that exposure to high dust event levels may exacerbate pediatric asthma. However, future studies are needed which employ a larger sample size and a longer observation period in order to improve statistical contrast of maximal and minimal dust aerosol periods for the data analyses especially in highly dust prone areas such as in El Paso which is situated right on the edge of the northern Chihuahua desert. This area is one of the major dust sources for much of the region. The evidence from this small study of a highly dust exposed population living on the northern edge of the Chihuahua desert when viewed in conjunction with emerging evidence from other areas of the U.S. and elsewhere, suggests that more attention should be paid to this putative environmental hazard especially in vulnerable asthmatic children.

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Glossray

Asthma-Related Definitions

Asthma- An inflammatory chronic disease of the lungs where there is swelling of the airway lining, tightening of the bronchial muscle, and increase airway mucus secretion. Cells and cellular elements play a role, such eosinophils, T lymphocytes, and cytokines (ALA, 2007; Urbina, 2001).

Asthma Exacerbation- An asthma-related emergency department visit or night of hospitalization as a result of the severity of asthma attacks (Miller et al., 2007).

Rescue Medication-*Short-term*- A quick reliever which works rapidly to stop the attacks or to relieve the symptoms (COMAAIC, 2008); *Long-term*- A prolonged action, especially in the anti-inflammatory agents, preventing the initiation of the symptoms (COMAAIC, 2008).

Particulate Matter- Fine particles that include solid and liquid particles that are suspended in the air which vary in size, composition and origin and are contain a mixture of soot, acid condensates, and sulfates and nitrate particles (Yang et al., 2005).

Air Pollution- There are two major types of air pollutants, gases and particulate matter (PM), in which harmful amounts of gases, dust, fumes, or odors are in the air and are made up of a number of components, such as acids, organic chemicals, metals, soil or dust particles, and allergens (EPA, 2006).

Table 4.1. Subject Characteristics

Characteristic	Mean + S.D. or No. (%)
Sex (% female)	14 (58.3)
Age (yrs)	11.8 + 3.0
	(range: 7-17 yrs)
Ethnicity (% Hispanic)	20 (83.3)
El Paso birthplace	22 (91.7)
Current residence	
Canutillo (79835)	2 (8.3)
Westside (79912)	2 (8.3)
Transmountain (79924)	4 (16.6)
Eastside (79925	4 (16.6)
Eastside (79936)	3 (12.5)
Northwest (79915)	2 (2.8)
Northwest (79930)	2 (2.8)
Northwest (79932)	1 (4.2)
Northeast (79904)	1 (4.2)
Downtown (79902)	1 (4.2)
Eastside (79907)	1 (4.2)
Horizon (79928)	1 (4.2)
Preferred interview language (English)	22 (83.3)
Presence of furred domestic pets in home	10 (41.7)
Health history	
Respiratory infections	13 (54.2)
Eczema	10 (41.6)
Sinus infections	11 (45.8)
Croup	20 (83.3)
Seasonal allergies or hay fever	20 (83.3)
Medication use	10 (41.6)
Symptom severity	

Cough	14 (58.3)
Wheezing	11 (45.8)
Excess mucus	11 (45.8)

Table 4.2. Association of Exposure to High PM25 or High PM10 and Indicators of Asthma Exacerbation

Indicators	High $PM_{2.5}$ (n=192 observations) No. (%)	Low $PM_{2.5}$ (n=816 observations) No. (%)	X^2	P	High PM_{10} day (n=96 observations) No. (%)	Low PM_{10} day (n=912 observations) No. (%)	X^2	P
Asthma symptoms								
• Frequent night-waking due to asthma	7 (3.6)	20 (2.5)	0.85	0.36	3 (3.1)	24 (2.6)		0.74*
• Moderate-severe asthma symptoms upon waking	8 (4.2)	26 (3.2)	0.46	0.50	5 (5.2)	28 (3.1)		0.23*
• Moderate-severe shortness of breath	15 (7.8)	36 (4.4)	3.7	0.049	11 (11.5)	40 (4.4)	9.04	0.002
• Moderate-severe chest tightness	8 (4.2)	22 (2.7)	1.2	0.28	5 (5.2)	25 (2.7)		0.20*
• Moderate-severe chest pain	8 (4.2)	15 (1.8)		0.006*	3 (3.1)	18 (2.0)		0.44*
• Moderate-severe wheezing	10 (5.2)	16 (2.0)		0.019*	6 (6.3)	20 (2.2)		0.03*
• Moderate-severe coughing	18 (9.4)	51 (6.3)	2.4	0.12	12 (12.5)	57 (6.3)	5.3	0.021
Medication Use								
• Bronchodilator use	7 (3.6)	33 (4.0)	0.6	0.80	4 (4.1)	36 (3.9)		0.78*
• Nebulizer use	20 (10.4)	92 (11.3)	0.12	0.73	10 (10.4)	101 (11.1)	0.04	0.84
• Other asthma and allergy medications	53 (27.6)	293 (35.9)	4.8	0.03	27 (28.1)	319 (35.0)	1.81	0.18
Asthma-related activity limitations								
• Moderate-severely limited activity	18 (9.4)	53 (6.5)	2.0	0.16	12 (12.5)	59 (6.5)	4.8	0.028
• Outdoor activities limited at school	18 (9.4)	77 (9.4)	0.0	0.98	12 (12.5)	83 (9.1)	1.3	0.28*
• Missed school	2 (1.0)	15 (1.8)		0.75*	1 (1.0)	16 (1.8)		1.00*
Emergency medical treatment/hospitalization for symptoms	6 (3.1)	14 (1.7)		0.24*	5 (5.2)	14 (1.5)		0.03*

* Fishers exact test, 2-tailed

PARTICIPANT RECORD
(ARCH Dust Storms & Asthma Exacerbation Study)

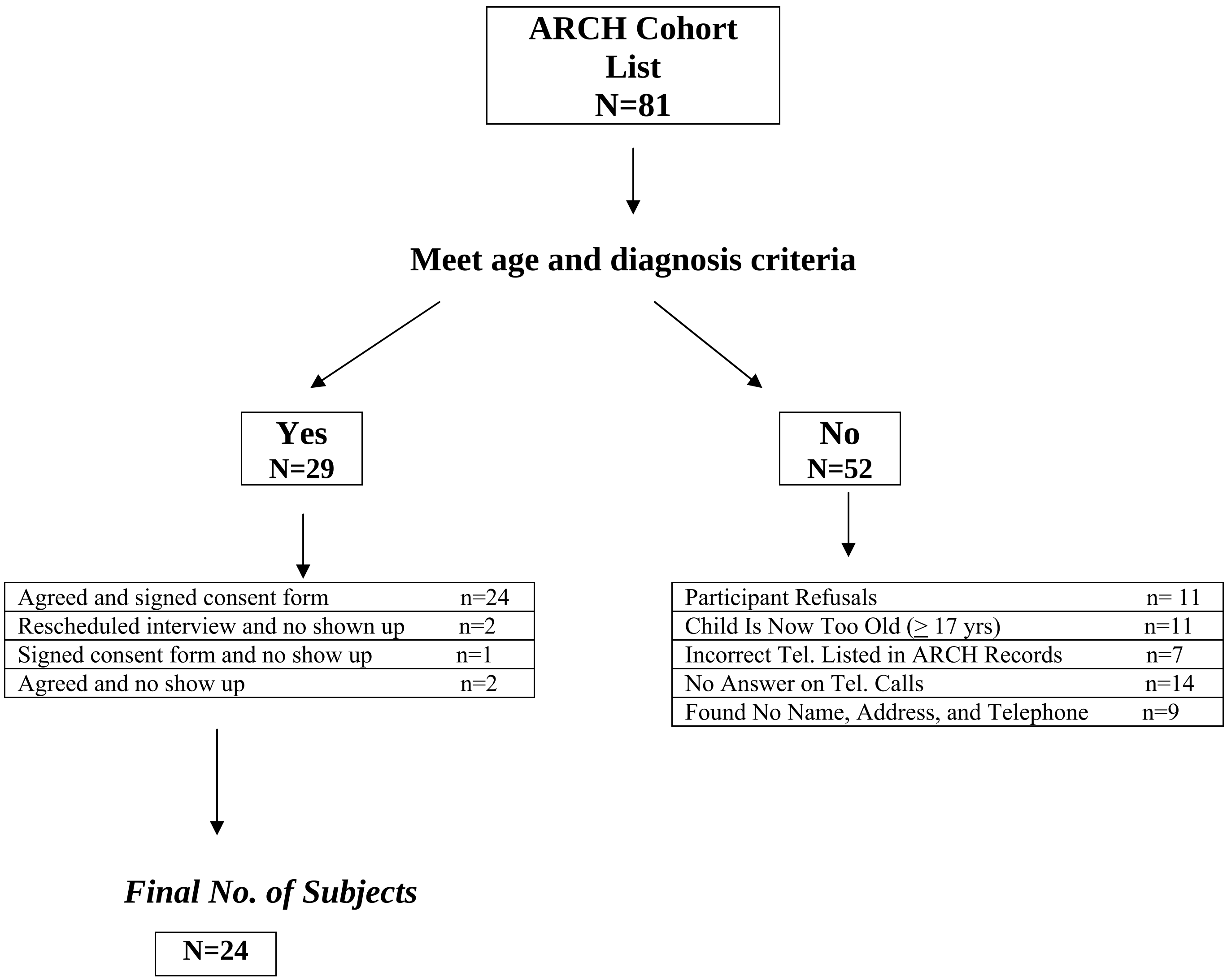
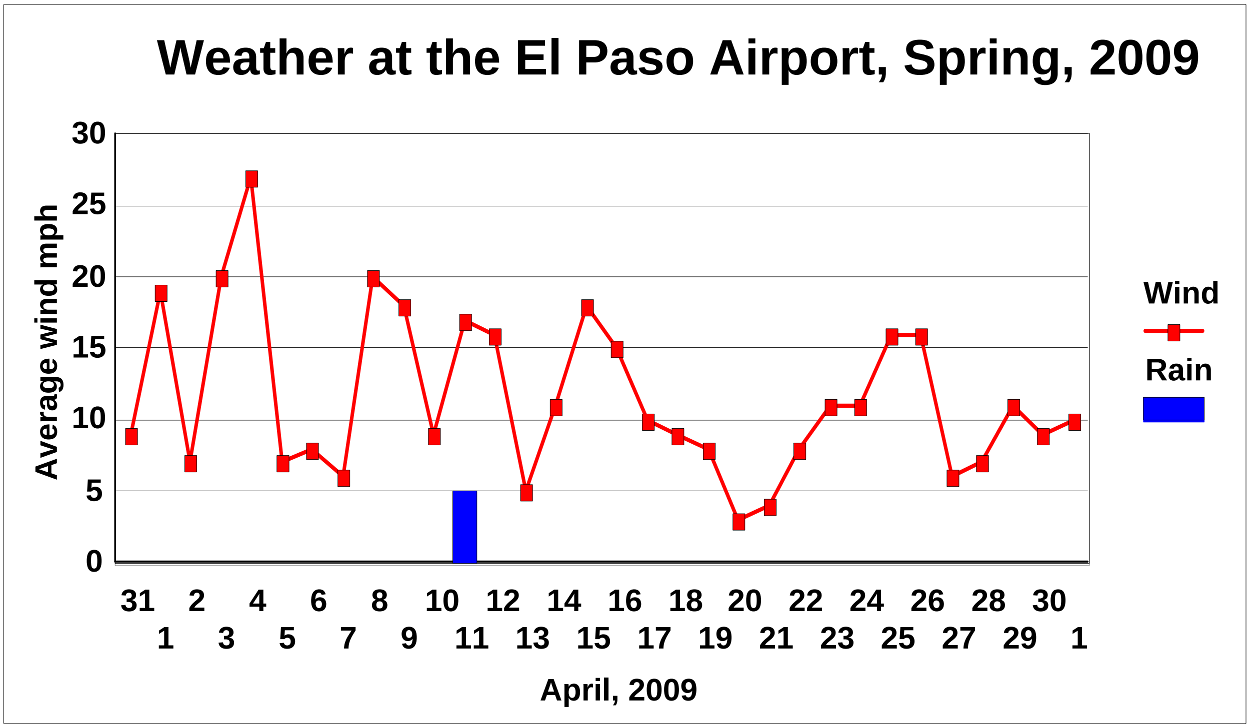


FIGURE 4.1 Participant Record



Source: Unpublished data, Drs. Kevin Perry, Tom Cahill, & Tom Gill

FIGURE 4.2 Weather at the El Paso Airport

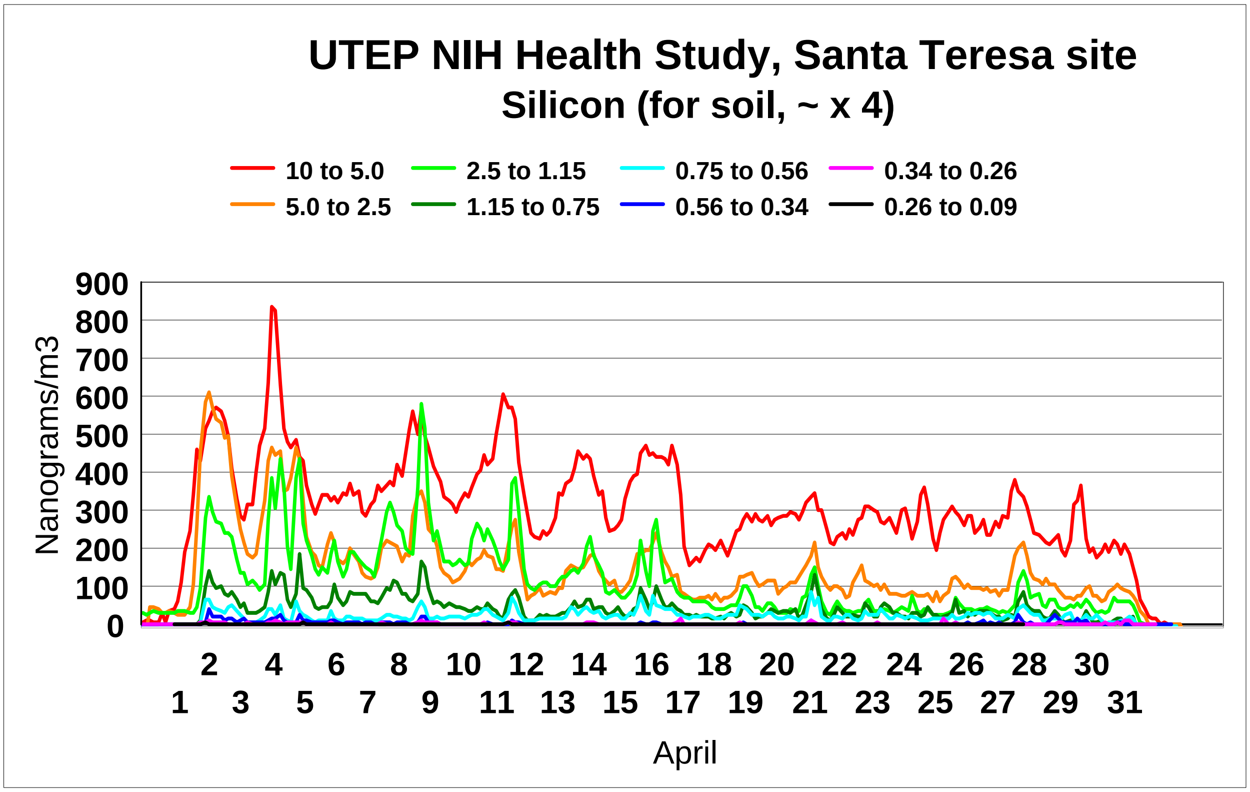


FIGURE 4.3 UTEP NIH Health Study, Santa Teresa site: Silicon

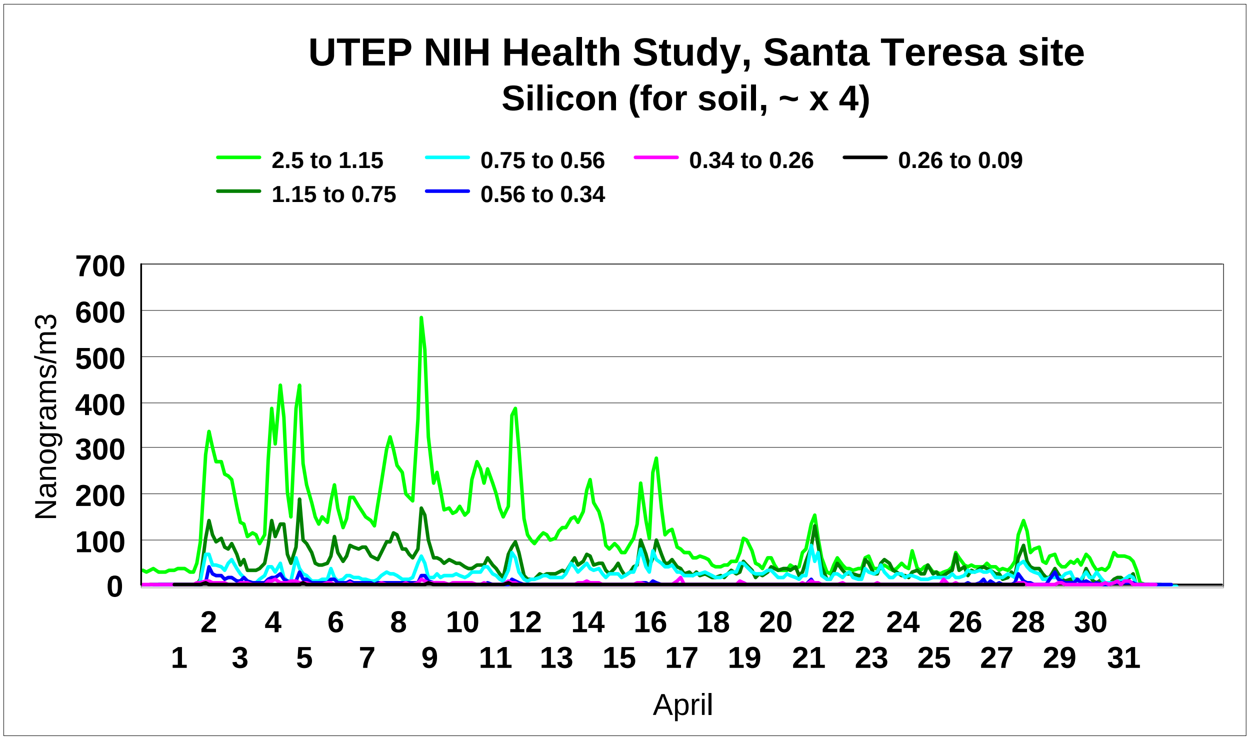


FIGURE 4.4 UTEP NIH Health Study, Santa Teresa site: Silicon

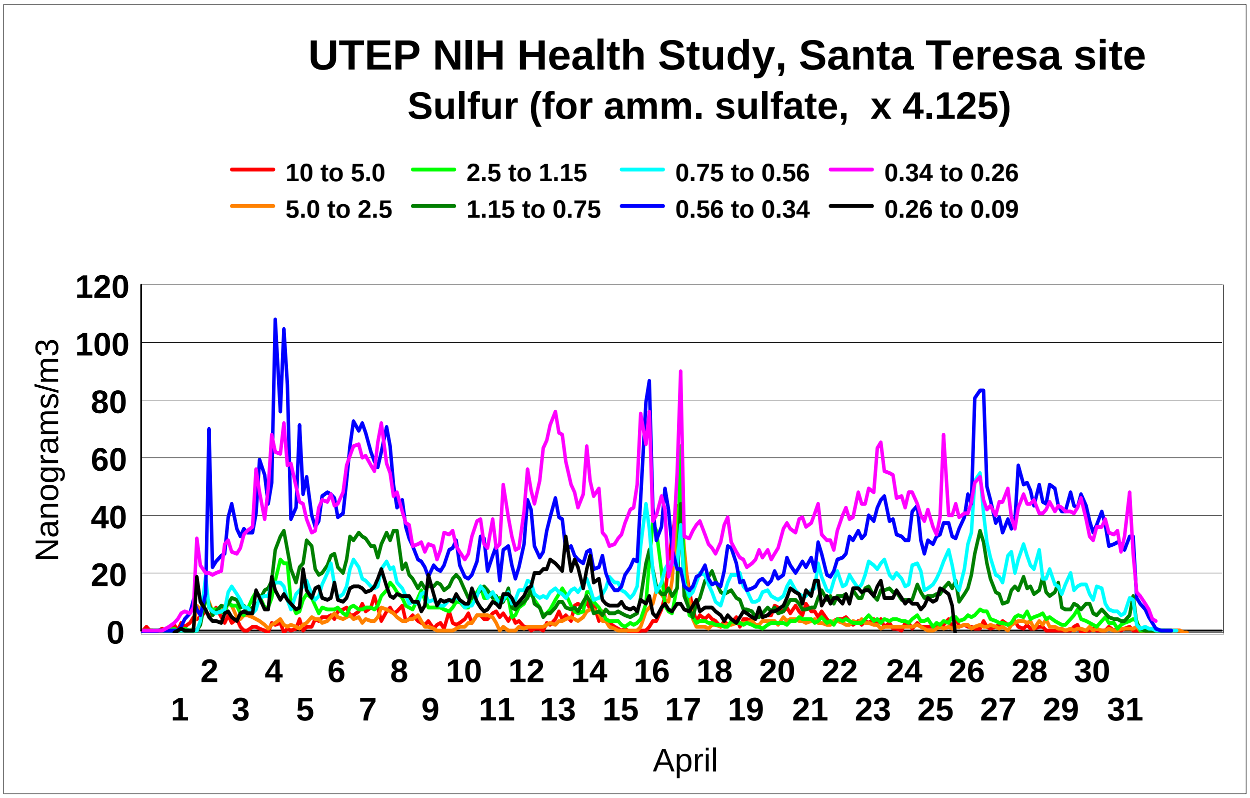


FIGURE 4.5 UTEP NIH Health Study, Santa Teresa site: Sulfur

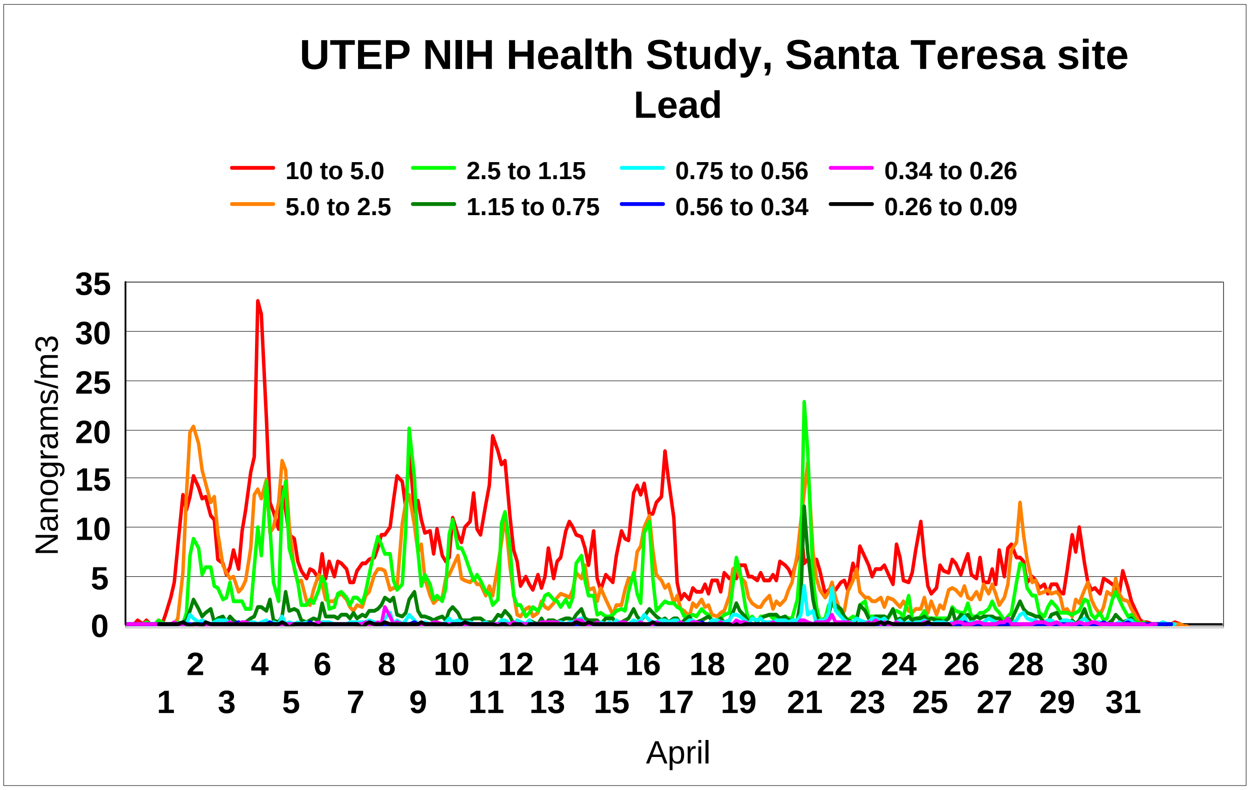


FIGURE 4.6 UTEP NIH Health Study, Santa Teresa site: Lead

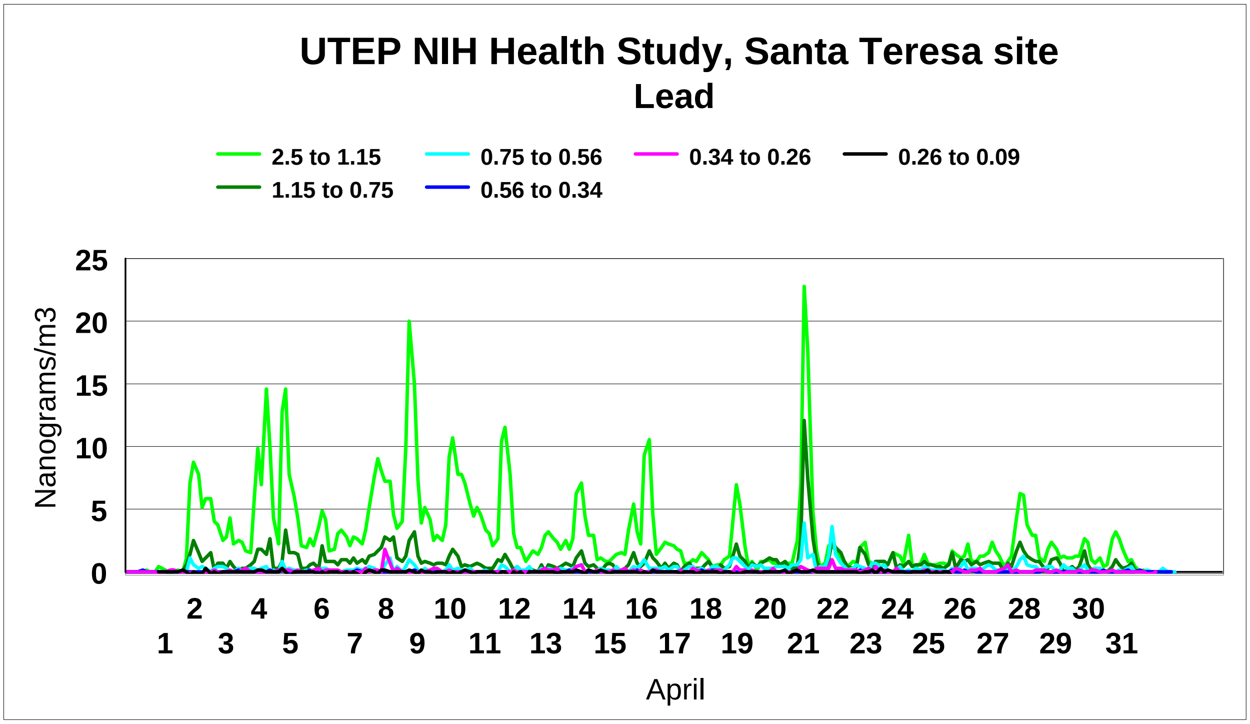


FIGURE 4.7 UTEP NIH Health Study, Santa Teresa site: Lead

Curriculum Vita

Monika Gaytan was born in El Paso, Texas. The first daughter of Dr. Carlos M. Gaytan Mazkwifelt and Diana Cardenas Heraldez, she graduated from the University of Texas at El Paso, in the Spring of 2005 obtaining a degree of Bachelor's of Science in Health Promotion with a minor in Speech-Language Pathology. After completion of her bachelor's degree, Monika worked as a speech therapist in Ciudad Juarez, Chihuahua, Mexico. She left work in order to pursue the Master of Public Health at the University of Texas at El Paso. While pursing her master's degree, she worked as a Research Assistant for the Department of Social Work and as a Teacher Assistant for the Department of Public Health Sciences.