

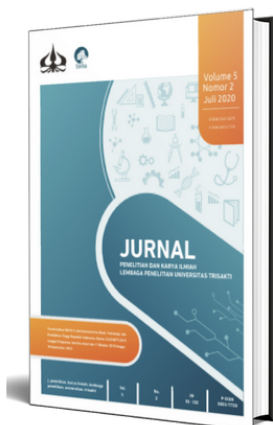


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THE IMPACT OF AIR POLLUTION ON CARDIOVASCULAR PROBLEMS

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ABSTRACT

Introduction: Air pollution is a significant environmental issue with adverse effects on public health. Numerous studies have investigated the association between air pollution exposure and the development of cardiovascular diseases (CVD). **The purpose of study:** This literature review aims to provide an overview of recent studies, focusing on key findings, mechanisms, and potential interventions related to air pollution and CVD. **Methods:** A thorough search for articles published between 2015 and 2024 was done in PubMed, Web of Science, and Google Scholar. **Epidemiological studies, experimental investigations, and earlier evaluations that look at the connection between air pollution and cardiovascular disorders were given priority in the study.** **Result study:** Research indicated that exposure to air pollution, namely fine particulate matter (PM_{2.5}) and gaseous pollutants, raised the risk of cardiovascular disease (CVD), which includes heart failure, hypertension, stroke, and coronary artery disease. **The mechanisms included oxidative stress, inflammation, and endothelial dysfunction.** **Conclusion:** To mitigate the global health risks associated with air pollution, improving air quality, implementing policy changes, and promoting public health campaigns are essential.

ABSTRAK

Pendahuluan: Polusi udara adalah masalah lingkungan signifikan yang berdampak negatif pada kesehatan masyarakat. Banyak penelitian telah mengkaji hubungan antara paparan polusi udara dan perkembangan penyakit kardiovaskular (CVD). **Tujuan penelitian:** Tinjauan literatur ini bertujuan memberikan gambaran tentang penelitian terbaru, dengan menyoroti temuan utama, mekanisme, dan potensi intervensi terkait polusi udara dan CVD. **Metode:** Pencarian literatur dilakukan secara komprehensif menggunakan Google Scholar, Web of Science, dan PubMed, dengan fokus pada artikel yang diterbitkan antara tahun 2015 hingga 2024. Tinjauan ini memprioritaskan studi epidemiologis, penelitian eksperimental, dan tinjauan sistematis sebelumnya yang membahas hubungan antara polusi udara dan penyakit kardiovaskular. **Hasil penelitian:** Bukti menunjukkan bahwa paparan polusi udara, terutama partikulat halus (PM_{2.5}) dan polutan gas, meningkatkan risiko CVD, termasuk gagal jantung, hipertensi, stroke, dan penyakit arteri koroner. **Mekanisme yang terlibat meliputi disfungsi endotel, peradangan, dan stres oksidatif.** **Kesimpulan:** Untuk mengurangi risiko kesehatan global terkait polusi udara, penting untuk meningkatkan kualitas udara, menerapkan perubahan kebijakan, dan menggalakkan kampanye kesehatan masyarakat.

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INTRODUCTION

Global public health is seriously threatened by air pollution, a widespread environmental problem. The primary cause of death worldwide is cardiovascular disease (CVD), and there is mounting evidence that exposure to air pollution may have a role in the onset, progression, and aggravation of CVD. By highlighting the underlying mechanisms and investigating prospective preventive and mitigation techniques, this literature review seeks to present an updated picture of the link between air pollution and cardiovascular health (Bhatnagar, 2022; Hu et al., 2023; Manisalidis et al., 2020; Shetty et al., 2023; Xu et al., 2022).

Several studies have shown a considerable correlation between different cardiovascular diseases and air pollution. Particulate matter (PM), ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and carbon monoxide (CO) are important pollutants of concern. (Shetty et al., 2023; US EPA, 2019; US Environmental Protection Agency, 2016). These pollutants originate from a variety of sources, including burning fossil fuels, car emissions, industrial operations, and natural occurrences like volcanic eruptions and wildfires (Bhatnagar, 2022; Hu et al., 2023; Manisalidis et al., 2020; Shetty et al., 2023; Xu et al., 2022). Each pollutant has distinct pathways that can harm cardiovascular health, including oxidative stress, systemic inflammation, and endothelial dysfunction.

1. METHODS

A thorough search of the peer-reviewed literature was carried out with the aid of databases including Google Scholar, Web of Science, and PubMed. Articles published between 2015 and 2024 were primarily focused on reviews, experimental studies, and epidemiological investigations that looked at the connection between air pollution and cardiovascular diseases.

Ethical Considerations

Ethical approval was not required since this study is a literature review and does not involve primary data collection.

2. RESULTS AND DISCUSSION

Epidemiological Evidence:

Numerous epidemiological studies have consistently demonstrated a substantial link between exposure to air pollution and a higher risk of cardiovascular diseases. Particular emphasis has been paid to fine particulate matter (PM_{2.5}), a prevalent air contaminant. An increased risk of heart attacks, strokes, hypertension, and heart failure has been linked to persistently elevated PM_{2.5} levels. Other pollutants including NO₂, SO₂, O₃, and CO can also have negative effects on the cardiovascular system (Bhatnagar, 2022; de Bont et al., 2022; Manisalidis et al., 2020; Shetty et al., 2023; US EPA, 2016; Xu et al., 2022).

In recent years, there has been a lot of research on the relationship between ambient air pollution and cardiovascular illnesses (CVDs) (Bhatnagar, 2022; de Bont et al., 2022; Manisalidis et al., 2020; Shetty et al., 2023; Xu et al., 2022). The epidemiological information currently known linking ambient

air pollution and CVDs. De Bont evaluated the quality of the evidence and assessed its strength. Mortality from all causes of CVD, morbidity, and stroke (22 studies) were the most frequently studied outcomes among the 56 reviews that were taken into consideration (de Bont et al., 2022; Jaganathan et al., 2019). Higher levels of short- and long-term exposure to ambient air pollution have been linked to the highest rates of blood pressure, stroke, ischemic heart disease (IHD), and all-cause cardiovascular disease (CVD) mortality and morbidity (Basith et al., 2022; de Bont et al., 2022; Jaganathan et al., 2019; Xu et al., 2022). Short-term exposure to nitrogen oxides (NO_x), particulate matter <2.5 µm (PM_{2.5}), and <10 µm (PM₁₀) has often been linked to an elevated risk of hypertension, myocardial infarction (MI), and stroke (both fatal and nonfatal) (Basith et al., 2022; de Bont et al., 2022; Xu et al., 2022). The main risks linked to long-term exposure to PM_{2.5} are atherosclerosis, MI events, hypertension, stroke events, and stroke deaths. Although a few studies examined other CVD-related outcomes, such as heart failure, arrhythmias, or atrial fibrillation, they primarily found positive statistical associations (Basith et al., 2022; Bhatnagar, 2022; de Bont et al., 2022; Jaganathan et al., 2019; Manisalidis et al., 2020; Xu et al., 2022).

Pollution exposure causes a variety of illnesses and deaths. Over 60% of cases are caused by cardiovascular illness. These are the primary causes of death and disability. Compared to metabolic, behavioral, and tobacco-related risk factors, environmental factors account for a greater proportion of mortality from cardiovascular disease. The risk of cardiovascular disease is increased by airborne particulate matter scattered throughout the environment, depending on its size (Shetty et al., 2023; Rajagopalan et al., 2018). Nitrogen oxide (NO₂), elemental carbon, PM_{2.5}, PM₁₀, blood pressure fluctuations, and heart attacks have all been linked to these diseases (Shetty et al., 2023; de Bont et al., 2022).

Mechanisms of Action:

The pathophysiological mechanisms through which air pollution contributes to cardiovascular diseases are multifaceted. The central pathways include endothelial dysfunction, oxidative stress, inflammation, and dysregulation of the autonomic nervous system. The development and progression of CVD are facilitated by PM_{2.5} and gaseous pollutants, which can cause systemic inflammation, disturb cardiac rhythm, decrease vascular function, and encourage atherosclerosis (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020; Shetty et al., 2023).

An increased risk of cardiovascular diseases (CVD) is associated with air pollution through a number of complex pathophysiological pathways. Although the precise mechanisms are still unclear, a great deal of research has found numerous important mechanisms that connect exposure to air pollution to CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020; Shetty et al., 2023). These mechanisms include:

Inflammation: The body may experience inflammation as a result of air pollution, especially fine particulate matter (PM_{2.5}) and specific gases like ozone (O₃). One of the main risk factors for CVD is atherosclerosis, or the accumulation of plaque in arteries, which can be exacerbated by this inflammation and impact blood vessels (Basith et al., 2022; Miller et al., 2020; Rajagopalan et al., 2018; Shetty et al., 2023).

Oxidative Stress: Pollution of the air can cause oxidative stress on the body. Oxidative stress can result from an imbalance between the body's ability to remove harmful reactive oxygen species (ROS) and the production of these ROS. This oxidative stress has the potential to harm blood vessel walls, increase inflammation, and hasten the onset of CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020; Shetty et al., 2023).

Endothelial Dysfunction: The endothelium, or inner lining of blood vessels, may malfunction as a result of exposure to air pollution. Because endothelial dysfunction can result in blood vessel constriction, elevated blood pressure, and decreased blood flow, it is an important early event in the development of atherosclerosis (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Autonomic Nervous System Imbalance: The autonomic nervous system, which controls blood pressure and heart rate, can be impacted by air pollution. Changes in this system brought on by pollution may raise the risk of arrhythmias (abnormal cardiac rhythms) and other consequences associated with CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Blood Coagulation and Thrombosis: There is a correlation between increased blood coagulation and the development of thrombosis with exposure to air pollution. Due to thrombosis, or the formation of clots within blood arteries, this may raise the risk of heart attacks and strokes (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Blood Pressure Elevation: Air pollution, particularly PM_{2.5}, has been associated with acute and chronic increases in blood pressure. This elevation in blood pressure can strain the cardiovascular system and increase the risk of hypertension, a major risk factor for CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Accelerated Atherosclerosis: Long-term exposure to air pollution may accelerate the atherosclerosis process, which narrows the arteries and increases the risk of heart attacks and strokes (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Impaired Cardiac Function: Air pollution exposure has been shown to impair cardiac function by affecting heart rate variability and promoting cardiac arrhythmias. These effects can increase the risk of sudden cardiac events (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Systemic Effects: The body as a whole is affected by air pollution, not just the respiratory system. This involves the release of chemicals that can affect the cardiovascular system, such as pro-inflammatory cytokines (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

It's crucial to remember that the precise mechanisms may change based on the kind and makeup of air pollutants, a person's vulnerability, and the length and severity of exposure (Bhatnagar et al., 2022; Laumbach et al., 2015; Manisalidis et al., 2020). The risk of cardiovascular illnesses can also be raised by the combined effects of several contaminants and additional risk factors, such as nutrition and smoking. To lessen these detrimental cardiovascular consequences, reducing exposure to air pollution and addressing its sources is still a crucial public health objective (Bhatnagar, 2022; Laumbach et al., 2015; Manisalidis et al., 2020).

Effects on Cardiovascular Diseases:

All-cause CVD mortality and morbidity. Long-term exposure to air pollution, including fine particulate matter (PM_{2.5}) and ground-level ozone (O₃), is associated with heart-related death. This group of fatalities includes heart attacks, heart failure, strokes, and other cardiovascular conditions. Among the variables at work are oxidative stress, inflammation, and the worsening of underlying cardiovascular diseases. (Atkinson et al., 2015; Chen et al., 2020; de Bont et al., 2022; Fajersztajn et al., 2017; Jaganathan et al., 2019).

Air pollution not only increases the risk of death from cardiovascular disease but also increases rates of morbidity. The risk of non-fatal cardiovascular events, such as angina (chest discomfort), heart attacks, strokes, and hospitalizations related to heart problems, is increased by high exposure to air pollution (Atkinson et al., 2015; Chen et al., 2020; de Bont et al., 2022; Fajersztajn et al., 2017; Jaganathan et al., 2019).

Ischemic heart disease and myocardial infarction. Exposure to air pollutants, particularly fine particulate matter (PM_{2.5}) and ground-level ozone (O₃), can cause oxidative stress and inflammation in the body. A heart attack may result from the formation and rupture of arterial plaques as a result of this (Akintoye et al., 2016; Atkinson et al., 2015; Chen et al., 2020; Fajersztajn et al., 2017; Pranata et al., 2020; Zhang et al., 2020).

People who currently have heart conditions like coronary artery disease or congestive heart failure are more likely to see their symptoms deteriorate when exposed to air pollution. Pollutants can strain the heart by reducing the oxygen supply and increasing the workload (Atkinson et al., 2015; Chen et al., 2020; de Bont et al., 2022; Fajersztajn et al., 2017; Pranata et al., 2020; Zhang et al., 2020).

Atherosclerosis and arterial stiffness. Atherosclerosis is the narrowing and hardening of arteries due to the accumulation of plaque, consisting of cholesterol, fat, calcium, and inflammatory cells. This narrowing reduces blood flow and can lead to the formation of blood clots (Akintoye et al., 2016; de Bont et al., 2022; Liu et al., 2017).

Long-term exposure to air pollution, particularly fine particulate matter (PM_{2.5}), might hasten atherosclerosis. The endothelium, the lining that surrounds blood vessels, can be harmed by pollutants, and they can also encourage the buildup of fatty deposits, which reduces the artery's flexibility and increases its susceptibility to blockages (Akintoye et al., 2016; de Bont et al., 2022; Liu et al., 2017).

Blood pressure and hypertension. One of the main risk factors for ischemic heart disease is elevated blood pressure, or hypertension, which is linked to exposure to air pollution. Because hypertension puts more strain on the heart, it makes heart disease more likely to occur (de Bont et al., 2022).

Heart failure. The development and aggravation of heart failure, a chronic cardiovascular disease in which the heart's capacity to pump blood effectively is compromised, can be attributed to air pollution. (Pranata et al., 2020). Here's how air pollution is linked to heart failure:

1. **Inflammation and Oxidative Stress:** Air pollution, particularly ozone (O₃) and fine particulate matter (PM_{2.5}), can cause the body to experience oxidative stress and inflammation. Systemic inflammation brought on by these reactions can have an impact on blood vessels and the heart. Oxidative stress and persistent inflammation can harm the heart muscle and hasten the onset of heart failure.

2. **Worsening of Pre-existing Conditions:** Individuals with existing cardiovascular conditions, such as coronary artery disease and hypertension, are at an increased risk of heart failure when exposed to air pollution. Air pollution can exacerbate these conditions, leading to further damage to the heart muscle over time.
3. **Reduced Oxygen Supply:** High levels of air pollution, including PM2.5, can reduce the oxygen-carrying capacity of the blood. This means that the heart must work harder to provide sufficient oxygen to the body's tissues, including the heart muscle itself. The increased workload on the heart can lead to hypertrophy (enlargement) of the heart chambers and, eventually, heart failure.
4. **Elevated Blood Pressure:** Air pollution is associated with elevated blood pressure (hypertension). Hypertension can increase the workload on the heart and lead to left ventricular hypertrophy (thickening of the heart's left ventricle). Over time, this can impair the heart's ability to pump effectively and contribute to heart failure.
5. **Impaired Endothelial Function:** The function of the endothelial cells lining blood arteries can be hampered by air pollution. Blood artery constriction and decreased blood flow to the heart muscle can result from this endothelial dysfunction. Heart failure may be exacerbated by persistently compromised endothelial function.
6. **Arrhythmias:** Air pollution can cause arrhythmias, or abnormal cardiac rhythms, by interfering with the heart's electrical transmission. Arrhythmias can raise the risk of heart failure and decrease the heart's ability to pump blood efficiently.

Arrhythmias, atrial fibrillation, and cardiac arrest. Air pollution can contribute to the development of arrhythmias, including atrial fibrillation, and may increase the risk of cardiac arrest through various mechanisms (Pranata et al., 2020; Sangkharat et al., 2019; Shao et al., 2016; Yue et al., 2022; Zhao et al., 2017).

Regarding atrial fibrillation specifically, studies have shown an association between air pollution exposure and an increased risk of developing atrial fibrillation. The widespread arrhythmia known as atrial fibrillation is typified by fast and erratic heartbeats in the atria, or upper chambers of the heart. The processes that connect air pollution to atrial fibrillation are probably complex and could involve endothelial dysfunction, oxidative stress, inflammation, and dysregulation of the autonomic nervous system (Pranata et al., 2020; Sangkharat et al., 2019; Shao et al., 2016; Yue et al., 2022; Zhao et al., 2017).

In the case of cardiac arrest, while air pollution itself is not a direct cause, the increased risk of arrhythmias induced by air pollution can contribute to the occurrence of cardiac arrest, especially in individuals with pre-existing heart conditions. Cardiac arrest occurs when the heart's electrical activity becomes chaotic, leading to a sudden loss of effective blood circulation. Air pollution's impact on the heart's electrical system can play a role in triggering these life-threatening events mechanisms (Pranata et al., 2020; Sangkharat et al., 2019; Shao et al., 2016; Yue et al., 2022; Zhao et al., 2017).

Exacerbation of Pre-existing Cardiovascular Conditions. Cardiovascular diseases can get worse due to air pollution. The negative consequences of air pollution are more likely to affect people who have heart disease, hypertension, or other cardiovascular disease risk factors. It may intensify heart failure symptoms or cause heart attacks (de Bont et al., 2022; Konduracka et al., 2022).

Reduced Exercise Tolerance. Air pollution can reduce an individual's exercise capacity and tolerance. This can discourage physical activity, which is essential for cardiovascular health (Del Buono et al., 2019; Hahad et al., 2021; You et al., 2022).

Reduced Life Expectancy. Life expectancy can be lowered by prolonged exposure to air pollution, and cardiovascular illnesses are partly to blame for this decrease (Lelieveld et al., 2020; Miller et al., 2020; Public Health England, 2018).

Vulnerable Populations:

Certain populations, such as the elderly, children, and individuals with preexisting cardiovascular conditions, are disproportionately susceptible to the adverse effects of air pollution. These groups are at heightened risk of experiencing severe cardiovascular outcomes when exposed to polluted air (Manisalidis et al., 2020; United States Environmental Protection Agency, 2023).

Reducing exposure to air pollution through regulatory measures, lifestyle changes (e.g., reducing outdoor activity during high pollution days), and transitioning to cleaner energy sources can help mitigate these health risks and improve cardiovascular outcomes (Manisalidis et al., 2020; United States Environmental Protection Agency, 2023).

Intervention Strategies:

The influence of air pollution on cardiovascular health is being lessened by a variety of measures. Strict air quality laws, emission limitations, the promotion of renewable energy sources, and exposure-reducing urban planning strategies are a few of these. Additionally crucial are public health initiatives such awareness campaigns and advice on reducing exposure during periods of high pollution (Al-Kindi et al., 2020; Hadley et al., 2018; United States Environmental Protection Agency, 2023; Public health England, 2019).

3. CONCLUSION

In conclusion, there is strong evidence that air pollution plays a role in the onset and aggravation of cardiovascular diseases (CVD). Through a variety of intricate processes, including as oxidative stress, endothelial dysfunction, systemic inflammation, and autonomic nervous system instability, exposure to pollutants, especially PM_{2.5}, raises the risk of CVD. **Targeted interventions** are necessary since **vulnerable groups—like the elderly and people with pre-existing conditions—are more at risk.**

Comprehensive approaches are needed to address this worldwide public health concern. These include supporting the use of sustainable energy sources, enforcing laws to enhance air quality, and educating the public on the dangers that air pollution poses to human health. It is nevertheless crucial to reduce air pollution in order to protect cardiovascular health and advance general wellbeing.

5. ACKNOWLEDGEMENT

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THE IMPACT OF AIR POLLUTION ON CARDIOVASCULAR PROBLEMS

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THE IMPACT OF AIR POLLUTION ON CARDIOVASCULAR PROBLEMS

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ABSTRACT

3 Introduction: Air pollution is a significant environmental issue with adverse effects on public health. Numerous studies have investigated the association between air pollution exposure and the development of cardiovascular diseases (CVD). **4** The purpose of study: This literature review aims to provide an overview of recent studies, focusing on key findings, mechanisms, and potential interventions related to air pollution and CVD. Methods: A thorough search for articles published between 2015 and 2024 was done in PubMed, Web of Science, and Google Scholar. Epidemiological studies, experimental investigations, and earlier evaluations that look at the connection between air pollution and cardiovascular disorders were given priority in the study. Result study: Research indicated that exposure to air pollution, namely fine particulate matter (PM2.5) and gaseous pollutants, raised the risk of cardiovascular disease (CVD), which includes heart failure, hypertension, stroke, and coronary artery disease. The mechanisms include oxidative stress, inflammation, and endothelial dysfunction. Conclusion: To **11** mitigate the global health risks associated with air pollution, improving air quality, implementing policy changes, and promoting public health campaigns are essential.

ABSTRAK

Pendahuluan: Polusi udara adalah masalah lingkungan signifikan yang berdampak negatif pada kesehatan masyarakat. Banyak penelitian telah mengkaji hubungan antara paparan polusi udara dan perkembangan penyakit kardiovaskular (CVD). Tujuan penelitian: Tinjauan literatur ini bertujuan memberikan gambaran tentang penelitian terbaru, dengan menyoroti temuan utama, mekanisme, dan potensi intervensi terkait polusi udara dan CVD. Metode: Pencarian literatur dilakukan secara komprehensif menggunakan Google Scholar, Web of Science, dan PubMed, dengan fokus pada artikel yang diterbitkan antara tahun 2015 hingga 2024. Tinjauan ini memprioritaskan studi epidemiologis, penelitian eksperimental, dan tinjauan sistematis sebelumnya yang membahas hubungan antara polusi udara dan penyakit kardiovaskular. Hasil penelitian: Bukti menunjukkan bahwa paparan polusi udara, terutama partikulat halus (PM2.5) dan polutan gas, meningkatkan risiko CVD, termasuk gagal jantung, hipertensi, stroke, dan penyakit arteri koroner. Mekanisme

14

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KEYWORDS

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- Cardiovascular diseases,
- Endothelial dysfunction,
- inflammation and oxidative stress,
- reduced life expectancy

KATA KUNCI

- Polusi udara
- Penyakit kardiovaskular
- Disfungsi endothel
- Inflamasi dan stress

yang terlibat meliputi disfungsi endotel, peradangan, dan stres oksidatif. Kesimpulan: Untuk mengurangi risiko kesehatan global terkait polusi udara, penting untuk meningkatkan kualitas udara, menerapkan perubahan kebijakan, dan menggalakkan kampanye kesehatan masyarakat.

- oksidatif
Mengurangi usia harapan hidup

1. INTRODUCTION

Global public health is seriously threatened by air pollution, a widespread environmental problem. The primary cause of death worldwide is cardiovascular disease (CVD), and there is mounting evidence that exposure to air pollution may have a role in the onset, progression, and aggravation of CVD. By highlighting the underlying mechanisms and investigating prospective preventive and mitigation techniques, this literature review seeks to present an updated picture of the link between air pollution and cardiovascular health (Bhatnagar, 2022; Hu et al., 2023; Manisalidis et al., 2020; Shetty et al., 2023; Xu et al., 2022).

Several studies have shown a considerable correlation between different cardiovascular diseases and air pollution. Particulate matter (PM), ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and carbon monoxide (CO) are important pollutants of concern. (Shetty et al., 2023; US EPA, 2019; US Environmental Protection Agency, 2016). These pollutants originate from a variety of sources, including burning fossil fuels, car emissions, industrial operations, and natural occurrences like volcanic eruptions and wildfires (Bhatnagar, 2022; Hu et al., 2023; Manisalidis et al., 2020; Shetty et al., 2023; Xu et al., 2022). Each pollutant has distinct pathways that can harm cardiovascular health, including oxidative stress, systemic inflammation, and endothelial dysfunction.

2. METHODS

A thorough search of the peer-reviewed literature was carried out with the aid of databases including Google Scholar, Web of Science, and PubMed. Articles published between 2015 and 2024 were primarily focused on reviews, experimental studies, and epidemiological investigations that looked at the connection between air pollution and cardiovascular diseases.

Ethical Considerations

Ethical approval was not required since this study is a literature review and does not involve primary data collection.

2. RESULTS AND DISCUSSION

Epidemiological Evidence:

Numerous epidemiological studies have consistently demonstrated a substantial link between exposure to air pollution and a higher risk of cardiovascular diseases. Particular emphasis has been paid to fine particulate matter (PM_{2.5}), a prevalent air contaminant. An increased risk of heart attacks, strokes, hypertension, and heart failure has been linked to persistently elevated PM_{2.5} levels. Other pollutants including NO₂, SO₂, O₃, and CO can also have negative effects on the cardiovascular system (Bhatnagar, 2022; de Bont et al., 2022; Manisalidis et al., 2020; Shetty et al., 2023; US EPA, 2016; Xu et al., 2022).

In recent years, there has been a lot of research on the relationship between ambient air pollution and cardiovascular illnesses (CVDs) (Bhatnagar, 2022; de Bont et al., 2022; Manisalidis et al., 2020; Shetty et al., 2023; Xu et al., 2022). The epidemiological information currently known linking ambient air pollution and CVDs. De Bont evaluated the quality of the evidence and assessed its strength. Mortality from all causes of CVD, morbidity, and stroke (22 studies) were the most frequently studied outcomes among the 56 reviews that were taken into consideration (de Bont et al., 2022; Jaganathan

et al., 2019). Higher levels of short- and ¹¹ long-term exposure to ambient air pollution have been linked to the highest rates of blood pressure, stroke, ischemic heart disease (IHD), and all-cause cardiovascular disease (CVD) mortality and morbidity (Basith et al., 2022; de Bont et al., 2022; Jaganathan et al., 2019; Xu et al., 2022). Short-term exposure to nitrogen oxides (NOx), particulate matter <2.5 µm (PM2.5), and <10 µm (PM10) has often been linked to an elevated risk of hypertension, myocardial infarction (MI), and stroke (both fatal and nonfatal) (Basith et al., 2022; de Bont et al., 2022; Xu et al., 2022). The main risks linked to ³ long-term exposure to PM2.5 are atherosclerosis, MI events, hypertension, stroke events, and stroke deaths. Although a few studies examined other CVD-related outcomes, such as heart failure, arrhythmias, or atrial fibrillation, they primarily found positive statistical associations (Basith et al., 2022; Bhatnagar, 2022; de Bont et al., 2022; Jaganathan et al., 2019; Manisalidis et al., 2020; Xu et al., 2022).

Pollution exposure causes a variety of illnesses and deaths. Over 60% of cases are caused by cardiovascular illness. These are the primary causes of death and disability. Compared to metabolic, behavioral, and tobacco-related risk factors, environmental factors account for a greater proportion of mortality from cardiovascular disease. The risk of cardiovascular disease is increased by airborne particulate matter scattered throughout the environment, depending on its size (Shetty et al., 2023; Rajagopalan et al., 2018). Nitrogen oxide (NO₂), elemental carbon, PM_{2.5}, PM₁₀, blood pressure fluctuations, and heart attacks have all been linked to these diseases (Shetty et al., 2023; de Bont et al., 2022).

Mechanisms of Action:

The pathophysiological mechanisms through which air pollution contributes to cardiovascular diseases are multifaceted. The ⁹ central pathways include endothelial dysfunction, oxidative stress, inflammation, and dysregulation of the autonomic nervous system. The development and progression of CVD are facilitated by PM_{2.5} and gaseous pollutants, which can cause systemic inflammation, disturb cardiac rhythm, decrease vascular function, and encourage atherosclerosis (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020; Shetty et al., 2023).

An increased risk of cardiovascular diseases (CVD) is associated with air pollution through a number of complex pathophysiological pathways. Although the precise mechanisms are still unclear, a great deal of research has found numerous ¹ important mechanisms that connect exposure to air pollution to CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020; Shetty et al., 2023). These mechanisms include:

⁶
Inflammation: The body may experience inflammation as a result of air pollution, especially fine particulate matter (PM_{2.5}) and specific gases like ozone (O₃). One of the main risk factors for CVD is atherosclerosis, or the accumulation of plaque in arteries, which can be exacerbated by this inflammation and impact blood vessels (Basith et al., 2022; Miller et al., 2020; Rajagopalan et al., 2018; Shetty et al., 2023).

¹⁰
Oxidative Stress: Pollution of the air can cause oxidative stress on the body. Oxidative stress can result from an imbalance between the body's ability to remove harmful reactive oxygen species (ROS) and the production of these ROS. This oxidative stress has the potential to harm blood vessel walls, increase inflammation, and hasten the onset of CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020; Shetty et al., 2023).

⁵
Endothelial Dysfunction: The endothelium, or inner lining of blood vessels, may malfunction as a result of exposure to air pollution. Because endothelial dysfunction can result in blood vessel

constriction, elevated blood pressure, and decreased blood flow, it is an important early event in the development of atherosclerosis (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Autonomic Nervous System Imbalance: The autonomic nervous system, which controls blood pressure and heart rate, can be impacted by air pollution. Changes in this system brought on by pollution may raise the risk of arrhythmias (abnormal cardiac rhythms) and other consequences associated with CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Blood Coagulation and Thrombosis: There is a correlation between increased blood coagulation and the development of thrombosis with exposure to air pollution. Due to thrombosis, or the formation of clots within blood arteries, this may raise the risk of heart attacks and strokes (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Blood Pressure Elevation: Air pollution, particularly PM2.5, has been associated with acute and chronic increases in blood pressure. This elevation in blood pressure can strain the cardiovascular system and increase the risk of hypertension, a major risk factor for CVD (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Accelerated Atherosclerosis: Long-term exposure to air pollution may accelerate the atherosclerosis process, which narrows the arteries and increases the risk of heart attacks and strokes (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Impaired Cardiac Function: Air pollution exposure has been shown to impair cardiac function by affecting heart rate variability and promoting cardiac arrhythmias. These effects can increase the risk of sudden cardiac events (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

Systemic Effects: The body as a whole is affected by air pollution, not just the respiratory system. This involves the release of chemicals that can affect the cardiovascular system, such as pro-inflammatory cytokines (Basith et al., 2022; Rajagopalan et al., 2018; Miller et al., 2020).

It's crucial to remember that the precise mechanisms may change based on the kind and makeup of air pollutants, a person's vulnerability, and the length and severity of exposure (Bhatnagar et al., 2022; Laumbach et al., 2015; Manisalidis et al., 2020). The risk of cardiovascular illnesses can also be raised by the combined effects of several contaminants and additional risk factors such as nutrition and smoking. To lessen these detrimental cardiovascular consequences, reducing exposure to air pollution and addressing its sources is still a crucial public health objective (Bhatnagar, 2022; Laumbach et al., 2015; Manisalidis et al., 2020).

Effects on Cardiovascular Diseases:

All-cause CVD mortality and morbidity. Long-term exposure to air pollution, including fine particulate matter (PM2.5) and ground-level ozone (O3), is associated with heart-related death. This group of fatalities includes heart attacks, heart failure, strokes, and other cardiovascular conditions. Among the variables at work are oxidative stress, inflammation, and the worsening of underlying cardiovascular diseases. (Atkinson et al., 2015; Chen et al., 2020; de Bont et al., 2022; Fajersztajn et al., 2017; Jaganathan et al., 2019).

Air pollution not only increases the risk of death from cardiovascular disease but also increases rates of morbidity. The risk of non-fatal cardiovascular events, such as angina (chest discomfort), heart attacks, strokes, and hospitalizations related to heart problems, is increased by high exposure to air pollution (Atkinson et al., 2015; Chen et al., 2020; de Bont et al., 2022; Fajersztajn et al., 2017; Jaganathan et al., 2019).

Ischemic heart disease and myocardial infarction. Exposure to air pollutants, particularly fine particulate matter (PM2.5) and ground-level ozone (O3), can cause oxidative stress and inflammation in the body. A heart attack may result from the formation and rupture of arterial plaques as a result of this (Akintoye et al., 2016; Atkinson et al., 2015; Chen et al., 2020; Fajersztajn et al., 2017; Pranata et al., 2020; Zhang et al., 2020).

People who currently have heart conditions like coronary artery disease or congestive heart failure are more likely to see their symptoms deteriorate when exposed to air pollution. Pollutants can strain the heart by reducing the oxygen supply and increasing the workload (Atkinson et al., 2015; Chen et al., 2020; de Bont et al., 2022; Fajersztajn et al., 2017; Pranata et al., 2020; Zhang et al., 2020).

Atherosclerosis and arterial stiffness. Atherosclerosis is the narrowing and hardening of arteries due to the accumulation of plaque, consisting of cholesterol, fat, calcium, and inflammatory cells. This narrowing reduces blood flow and can lead to the formation of blood clots (Akintoye et al., 2016; de Bont et al., 2022; Liu et al., 2017; Zanolli et al., 2017).

Long-term exposure to air pollution, particularly fine particulate matter (PM2.5), might hasten atherosclerosis. The endothelium, the lining that surrounds blood vessels, can be harmed by pollutants, and they can also encourage the buildup of fatty deposits, which reduces the artery's flexibility and increases its susceptibility to blockages (Akintoye et al., 2016; de Bont et al., 2022; Liu et al., 2017).

Blood pressure and hypertension. One of the main risk factors for ischemic heart disease is elevated blood pressure, or hypertension, which is linked to exposure to air pollution. Because hypertension puts more strain on the heart, it makes heart disease more likely to occur (de Bont et al., 2022).

Heart failure. The development and aggravation of heart failure, a chronic cardiovascular disease in which the heart's capacity to pump blood effectively is compromised, can be attributed to air pollution. (Pranata et al., 2020). Here's how air pollution is linked to heart failure:

- 1. Inflammation and Oxidative Stress:** Air pollution, particularly ozone (O3) and fine particulate matter (PM2.5), can cause the body to experience oxidative stress and inflammation. Systemic inflammation brought on by these reactions can have an impact on blood vessels and the heart. Oxidative stress and persistent inflammation can harm the heart muscle and hasten the onset of heart failure.
- 2. Worsening of Pre-existing Conditions:** Individuals with existing cardiovascular conditions, such as coronary artery disease and hypertension, are at an increased risk of heart failure when exposed to air pollution. Air pollution can exacerbate these conditions, leading to further damage to the heart muscle over time.
- 3. Reduced Oxygen Supply:** High levels of air pollution, including PM2.5, can reduce the oxygen-carrying capacity of the blood. This means that the heart must work harder to provide sufficient oxygen to the body's tissues, including the heart muscle itself. The increased workload on the heart can lead to hypertrophy (enlargement) of the heart chambers and, eventually, heart failure.
- 4. Elevated Blood Pressure:** Air pollution is associated with elevated blood pressure (hypertension). Hypertension can increase the workload on the heart and lead to left ventricular hypertrophy (thickening of the heart's left ventricle). Over time, this can impair the heart's ability to pump effectively and contribute to heart failure.
- 5. Impaired Endothelial Function:** The function of the endothelial cells lining blood arteries can be hampered by air pollution. Blood artery constriction and decreased blood flow to the heart

muscle can result from this endothelial dysfunction. Heart failure may be exacerbated by persistently compromised endothelial function.

6. **Arrhythmias:** Air pollution can cause arrhythmias, or abnormal cardiac rhythms, by interfering with the heart's electrical transmission. Arrhythmias can raise the risk of heart failure and decrease the heart's ability to pump blood efficiently.

Arrhythmias, atrial fibrillation, and cardiac arrest. Air pollution can contribute to the development of arrhythmias, including atrial fibrillation, and may increase the risk of cardiac arrest through various mechanisms (Pranata et al., 2020; Sangkharat et al., 2019; Shao et al., 2016; Yue et al., 2022; Zhao et al., 2017).

Regarding atrial fibrillation specifically, studies have shown an association between air pollution exposure and an increased risk of developing atrial fibrillation. The widespread arrhythmia known as atrial fibrillation is typified by fast and erratic heartbeats in the atria, or upper chambers of the heart. The processes that connect air pollution to atrial fibrillation are probably complex and could involve endothelial dysfunction, oxidative stress, inflammation, and dysregulation of the autonomic nervous system (Pranata et al., 2020; Sangkharat et al., 2019; Shao et al., 2016; Yue et al., 2022; Zhao et al., 2017).

In the case of cardiac arrest, while air pollution itself is not a direct cause, the increased risk of arrhythmias induced by air pollution can contribute to the occurrence of cardiac arrest, especially in individuals with pre-existing heart conditions. Cardiac arrest occurs when the heart's electrical activity becomes chaotic, leading to a sudden loss of effective blood circulation. Air pollution's impact on the heart's electrical system can play a role in triggering these life-threatening events mechanisms (Pranata et al., 2020; Sangkharat et al., 2019; Shao et al., 2016; Yue et al., 2022; Zhao et al., 2017).

Exacerbation of Pre-existing Cardiovascular Conditions. Cardiovascular diseases can get worse due to air pollution. The negative consequences of air pollution are more likely to affect people who have heart disease, hypertension, or other cardiovascular disease risk factors. It may intensify heart failure symptoms or cause heart attacks (de Bont et al., 2022; Konduracka et al., 2022).

Reduced Exercise Tolerance. Air pollution can reduce an individual's exercise capacity and tolerance. This can discourage physical activity, which is essential for cardiovascular health (Del Buono et al., 2019; Hahad et al., 2021; You et al., 2022).

Reduced Life Expectancy. Life expectancy can be lowered by prolonged exposure to air pollution, and cardiovascular illnesses are partly to blame for this decrease (Lelieveld et al., 2020; Miller et al., 2020; Public Health England, 2018).

Vulnerable Populations:

Certain populations, such as the elderly, children, and individuals with preexisting cardiovascular conditions, are disproportionately susceptible to the adverse effects of air pollution. These groups are at heightened risk of experiencing severe cardiovascular outcomes when exposed to polluted air (Manisalidis et al., 2020; United States Environmental Protection Agency, 2023).

Reducing exposure to air pollution through regulatory measures, lifestyle changes (e.g., reducing outdoor activity during high pollution days), and transitioning to cleaner energy sources can help mitigate these health risks and improve cardiovascular outcomes (Manisalidis et al., 2020; United States Environmental Protection Agency, 2023).

Intervention Strategies:

The influence of air pollution on cardiovascular health is being lessened by a variety of measures. Strict air quality laws, emission limitations, the promotion of renewable energy sources, and exposure-reducing urban planning strategies are a few of these. Additionally crucial are public health initiatives such awareness campaigns and advice on reducing exposure during periods of high pollution (Al-Kindi et al., 2020; Hadley et al., 2018; United States Environmental Protection Agency, 2023; Public health England, 2019).

3. CONCLUSION

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In conclusion, there is strong evidence that air pollution plays a role in the onset and aggravation of cardiovascular diseases (CVD). Through a variety of intricate processes, including as oxidative stress, endothelial dysfunction, systemic inflammation, and autonomic nervous system instability, exposure to pollutants, especially PM2.5⁸ raises the risk of CVD. **Targeted interventions** are necessary since **vulnerable groups—like the elderly and people with pre-existing conditions—are more at risk.**

Comprehensive approaches are needed to address this worldwide public health concern. These include supporting the use of sustainable energy sources, enforcing laws to enhance air quality, and educating⁵ the public on the dangers that air pollution poses to human health. It is nevertheless crucial **to reduce air pollution in order to** protect cardiovascular **health** and advance general wellbeing.

THE IMPACT OF AIR POLLUTION ON CARDIOVASCULAR PROBLEMS

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