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The effects of particulate matter on atopic dermatitis symptoms are influenced by weather type: Application of spatial synoptic classification (SSC)

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ABSTRACT

The effects of weather and air pollution on atopic dermatitis (AD) flares have not been well investigated. To investigate the effects of particulate matter (PM) on AD symptoms by weather type, a total of 125 young children (76 boys and 49 girls) under 6 years of age with AD living in Seoul, Korea, were enrolled as a panel and followed for 17 months between August 2013 and December 2014. AD symptoms were recorded on a daily basis, including itching, sleep disturbance, erythema, dry skin, oozing, and edema. Daily weather was classified into 7 categories according to spatial synoptic classification (SSC). Personal exposure to PM with an aerodynamic diameter less than 2.5 and 10 µm ($PM_{2.5}$ and PM_{10}, respectively) in each individual was estimated with time-weighted average concentrations considering outdoor and indoor levels of PMs and time to spend outdoors or indoors in a day. Generalized linear mixed models were used to analyze the effects of $PM_{2.5}$ and PM_{10} on AD symptoms, controlling for ambient temperature, humidity, age, sex, SCORAD (SCORing of AD) at enrollment, fever, day of week, and topical corticosteroid use. A total of 20,168 person-days of symptom records were collected. The presence of AD symptoms was higher on dry polar (DP) days (45.4%, $P < .0001$) than on moist tropical (MT) days (37.7%, $P < .0001$). Overall, the risk of AD symptoms significantly increased with increased exposure to $PM_{2.5}$ and PM_{10}. Among the 7 weather types, the risks of AD symptoms caused by $PM_{2.5}$ and PM_{10} exposure were significantly increased on dry moderate (DM) days, while not significant on the other weather types. In addition, lagged effect of $PM_{2.5}$ up to 4 days was found on DM days. In conclusion, dry moderate weather type, particulate matters, and their modifying effects should be simultaneously considered for proper management of AD.

1. Introduction

Air pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), and ozone (O_3) are associated with allergic disease or allergic sensitization (Ahn, 2014; Baldacci et al., 2015; Eberlein-Konig et al., 1998; Jacquemin et al., 2015; Kim et al., 2017a; Lin et al., 2002; Matsui, 2014; Penard-Morand et al., 2010). Among them, exposure to ambient PMs is a growing concern for public health, particularly in Asia due to large amount of anthropogenic emissions from East Asia including China (Saikawa et al., 2017).

Atopic dermatitis (AD) is a chronically relapsing inflammatory skin disease, commonly occurring in children. According to a population-based study using data from the 2008–2011 Korea National Health and Nutrition Examination Survey (KNHANES), 13.50% of Korean children aged 18 years or younger have been diagnosed with AD (Lee et al., 2016a). Phases One and Three of the International Study of Asthma and Allergies in Childhood revealed that AD symptom prevalence increased in 6–7 year-old and 12–13 year-old Korean children between 2000 and 2010 (Ahn, 2016; Oh et al., 2004; Park et al., 2016). This result is consistent with the observation that AD prevalence is increasing in

Abbreviations: AhR, aryl hydrocarbon receptor; AD, atopic dermatitis; AQMS, air quality monitoring system; DEP, diesel exhaust particle; DOW, day of week; DM, dry moderate; DP, dry polar; DT, dry tropical; GAMM, generalized additive mixed model; GLMM, generalized linear mixed model; IOR, indoor-to-outdoor pollutant concentration ratio; MM, moist moderate; MP, moist polar; MT, moist tropical; NO2, nitrogen dioxide; O_3, ozone; PM, particulate matter; $PM_{2.5}$, particulate matter with a diameter less than 2.5 µm; PM_{10}, particulate matter with a diameter less than 10 µm; RH, relative humidity; SCORAD, SCORing atopic dermatitis; Tr, transitional; TWA, time-weighted averages

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many developing countries (Williams et al., 2008). Although the exact pathogenesis of AD remains to be investigated, birth cohort studies have revealed that air pollutants such as tabocco smoke, PM, NO_2 or phthalate might contribute to AD development (Deng et al., 2016; Herberth et al., 2014; Hidaka et al., 2017; Jedrychowski et al., 2011; Just et al., 2012; Lu et al., 2017; Wang et al., 2013; Wang et al., 2010). Air pollutants also act as an aggravating factor in pre-existing AD. Increased exposure to PM_{10} has been strongly associated with increased AD flares (Kim et al., 2013; Kim et al., 2017a; Kim et al., 2017b). Exposure to airborne formaldehyde increased transepidermal water loss and skin pH in children with AD (Kim et al., 2016).

Climate is another environmental factor that should be considered in the management of AD. Poorly controlled eczema and AD prevalence have been associated with weather (Byremo et al., 2006; Lee et al., 2008; Silverberg et al., 2013; Suarez-Varela et al., 2008; Weiland et al., 2004). However, most prior studies have estimated the independent effects of air pollution and weather on AD and have not incorporated interactions of these variables (Vanos et al., 2013). Indeed, atmospheric chemistry is complex within urban areas, with ambient air pollutant levels modulated by meteorological factors such as humidity, temperature, wind speed, and wave radiation (Portier et al., 2010; Vanos et al., 2013). Elevated ambient temperature is associated with mortality, with ozone acting as an effect modifier of the association (Basu, 2009). Thus, both air pollution and weather should be evaluated and monitored for the treatment of AD, because avoiding aggravating factors is the basic management principle of AD (Bieber, 2008; Boguniewicz and Leung, 2013).

Spatial synoptic classification (SSC), also called air-mass-based classification, has been used to study human health outcomes, age-related effects, and air pollution variations under various synoptic weather types (Greene et al., 1999; Hanna et al., 2011; Hebbern and Cakmak, 2015; Rainham et al., 2005). The idea behind the air-mass-based approach is that human physiology responds to the whole 'umbrella of air' instead of single weather elements (Kysely et al., 2010). In this regard, the air-mass-based approach can be a useful tool for AD research, in which skin symptoms are affected by weather as well as air pollution such as PMs (Kim et al., 2017a).

This study aimed to investigate how the effects of PM exposures on AD symptoms are influenced by weather types. For this goal, we first built a panel of AD children, gathered daily AD symptoms, and then, assessed personal exposure to PMs on a daily basis. Finally, we estimated the risk of PMs on AD symptoms by SSC weather type.

2. Material and methods

2.1. Study population and AD symptoms

A total of 125 children with AD (76 boys and 49 girls under six years) living in Seoul, Korea, were enrolled as a panel. They were followed for 17 months between September 2013 and December 2014. AD diagnosis was determined according to the Hanifin and Rajka criteria (Hanifin and Rajka, 1980). The severity of AD was assessed by the SCORing Atopic Dermatitis (SCORAD) index (European Task Force on Atopic Dermatitis, 1993). Total IgE and specific IgE against common food and inhalant allergens in peripheral blood were measured using ImmunoCAP (ThermoFisher Scientific, Waltham, MA), and sensitization was defined when the level was over 0.35 kU/L. Common allergens included egg white, cow's milk, soybean, wheat, peanut, *Dermatophagoides pteronyssinus*, and *D. farinae*.

Parents or guardians were instructed to record AD symptoms on a daily basis using a symptom diary designed to easily measure AD symptom severity by describing the extent of subjective symptoms (itching and sleep disturbance) and the degree of objective signs (erythema, dryness, oozing, and edema) on a scale of 0–4. The presence of AD symptoms was defined when each subjective symptom score was 2 or greater and accompanied by at least two objective signs. All patients took a daily bath or shower and applied moisturizers frequently during the study period. Intermittent use of low potency topical corticosteroids and oral antihistamines was allowed when needed. Those who were allergic to an inhalant or food allergen avoided exposure to the offending allergens.

Written informed consent was obtained from the parent or guardian of each participating child. The study protocols were reviewed and approved by the Institutional Review Board (IRB) at Samsung Medical Center (IRB No. 2013–05–009).

2.2. Synoptic weather types

Information on the daily synoptic weather types for Seoul was accessed from the spatial synoptic classification (SSC) website (http://sheridan.geog.kent.edu/ssc.html). The SSC system is a semi-automated statistical approach designed to group daily weather conditions under one of several distinct categories (Sheridan, 2002). The SSC is determined by surface-based observations at individual monitoring stations based on air temperature, dew point temperature, sea level pressure, cloud cover, and wind velocity measurements at four equally spaced times throughout the day (0300, 0900, 1500, 2100 h). Sliding seed days are used to represent the expected and observed meteorological conditions at each location throughout the year for each weather type. Each seed day was quantified by the typical meteorological variables for the location and time of year, with ranges specified to indicate threshold values for each weather type. The weather types include dry moderate (DM), dry polar (DP), dry tropical (DT), moist moderate (MM), moist polar (MP), and moist tropical (MT), plus a transitional (Tr) category representing a shift from one weather type to another. A description of each weather type can be found in Sheridan (2002) and Rainham et al. (2005). The characteristics of each weather type was seen in Supplementary Table S1.

Air masses usually take on the characteristics of the underlying surface in their source region. On moving from its source region, an air-mass can be subject to warming, cooling, and the addition or removal of water. However, when an air-mass crosses the same area at a similar speed and time of year, its characteristics will be similar, allowing days with similar weather characteristics to be classified as the same air-mass type (Davis and Kalkstein, 1990).

2.3. Exposure assessment to particulate matters

Exposure to PMs with an aerodynamic diameter less than 2.5 and 10 µm ($PM_{2.5}$ and PM_{10}, respectively) by each individual was estimated with time-weighted average (TWA) concentrations. We estimated the TWA concentrations based on outdoor and indoor levels of PMs and time to spend each outdoor or indoor (time-activity) of each individual. The process to estimate personal exposure to $PM_{2.5}$ and PM_{10} is as below.

2.3.1. Outdoor levels of PM_{10} and $PM_{2.5}$

We obtained hourly PM_{10} and $PM_{2.5}$ data from 25 air quality monitoring system (AQMS) stations operated by the Seoul Metropolitan Government Research Institute of Public Health and Environment. We then calculated 24 h-average levels of PM_{10} and $PM_{2.5}$ for each AQMS station. Based on the administrative district where the patient resided, we matched the daily AD symptom data of each patient with the 24 h-average levels of PM_{10} and $PM_{2.5}$ to determine outdoor PM exposure.

2.3.2. Indoor/outdoor ratio (IOR)

To estimate indoor PM levels for the patients, IORs for PM_{10} and $PM_{2.5}$ were calculated based on a previous study conducted in Seoul (Lee et al., 2016b). Sixteen parents of AD children measured indoor and outdoor PM levels at their homes for 48 h. Information regarding indoor activities, housing and residents, and meteorological parameters from the Korean Meteorological Administration (KMA) were also collected as