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Article

Correlation between particulate matter concentrations and COPD hospitalization rates in Massachusetts

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SUMMARY

As air pollution becomes a greater problem in modern society, it becomes necessary to learn exactly how this pollution affects human health. Fine particulate matter ($PM_{2.5}$) is an air pollutant that has become prevalent due to emissions from factories and cars. We sought to examine the correlation between $PM_{2.5}$ concentration and hospitalization rates for chronic obstructive pulmonary disease (COPD), a widespread respiratory disease accounting for millions of deaths across the world. We hypothesized that a strong positive correlation would exist between $PM_{2.5}$ concentration and COPD hospitalization rates. In order to examine the correlation between $PM_{2.5}$ concentration and COPD hospitalization rate, we utilized Centers for Disease Control (CDC) published data regarding $PM_{2.5}$ concentrations and age-adjusted COPD hospitalization rates by county in Massachusetts. We used the CDC data to determine the strength of the correlation between $PM_{2.5}$ concentrations and COPD hospitalization rates. We found strong evidence of a positive correlation between $PM_{2.5}$ concentration and COPD hospitalization rates in Massachusetts counties when average $PM_{2.5}$ concentration was 8.50 $\mu g/m^3$; however, we found minimal evidence of correlation between the two variables when average $PM_{2.5}$ concentration was 6.4946 $\mu g/m^3$. Based on this, we concluded that the correlation between $PM_{2.5}$ concentration and COPD hospitalization rate does not exist at relatively lower $PM_{2.5}$ concentrations as there may not be enough $PM_{2.5}$ to induce a symptomatic outcome.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a group of lung diseases, including emphysema and bronchitis, that block airflow and cause difficulty breathing (1). Worldwide, COPD is the third leading cause of death, accounting for 3.23 million deaths globally in 2019 (2). COPD generally affects those above 40 years of age and is commonly known as a "smokers" disease due to it affecting a large proportion of smokers who have undergone significant lung damage throughout a lifetime of smoking (2). In the state of Massachusetts, COPD consistently ranks among the top ten causes of death (3).

Fine particulate matter ($PM_{2.5}$) is a subset of particle pollution describing inhalable airborne particles with a diameter less than 2.5 μmeters and is most commonly produced by the industrial and transportation sectors in the form of combustible particles (4). $PM_{2.5}$ has been shown to be positively correlated with daily, non-accidental mortality in humans as the Global Burden of Disease (GBD) estimates that nearly five million deaths are caused by $PM_{2.5}$ annually (5, 6). When inhaled by humans, $PM_{2.5}$ is able to accumulate in the respiratory tracts, thereby leading to difficulty breathing (7). During long exposure, $PM_{2.5}$ has been shown to increase prevalence of COPD, and COPD hospitalization rates for COVID-19 patients were positively correlated with $PM_{2.5}$ concentration (8). We wondered whether the proven effects of $PM_{2.5}$ on individuals with COPD would result in an increase in COPD hospitalization rates in areas with high $PM_{2.5}$ concentrations. To answer this question, we sought to quantify the correlation between $PM_{2.5}$ concentration and hospitalization rates of COPD in our home state of Massachusetts.

Due to the negative effect of ambient $PM_{2.5}$ on individuals with COPD, we hypothesized that a positive correlation would exist between $PM_{2.5}$ concentration and COPD hospitalization rates in Massachusetts (9). The results of our study indicate that there is a moderate positive linear relationship between particulate matter concentration and COPD hospitalization rate; however, the relationship is significantly weaker or nonexistent at lower concentrations of $PM_{2.5}$. In 2015, in order to reduce emissions in the United States, the Clean Power Plan was passed putting into effect new emissions standards for states to meet, including targets for the reduction of particulate matter concentration (10). Our data showed that after the Clean Power Plan was enacted, $PM_{2.5}$ concentrations in Massachusetts counties reduced significantly; subsequently, the correlation between $PM_{2.5}$ concentration and COPD hospitalization rate ceased to exist. These results highlight the importance of environmental policy not only on the environment but also on human health. These data show that environmental policy can improve health outcomes for patients suffering from COPD.

RESULTS

When determining if there was a positive correlation between $PM_{2.5}$ concentration and COPD hospitalization rate in Massachusetts counties from 2010 to 2019, we did not find significant evidence of a linear relationship between the two variables (**Figure 1**). The p-value of $p = 0.10 > 0.05 = \alpha$ indicated that the line of fit did not sufficiently explain variability in COPD hospitalization rates in Massachusetts counties. Surmising that the results may have been affected by the passage of the Clean Power Plan in 2015, we split the data from the decade into two portions: before the Clean Power Plan (2010 to 2014) and after the Clean Power Plan

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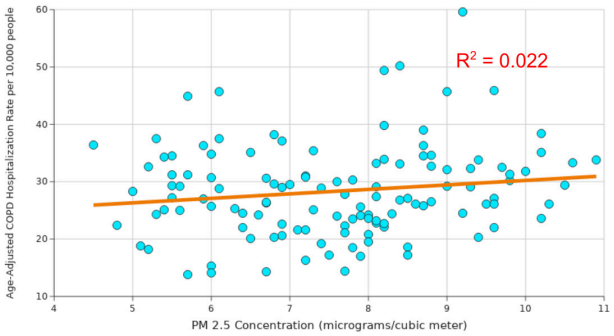

Figure 1: Correlation between $PM_{2.5}$ concentration and chronic obstructive pulmonary disease (COPD) hospitalization rate for Massachusetts counties from 2010 to 2019. COPD hospitalization rate per 10,000 people by annual average modeled PM2.5 concentration ($\mu g/m^3$) for each county for all years 2010 to 2019, n = 123. Equation of the regression line is y = 0.7818x + 22.41. Pearson's correlation coefficient r = 0.148, r^2 = 0.022. Spearman rank coefficient ρ=0.145. Hypothesis test for correlation yielded p = 0.10. Note: COPD hospitalization rates for Nantucket in 2010, 2012, and 2013 were unavailable due to confidentiality concerns.

(2016 to 2019). We found that there was a significant decrease in mean $PM_{2.5}$ concentration for Massachusetts counties in 2016 to 2019 as compared with 2010 to 2014 (**Figure 2**).

We found evidence of a positive correlation between $PM_{2.5}$ concentration and COPD hospitalization rate in Massachusetts from 2010 to 2014 where average $PM_{2.5}$ concentration was 8.50 $\mu g/m^3$ (Pearson's correlation coefficient r=0.44865, Spearman rank correlation coefficient ρ =0.53396; **Figure 3**). Pearson's r and Spearman's ρ measure the strength of linear association in bivariate data with coefficients closer to 1 indicating a stronger positive association. Both Pearson's r and Spearman's ρ for the 2010 to 2014 dataset indicate a moderately strong positive linear relationship between $PM_{2.5}$ concentration and COPD hospitalization rates for Massachusetts counties in this time frame. A two-sided hypothesis test for linear regression yielded p<0.01, which is statistically significant with $\alpha = 0.05$ indicating strong evidence of a positive linear relationship between $PM_{2.5}$ concentrations and COPD hospitalization rates for Massachusetts counties from 2010 to 2014. These findings indicate that higher $PM_{2.5}$ concentrations were correlated with higher COPD hospitalization rates for Massachusetts counties from 2010 to 2014.

From 2016 to 2019, there was a significant decrease in $PM_{2.5}$ concentration in Massachusetts counties compared to 2010 to 2014 (**Figure 2**). After this decrease, we found negligible evidence of a correlation between $PM_{2.5}$ concentration and COPD hospitalization rate. We quantified correlation for the 2019 to 2019 dataset where average $PM_{2.5}$ concentration was 6.4946 $\mu g/m^3$ as r=-0.14501, r^2=0.02103, and ρ=-0.13018 (**Figure 4**). These coefficients indicated a negligible linear relationship between $PM_{2.5}$ concentration and COPD hospitalization rate for Massachusetts counties from 2016 to 2019. A two-sided hypothesis test for linear regression yielded p = 0.29 > 0.05 = α, which is not statistically significant indicating insignificant evidence of a linear relationship between the two variables.

We utilized a simple linear regression model to fit these data as the r^2 value was highest for each dataset when using a linear model and we were unbale to observe a non-linear pattern in the data.

DISCUSSION

The evidence from the 2010 to 2014 dataset supported our hypothesis that a positive correlation exists between $PM_{2.5}$ concentration and COPD hospitalization rates. The correlation may be explained by the presence of $PM_{2.5}$ irritating the lungs, aggravating COPD symptoms, and increasing the incidence of flare-ups and potentially acute exacerbation (AECOPD) episodes. Prior research has shown that PM exposure can lead to decreased lung function and higher risk of AECOPD episodes in COPD patients (8). Because our findings from the 2010 to 2014 dataset indicate an increase in COPD hospitalization rate as $PM_{2.5}$ concentration increased, the findings from the 2010-2014 dataset support previous research into the relationship between $PM_{2.5}$ concentrations and COPD hospitalization rates (8).

Based on our data, after the Clean Power Plan was put into effect across the United States in 2015, particulate matter concentrations decreased in Massachusetts. The average $PM_{2.5}$ concentration across Massachusetts counties fell from an average of 8.50 $\mu g/m^3$ in 2010-2014 to an average of 6.4946 $\mu g/m^3$ in 2016-2019 (**Figure 2**). Cohen's d of 1.88 standard deviations indicated that this decrease was large (11). After this decrease, the correlation between $PM_{2.5}$ concentration and COPD hospitalization rates was quantified as r=-0.14501 and ρ=-0.13018 (**Figure 4**). These coefficients indicate no significant linear relationship between the two variables. Since the model did not accurately capture the expected relationship between $PM_{2.5}$ concentration and COPD hospitalization rate, we concluded that we did not have evidence of a significant linear relationship between $PM_{2.5}$ concentration and COPD hospitalization rates in Massachusetts counties from 2016 to 2019. The observed decrease in correlation between $PM_{2.5}$ and COPD hospitalization rate may have been because the Clean Power Plan's enactment also resulted in decreased

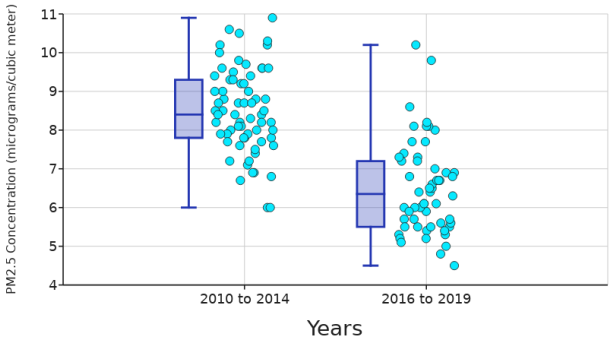

Figure 2: Change in annual $PM_{2.5}$ concentration (μg/m³) for all Massachusetts counties in years 2010 to 2014 and 2016 to 2019. Annual average modeled $PM_{2.5}$ concentration ($\mu g/m^3$) for each Massachusetts county for years 2010 to 2014 and 2016 to 2019 inclusive, n = 123. Box and whiskers plot shows the median value (line), interquartile range (box), and the extent of the data (whiskers above and below at min / max data points). Boxes showing interquartile range had no overlap. Cohen's d=1.88. Mean annual average $PM_{2.5}$ concentration of Massachusetts counties in 2016 to 2019 was 1.88 standard deviations lower than mean annual average $PM_{2.5}$ concentration of Massachusetts counties in 2010 to 2014.

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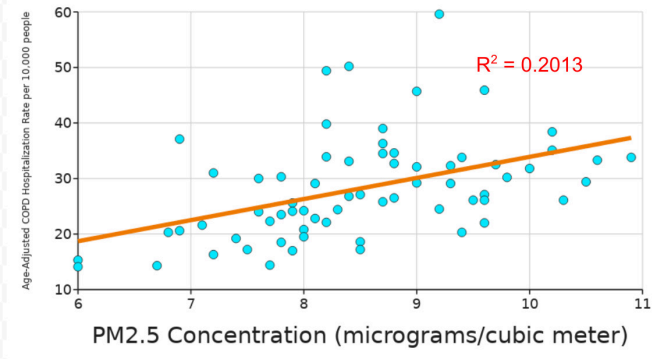

Figure 3: Correlation between $PM_{2.5}$ concentration and chronic obstructive pulmonary disease (COPD) hospitalization rate for Massachusetts counties from 2010 to 2014. COPD hospitalization rate per 10,000 people by annual average modeled $PM_{2.5}$ concentration ($\mu g/m^3$) for each county for all 5 years 2010 to 2014, n = 67. Regression line of y = 3.8x − 4.097 indicates positive correlation. Pearson's correlation coefficient r = 0.44865, r^2 = 0.2013. Spearman rank coefficient ρ=0.53396. Hypothesis test for correlation yielded p < 0.01.

levels of pollutants such as ozone (O_3) and PM_{10}, which have also been correlated with COPD hospitalizations (12). The overall decrease in concentrations of these airborne pollutants may have resulted in variables such as smoking playing a larger role in COPD hospitalizations than $PM_{2.5}$ leading to the observed decreased correlation.

Additionally, because $PM_{2.5}$ is a respiratory irritant, it is likely that a certain concentration of $PM_{2.5}$ must be reached in order for a sufficient amount of particulate matter to accumulate in the lungs of individuals suffering from COPD to induce a significant symptomatic outcome. Thus, when $PM_{2.5}$ concentrations are low enough to not pose a significant threat to individuals suffering from COPD, a correlation between particulate matter concentration and COPD hospitalization rates will not exist. Based on our study, the correlation between $PM_{2.5}$ concentration and COPD hospitalization rates is significant and positive when the average $PM_{2.5}$ concentration is at least 8.50 $\mu g/m^3$.

PM_{coarse} (particulate matter with diameter between 2.5 and 10 μmeters) is a type of particle pollution common in Massachusetts that is produced by windblown soil and industrial residue (13). Previous modeling of PM_{coarse} concentration and acute exacerbation of COPD saw an exposure-response curve that followed a non-linear pattern (14). However, we did not observe this pattern in our data, and because our dataset may not be representative of national or global trends, it is possible that a non-linear model may better describe the relationship between $PM_{2.5}$ concentrations and COPD hospitalization rates.

Predicting COPD hospitalization rates is difficult when using only $PM_{2.5}$ concentration as an explanatory variable. This is exemplified by relatively low r^2 values obtained in our simple linear regression models, all of which were less than 0.50 meaning they did not capture a majority of the variability within the response variable of COPD hospitalization rate. In addition, chronic exposure to $PM_{2.5}$ also affects lung function, meaning $PM_{2.5}$ concentration is not the only variable affecting COPD hospitalization rate. A multiple regression model that combined $PM_{2.5}$ concentration with other variables such as duration of exposure and concentration of other pollutants that contribute to air quality, such as PM_{coarse} and O_3, could make an improved model of COPD hospitalization rates.

Although there exists a positive correlation between $PM_{2.5}$ concentration and COPD hospitalization rates, $PM_{2.5}$ does not necessarily cause COPD hospitalization. Hospitalization from COPD can be influenced by various factors such as duration of pollutant exposure, smoking history, and concentration of other pollutants such as O_3 and PM_{coarse} (15). All these factors can influence the development of COPD, which can lead to hospitalization; thus, although increased $PM_{2.5}$ concentrations are correlated with higher COPD hospitalization rates, $PM_{2.5}$ does not necessarily cause COPD or COPD hospitalization.

The scope of this study may be limited by using data only from Massachusetts to examine the correlation between $PM_{2.5}$ concentration and COPD hospitalization rates. The topographical features of Massachusetts, notably its hilly landscape and coastline, contribute to pollutant dispersion and lower particulate matter concentrations (16). Additionally, demographics such as median income and population density are representative of a region's industrialization which may influence the presence of pollution (17). As Massachusetts ranks among the wealthiest states in the nation, our results may not be indicative of national trends (18). As such, a more representative survey of the entire United States may be necessary in order to confirm the results we observed. Though we used ten years' worth of data, it may be too large a jump to make generalizations outside of Massachusetts based on this study.

The data collected in this study is insufficient to determine the exact average $PM_{2.5}$ concentration below which the correlation between particulate matter concentration and COPD ceases to exist. Our data shows that this value may be below 8.50 $\mu g/m^3$; however, more data is needed in order to determine the precise range of concentrations below which we can be certain $PM_{2.5}$ concentration has no quantifiable effect on COPD hospitalization rate or whether such a critical value exists. In order to ascertain this value, either a large national or global study would be required. Additionally,

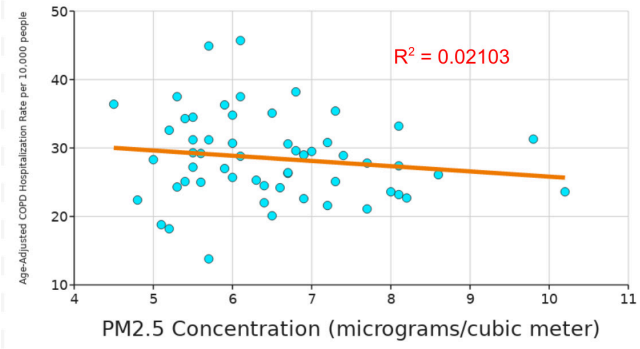

Figure 4: Correlation between $PM_{2.5}$ concentration and chronic obstructive pulmonary disease (COPD) hospitalization rate for Massachusetts counties in 2016 to 2019. COPD hospitalization rate per 10,000 people by annual average modeled $PM_{2.5}$ concentration ($\mu g/m^3$) for each county for all 4 years 2016 to 2019, n = 56. Regression line of y = −0.02753x + 7.279 indicates negative correlation. Pearson's correlation coefficient r = -0.14501, r^2 = 0.02103. Spearman correlation coefficient ρ=-0.13018. Hypothesis test for correlation yielded p = 0.29.

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in order to verify a causal relationship between $PM_{2.5}$ and COPD, supervised and approved lab testing on lung samples would need to be conducted to verify the effect of $PM_{2.5}$ on the respiratory system and determine whether $PM_{2.5}$ causes COPD. The objective of this study was to quantify a possible relationship between $PM_{2.5}$ concentration and COPD hospitalization rates as well as to investigate the efficacy of environmental policies like the Clean Power Plan on pollution and human health. We hope that our findings may serve as a catalyst to spark further investigation into the effect of particulate matter concentration on individuals with COPD and that our findings may be used to demonstrate the benefits of environmental policy.

MATERIALS AND METHODS

Data

In order to examine the correlation between $PM_{2.5}$ concentration and COPD hospitalization rates, we utilized annual modeled average $PM_{2.5}$ concentration data for each county in the state of Massachusetts. Data for all years from 2010 to 2019 was obtained from the Centers for Disease Control and Prevention (CDC) using the National Environmental Public Health Tracking Network Tool (19). The National Environmental Public Health Tracking Network Tool was used to obtain annual average monitored+modeled $PM_{2.5}$ concentration in $\mu g/m^3$ and to obtain annual average age adjusted COPD hospitalization rate per 10,000 people for each Massachusetts county from 2010 to 2019. age adjusted COPD hospitalization rate for each Due to the significant role that age plays in the effects of COPD, we opted to use age-adjusted COPD hospitalization rates rather than raw COPD hospitalization rates (20).

Statistical Analysis

To determine the existence of correlation between $PM_{2.5}$ concentration and COPD hospitalization rates, a simple linear regression test was used to obtain r and r^2 values. To obtain a coefficient robust against outliers, $PM_{2.5}$ concentrations and COPD hospitalization rates were ranked from low to high in each dataset, and a simple linear regression test was conducted to obtain Spearman rank correlation coefficient ρ. Pearson's r and Spearman's ρ differ in that Pearson's r can be affected by outlier data while Spearman's ρ is more robust to outliers as values are ranked. Cohen's d was calculated to evaluate the difference in mean $PM_{2.5}$ concentrations for Massachusetts counties from 2010 to 2014 and 2016 to 2019. Statistical values and figures were obtained with the use of Data Classroom. The data is representative of Massachusetts as data from all Massachusetts counties was used.

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