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Intervention on the impact of exposure to $PM_{2.5}$ air pollution on airway clearance of asthma sufferers through chest physiotherapy

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Abstract

Background: Exposure to $PM_{2.5}$ air pollution is a major risk factor for exacerbations and decreased lung function in asthmatics. The World Health Organization has declared air pollution a global health emergency. Fine $PM_{2.5}$ particles trigger oxidative stress, chronic inflammation, and impaired airway clearance, which exacerbate airway obstruction.
Purpose: Analyzing the effectiveness of chest physiotherapy in improving airway clearance in asthma patients exposed to $PM_{2.5}$.
Method: Using a pretest-posttest design, this study compared Peak Expiratory Flow (PEF) values in the first week as a baseline, with values recorded in the second and third weeks after chest physiotherapy intervention. The Wilcoxon test was used to analyze differences in PEF values over time.
Results: Analysis showed a significant increase in PEF values between the first and second weeks ($Z = -6.88$, $p < 0.00$) and between the first and third weeks ($Z = -7.51$, $p < 0.00$). The majority of participants showed an increase in PEF, with positive ratings of 72 in the second week and 75 in the third week, indicating improved airway clearance after the intervention.
Conclusion: Chest physiotherapy effectively improves airway clearance and ventilation function in asthma sufferers exposed to PM2.5, thus having the potential to become an applicable and sustainable non-pharmacological, environmentally based nursing intervention.

Keywords: Air Pollution; Airway Clearance; Asthma; Chest Physiotherapy.

INTRODUCTION

Air pollution has become an environmental issue with widespread impacts on human health, particularly the respiratory system (World Health Organization, 2021; Cohen, Brauer, Burnett, Anderson, Frostad, Estep, & Forouzanfar, 2017). One of the main indicators of air pollution is particulate matter (PM), which is widely used as a proxy in assessing ambient air quality (World Health Organization, 2021). PM is a complex mixture consisting of sulfate, nitrate, ammonia, sodium chloride, black carbon, mineral dust, and liquid components such as water vapor (Kim, Kabir, & Kabir, 2015).

The World Health Organization reports that a large portion of the world's population lives in areas where air pollutant concentrations exceed recommended thresholds, and long-term exposure to air pollution contributes to millions of deaths each year (World Health Organization, 2021). These facts confirm that air pollution is a global public health challenge that requires a cross-sectoral, evidence-based response (Cohen et al., 2017; World Health Organization, 2021).

Among the various fractions of particulate matter (PM), particles with a diameter of ≤2.5 micrometers ($PM_{2.5}$) are recognized as the most dangerous component for respiratory health due to their ability to

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penetrate the distal airways to reach the lung alveoli (Kelly & Fussell, 2015; Pratiwi, Taufik, Habibi, & Wibowo, 2023; Schraufnagel, Balmes, Cowl, De Matteis, Jung, Mortimer, & Wuebbles, 2019). Once deposited in lung tissue, $PM_{2.5}$ triggers the formation of reactive oxygen species which cause oxidative stress, epithelial dysfunction, and activation of chronic inflammatory responses (Kim et al., 2015). These mechanisms have implications for damage to the structure and function of the airways, including decreased ventilation capacity and impaired gas exchange (Schraufnagel et al., 2019). Chronic exposure to $PM_{2.5}$ is also associated with decreased lung function parameters such as forced expiratory volume in one second (FEV_1), increased frequency of exacerbations of respiratory tract disease, and impaired mucociliary clearance mechanisms or airway clearance (Guarnieri & Balmes, 2014; Ortega-García, López-Hernández, Cárceles-Álvarez, Fuster-Soler, Sotomayor, & Ramis, 2017).

Asthma is a chronic inflammatory disease of the airways characterized by episodic symptoms of shortness of breath, coughing, chest tightness, and wheezing (Дядюн, Волкова, Кононенко, & Тетерич, 2024). Pathophysiologically, asthma is characterized by bronchial mucosal inflammation, mucus hypersecretion, bronchoconstriction, and airflow obstruction, which are generally reversible (Holgate, 2012). In environmental conditions with poor air quality, exposure to $PM_{2.5}$ can worsen the existing inflammatory process in asthma sufferers by increasing bronchial hyperresponsiveness, mucus production, and disrupting the function of respiratory epithelial cilia (Guarnieri & Balmes, 2014; Kim et al., 2015). As a result, secretions accumulate in the lumen of the airways, which inhibits effective ventilation and worsens airway obstruction.

Impaired airway clearance in asthmatics exposed to $PM2_{2,5}$ is an important clinical issue because it is directly related to an increased risk of acute exacerbations and worsening asthma control (Ortega-García et al., 2017). Chronic inflammation and oxidative stress triggered by these fine particles accelerate the airway remodeling process, thereby increasing airflow resistance (Schraufnagel et al., 2019). This condition not only reduces the patient's quality of life, but also increases the burden on health services due to repeated visits and the need for intensive therapy (Cohen et al., 2017).

The World Health Organization recommends strict restrictions on PM2.5 concentrations to reduce the risk of morbidity and mortality from respiratory diseases, including asthma (World Health Organization, 2021). However, in many urban and industrial areas, air quality control is not yet fully optimal. Therefore, complementary interventions that are non-pharmacological, safe, and easy to apply are needed to help asthma sufferers maintain optimal respiratory function even in environments with high exposure to pollutants (World Health Organization, 2021).

One nursing intervention that has the potential to support the management of airway clearance disorders is chest physiotherapy. This technique, which includes percussion, vibration, and postural drainage, aims to mobilize secretions from the peripheral airways to the central airway for easier expectoration (McCool & Rosen, 2006). Physiologically, chest physiotherapy can increase alveolar ventilation, improve air distribution, and reduce airway resistance due to mucus accumulation (Pryor & Prasad, 2018). Although it has long been used in conditions with secretion retention, studies on the application of chest physiotherapy in asthma sufferers exposed to $PM_{2.5}$ from an environmental health perspective are still limited.

RESEARCH METHOD

This study used a quantitative approach with a quasi-experimental design using a one-group pretest–posttest design. This design is used to assess changes in a variable before and after treatment is administered to the same group, allowing researchers to directly evaluate the effectiveness of an intervention (Creswell, 2017; Polit & Beck, 2008). In this study, this design was used to evaluate changes in airway clearance conditions in asthma sufferers before and after being given chest physiotherapy intervention in the context of exposure to $PM_{2.5}$ air pollution.

The study was conducted over three weeks. In the first week, a pretest was conducted to determine the baseline airway clearance of the participants before the intervention. Subsequently, in the second and

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third weeks, the participants received structured chest physiotherapy intervention for 20 minutes over two weeks, which included percussion, vibration, and postural drainage techniques to help mobilize secretions in the respiratory tract (Pryor & Prasad, 2008; Jubair, Taufiqurrahman, & Kurniadi, 2020; Syafriningrum, 2022). After the intervention, a repeat measurement (posttest) was conducted to assess changes in the participants' airway clearance. Pre- and post-treatment measurements in this design allow researchers to identify changes resulting from the intervention (Polit & Beck, 2008).

The population in this study was all asthma sufferers in the Samarinda Community Health Center area who were exposed to $PM_{2.5}$ fine particulate air pollution and experienced impaired airway clearance. The sample consisted of 100 asthma sufferers who met the inclusion and exclusion criteria. Inclusion criteria included: patients diagnosed with asthma, aged 18 years or older, experiencing impaired airway clearance or the presence of secretions in the airways, willing to participate and sign informed consent, and able to participate in chest physiotherapy interventions during the study period. Exclusion criteria included: patients with respiratory emergencies, patients with other severe lung complications that prevented chest physiotherapy, and participants who did not complete the intervention within the three-week study period.

The measuring instruments used were the Microlife Digital PF 100/200 Peak Flow Meter (PFM) and an Air Quality Detector. The Microlife Digital PFM was used to assess Peak Expiratory Flow (PEF). PEF is an indicator that describes a patient's ability to maximally expel air from the lungs after a full inspiration. The PEF value is often used to assess the degree of airway obstruction in asthma sufferers. This device works by detecting the airflow velocity when the participants exhales forcefully through the mouthpiece. The measurement results are displayed digitally in liters per minute (L/min). An Air Quality Detector is a device that detects and measures the concentration of pollutant particles in the air, particularly $PM_{2.5}$. $PM_{2.5}$ particles are very small airborne particles that can penetrate the lower respiratory tract and alveoli, potentially worsening airway conditions in asthma sufferers. Air quality detectors work using laser or optical sensors that detect the number of particles in the air to determine the air quality index (AQI) and convert it into a particle concentration value.

This research has undergone an ethical review process and was declared suitable for implementation by the Health Research Ethics Committee of the Faculty of Medicine, Mulawarman University, with the ethical approval letter number: 225/KEPK-FK/XII/2025.

Data analysis in this study was conducted in two stages: univariate analysis and bivariate analysis. Univariate analysis was used to describe the distribution and characteristics of the study variables. The variables analyzed included participants characteristics (age, gender, and height), $PM_{2.5}$ exposure levels, and Peak Expiratory Flow (PEF) values before and after chest physiotherapy intervention.

Numerical data is presented in the form of mean, standard deviation, minimum, and maximum values, while categorical data is presented in the form of frequencies and percentages. Univariate analysis aims to provide an initial overview of the distribution of research data before further analysis is conducted (Dahlan, 2011). Bivariate analysis was used to determine the effect of chest physiotherapy intervention on changes in airway clearance in asthma patients exposed to $PM_{2.5}$ air pollution. The analysis was conducted by comparing PEF values before the intervention (pretest) and after the intervention (posttest). Before hypothesis testing, the data were first tested for normality using the Kolmogorov-Smirnov test (Dahlan, 2011; Ghasemi & Zahediasl, 2012). If the data is normally distributed, then analysis of differences in pretest and posttest scores is carried out using the Paired Sample t-test (Dahlan, 2011), However, if the data is not normally distributed, the Wilcoxon Signed Rank Test is used as a nonparametric test to assess the difference in values before and after the intervention in the same group (Field, 2024).

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RESEARCH RESULTS

Table 1. Participants Characteristics (N=100)

Variable	Results	Kolmogorov-Smirnov
Age (Mean±SD) (Range) (Year)	(55.8±11.3)(26-72)	
Gender (n/%)		
Male	62/62.0	
Female	38/38.0	
Height (Mean±SD)(Range)(Cm)	(156.7±6.1)(145-171)	
AQI (Mean±SD)(Range)(AQI)	(51.7±2.1)(45-55)	
AQI (n/%)		
Good	19/19.0	
Moderate	81/81.0	
Asthma Classification (n/%)		
Mild	1/1.0	
Moderate	74/74.0	
Severe	25/25.0	
PEF in the first week (Mean±SD)(Range)(L/min)		
PEF in the first week (n/%)	(277.9±38.1)(200-390)	
Mild asthma	1/1.0	0.000
Moderate asthma	74/74.0	
Severe asthma	25/25.0	
PEF in the Second Week (Mean±SD)(Range)(L/min)	(290.1±39.3)(200-420)	
PEF in the second week (n/%)		
Mild asthma	3/3.0	0.000
Moderate asthma	83/83.0	
Severe asthma	14/140	
PEF in the third week (Mean±SD)(Range)(L/min)	(297.7±42.0)(200-436)	
PEF in the third week (n/%)		
Mild asthma	8/8.0	0.000
Moderate asthma	85/85.0	
Severe asthma	7/7.0	
Airway clearance in the second week (n/%)		
Optimal	2/2.0	
Not optimal	98/98.0	
Airway clearance in the third week (n/%)		
Optimal	14/14.0	
Not optimal	86/86.0	

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This study involved 100 participants with fairly clear demographic characteristics: the majority were male (62%), with an average age of 55.8 years, indicating that the study population was predominantly adult to elderly. The average height of 156.7 cm indicated a relatively homogeneous physical profile, with a moderate range.

From an environmental perspective, air quality, as measured by the Air Quality Index (AQI), averaged 51.7, which is considered moderate. This is important because 81% of participants live in suboptimal air conditions, an external factor that can exacerbate asthma symptoms. Only 19% enjoy good air quality, making environmental context a significant determinant of health.

Clinically, asthma classification showed a predominance of moderate asthma (74%), with severe asthma remaining quite high (25%). Only 1% of participants were classified as having mild asthma. This figure suggests that the study population indeed comprised patients with a significant disease burden.

When lung function was measured using Peak Expiratory Flow (PEF), an interesting trend emerged. In the first week, the average PEF was 277.9 L/min, with patients still predominantly severe (25%). However, in the second week, the average increased to 290.1 L/min, and the proportion of severe patients decreased to 14%. This trend continued into the third week, with the average at 297.7 L/min, with only 7% of patients in the severe category remaining. Conversely, the proportion of patients in the mild category increased from 1% to 8%. This indicates a gradual improvement in lung function that was consistent over the three weeks. The Kolmogorov-Smirnov test indicated a non-normal distribution of the data, requiring further analysis using a non-parametric approach (Wilcoxon Signed Rank Test).

Regarding airway clearance, the results were slower. In the second week, only 2% of participants achieved optimal conditions, while 98% remained suboptimal. However, by the third week, there was an increase to 14% optimal. While this figure is still relatively small, a positive trend is still visible, indicating physiological adaptation or the effects of the intervention beginning to take effect.

Table 2. Analysis of Differences in Average Airway Clearance Before and After Chest Physiotherapy.

Variable	N	Mean Rank	Z	p-value
PEF Week One - PEF Week Two				
Negative Ranks	9	22.3	-6.883	0.000
Positive Ranks	72	43.3		
Ties	19			
PEF Week One - PEF Week Three				
Negative Ranks	6	10.9	-7.513	0.000
Positive Ranks	75	43.4		
Ties	19			

The analysis revealed a significant difference in Peak Expiratory Flow (PEF) values between the first and second weeks, and between the first and third weeks after chest physiotherapy.

Comparing the first and second weeks, 72 participants experienced an increase in PEF (positive ranks) with a mean rank of 43.3, while only 9 participants experienced a decrease (negative ranks) with a mean rank of 22.3. Nineteen participants showed no change (ties). The Wilcoxon test yielded $Z = -6.883$ with $p = 0.000$, confirming the statistical significance of the difference.

Similarly, comparing the first and third weeks, 75 participants experienced an increase in PEF (mean rank 43.4), only 6 participants experienced a decrease (mean rank 10.9), and 19 participants remained unchanged (ties). The Wilcoxon test yielded $Z = -7.513$ with $p = 0.000$, reaffirming the significant difference.

Interpretation of this data indicates that chest physiotherapy significantly improves lung function in asthma patients, as reflected in increases in PEF values. The predominance of participants with positive ratings indicates that this intervention is effective in improving expiratory capacity, thus supporting airway clearance.

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DISCUSSION

This study aims to analyze the effect of chest physiotherapy intervention on airway clearance in asthma patients exposed to $PM_{2.5}$ fine particulate air pollution. The results showed that the majority of participants were male (62%) with an average age of 55.8 years. This finding indicates that the study population is dominated by adults to elderly age groups. Physiologically, increasing age is associated with decreased lung tissue elasticity, decreased respiratory muscle strength, and increased susceptibility to airway inflammation, which can ultimately worsen chronic respiratory diseases such as asthma (Graham, Steenbruggen, Miller, Barjaktarevic, Cooper, Hall, & Thompson, 2019).

Previous research has also shown that older adults are at higher risk of experiencing decreased lung function due to a combination of biological factors and environmental exposures. Research by Elena Curto et al. showed that asthma patients aged ≥65 years had poorer lung function and higher rates of comorbidities than younger age groups (Curto et al., 2019). This condition indicates that the aging process is associated with decreased lung function and increased severity of respiratory disease. Thus, the characteristics of the participants in this study align with the theory that age is a significant factor in determining susceptibility to respiratory disorders.

From an environmental perspective, the study results showed that the average Air Quality Index (AQI) was 51.7, with the majority of participants (81%) living in moderate air quality conditions. This condition indicates exposure to air pollution that could potentially affect participants' respiratory health. According to a report from the World Health Organization, long-term exposure to fine particulate matter such as PM2.5 can increase the risk of airway inflammation, reduce lung function, and worsen asthma symptoms (World Health Organization, 2021). $PM_{2.5}$ particles are so small that they can penetrate into the lung alveoli and trigger inflammatory reactions and oxidative stress in lung tissue.

The findings of this study are also in line with a global study by Aaron J. Cohen et al. which showed that exposure to ambient air pollution is a major risk factor for chronic respiratory diseases and contributes to increased respiratory morbidity and mortality (Arcuri, Abarshi, Preston, Brine, & Pires Di Lorenzo, 2016). Furthermore, research by Paul E Pfeffer et al. also showed that exposure to air pollutants can exacerbate the inflammatory response in asthma sufferers, thereby increasing the frequency of respiratory symptoms (Pfeffer, Mudway, & Grigg, 2021). Thus, the environmental conditions of the participants in this study could be an external factor that worsens the clinical condition of asthma.

Clinically, the majority of participants in this study were classified as having moderate asthma (74%) and severe asthma (25%), while only 1% were classified as having mild asthma. This finding indicates that the study population had a relatively high level of disease severity. According to the asthma severity classification concept proposed by the Global Initiative for Asthma, asthma severity is related to the level of chronic inflammation in the airways, which causes bronchial narrowing and increased mucus production. This condition can ultimately inhibit the pulmonary ventilation process and reduce expiratory capacity.

Peak Expiratory Flow (PEF) lung function measurements showed a gradual increase over the three weeks of the study. The average PEF value increased from 277.9 L/min in the first week to 290.1 L/min in the second week and 297.7 L/min in the third week. Furthermore, the proportion of patients with severe asthma decreased from 25% to 7%, while the proportion with mild asthma increased from 1% to 8%. This increase indicates improved lung function following chest physiotherapy intervention.

Physiologically, an increase in PEF reflects reduced airway resistance and an increased lung capacity to maximally expel air during expiration (Graham et al., 2019). Research by Cr et al. shows that chest physiotherapy techniques such as percussion, vibration, and postural drainage can improve pulmonary ventilation and help mobilize secretions in the airways (Frownfelter, Dean, Stout, Kruger, & Anthony, 2022). Thus, the increase in PEF values in this study indicates that chest physiotherapy interventions contribute to improving pulmonary ventilation function.

The results of statistical analysis using the Wilcoxon Signed Rank Test showed a significant difference between PEF values before and after chest physiotherapy intervention. In the comparison of the

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first week with the second week, the Z value was obtained = -6.883 with p = 0.000, while in the comparison of the first week with the third week, the Z value was obtained = -7.513 with p = 0.000. The dominance of participants with positive ranks indicates that most participants experienced an increase in PEF values after the intervention was carried out.

These results are in line with research, which states that airway clearance techniques through chest physiotherapy can increase secretion mobilization and improve pulmonary ventilation function in patients with chronic respiratory disorders (Milibari, 2018).

However, the study results showed that improvements in airway clearance occurred more slowly than increases in PEF values. In the second week, only 2% of participants achieved optimal airway clearance, while 98% remained suboptimal. In the third week, this increased to 14% of participants with optimal airway clearance. While the increase was not significant, this trend still indicates gradual improvement.

According to the theory of respiratory physiotherapy put forward by Donna L. Frownfelter and Elizabeth Dean, chest physiotherapy techniques work by mobilizing secretions from the peripheral airways to the larger airways so that they can be expelled through effective coughing (Frownfelter et al., 2022). This process doesn't happen instantly, but rather requires several repeated therapy sessions to optimally mobilize secretions. The optimal effects of airway clearance therapy will be seen after routine intervention over several therapy sessions, as the process of mobilizing and eliminating secretions occurs gradually.

Based on the overall research results, it can be concluded that chest physiotherapy intervention has a positive impact on improving lung function in asthma patients exposed to PM2.5 air pollution. A significant increase in PEF values indicates improved pulmonary ventilation, while a gradual increase in airway clearance indicates physiological adaptation to the respiratory therapy.

Thus, chest physiotherapy can be an effective non-pharmacological intervention to help improve lung function and airway clearance in asthma patients, especially in populations living in environments with poor air quality. Researchers believe this intervention has the potential to be developed as part of a community-based asthma management program to improve the quality of life for patients with chronic respiratory disease.

This study has several limitations that should be considered. First, the study used a quasi-experimental design without a control group, so the possibility of external factors influencing the results cannot be completely eliminated. Second, the relatively short duration of the study, three weeks, may not have been sufficient to demonstrate the maximum effect of chest physiotherapy intervention on improving airway clearance. Third, this study only used one indicator of lung function, Peak Expiratory Flow (PEF), so it does not fully describe pulmonary ventilation function.

The results of this study provide important implications for nursing practice, particularly in the management of patients with chronic respiratory diseases. Chest physiotherapy can be used as a non-pharmacological nursing intervention to help improve lung function and airway clearance in asthma patients. Nurses play a crucial role in educating patients about chest physiotherapy techniques, such as percussion, vibration, and postural drainage, so that patients can perform the exercises independently as part of their asthma symptom management efforts.

Furthermore, nurses need to consider environmental factors, including exposure to air pollution such as $PM_{2.5}$, which can worsen patients' respiratory conditions. Education about the importance of maintaining air quality in the living environment and the use of protective equipment such as masks can help mitigate the negative impact of air pollution on patients' respiratory health.

CONCLUSION

This study shows that chest physiotherapy improves lung function and airway clearance in asthma patients exposed to $PM_{2.5}$. Peak expiratory flow (PEF) values increased from 277.9 L/min in the first week to 297.7 L/min in the third week, with a decrease in the proportion of severe asthma from 25% to 7%. The Wilcoxon signed rank test results showed a significant difference ($p < 0.05$), indicating that chest physiotherapy can be a non-pharmacological intervention that supports asthma management.

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SUGGESTIONS

Healthcare workers, particularly nurses, are advised to integrate chest physiotherapy as part of nursing interventions for asthma patients to help improve lung function and airway clearance. Patients and their families are advised to perform chest physiotherapy exercises regularly according to healthcare provider guidelines to help reduce respiratory symptoms and improve quality of life.

Future researchers are advised to conduct experimental studies involving a control group and a longer intervention period to obtain a more comprehensive picture of the effectiveness of chest physiotherapy on airway clearance in asthma patients.

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