REVIEW ARTICLE

Annals of Agricultural and Environmental Medicine 2023, Vol 30, No 1, 15–21
www.aaem.pl

Association between exposure to air pollution and incidence of atrial fibrillation

Robert Tomasz Błaszczyk[1,A-D,F] ✉, Adam Gorlo[2,A-B], Małgorzata Dukacz[3,A-B], Aleksander Konopka[1,A-B], Andrzej Głowniak[1,A,C,E-F]

[1] *Medical University, Lublin, Poland*
[2] *CardioVita Medical Centre, Suwałki, Poland*
[3] *Health Care Institute, Bronisław Markiewicz State Higher School of Technology and Economics, Jarosław, Poland*
A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

Błaszczyk RT, Gorlo A, Dukacz M, Konopka A, Głowniak A. Association between exposure to air pollution and incidence of atrial fibrillation. Ann Agric Environ Med. 2023; 30(1): 15–21. doi: 10.26444/aaem/157189

Abstract

Introduction and Objective. Air pollution is the largest environmental health risk, estimated to cause over 5 million premature deaths per year worldwide, including half a million deaths in Europe. It is associated with significant reductions in healthy life years and worker productivity. It may also be an important endocrine disrupter, contributing to the development of metabolic diseases, such as obesity, diabetes mellitus and acute ischaemic/thrombotic cardiovascular events. The aim of the study was to present current knowledge on short- and long-term exposure to air pollution, including particulate matter (PM2.5 and PM10) and the occurrence of atrial fibrillation (AF).

Review Methods. The review was based on data obtained from articles published in the PubMed or related databases, and searching observational studies.

Brief description of the state of knowledge. Some of the studies demonstrated a triggering effect of exposure to air pollution on acute exacerbation of atrial fibrillation. Evidence of the long-term effect of air pollution exposure on AF episodes is limited or scarce.

Summary. Data indicate that human exposure to air pollution is associated with an increased risk of atrial fibrillation. Studies confirmed that further efforts to reduce air pollution exposure should be undertaken to reduce the negative health effects in the general population. To better understand the effect of air pollution on the incidence of AF and related public health impact in the most polluted regions of the world, more high-quality studies are needed.

Key words

particulate matter, atrial fibrillation, short-term exposure, long-term exposure, air polltion

INTRODUCTION AND OBJECTIVE

Air pollution (AP) is the largest environmental health risk, estimated to cause over 5 million premature deaths per year globally, including half a million deaths in Europe [1, 2]. AP is associated with significant reductions in health quality and length of life, as well as work productivity. It may also be an important endocrine disrupter, contributing to the development of metabolic diseases, such as obesity, diabetes mellitus and acute ischaemic/thrombotic cardiovascular events [3, 4]. Among the commonly known air pollutants, such as sulphur oxides (SOx), nitrogen oxides (NOx), and ozone (O3), the presence of particular matter (PM) is especially important. In 1970, the concentration of particulate matter in the atmosphere was measured for the first time. Until 1987 total suspended particulate was determined, and the measuring range was a particle size up to about 40 µm. The first determining particulate matter fraction was PM10, i.e. dust particles smaller than 10 µm. Since 1998, PM2.5, i.e. particulate matter smaller than 2.5 µm, was determined. Particles that are larger than 10 µm have a faster fall rate and a short residence time in atmospheric air. The main source of PM10 dust is the combustion process in home furnaces and diesel-powered vehicles. The source of PM2.5 dust is gaseous pollutants in the form of sulphur oxides and nitrogen oxides. In the atmosphere, they undergo rapid chemical reactions, changing from gaseous to liquid form and producing acid aerosol; subsequent chemical reactions lead to the formation of sulphates and nitrates. PM2.5 dust is also called secondary dust because it is formed from gaseous pollutants. Additionally, PM2.5 dust also includes hydrocarbons, metal ions (including heavy metals) and nanoparticles [5].

The effect of environmental pollutants on total mortality and cardiovascular mortality is well–known. Air pollution is increasingly recognized as a contributor to cardiovascular risk, including arrhythmias. First of all, particulate matter is associated with an increased risk of myocardial infarction, and ventricular arrhythmias including ventricular tachycardia and ventricular fibrillation, while the relationship with atrial fibrillation (AF) is still under discussion. AF is the most common arrhythmia in adults, 5-fold increases the risk of ischaemic stroke and doubles the risk of death. In many patients, AF promotes the development of chronic heart failure. Currently, the prevalence of AF in adults is estimated at 2% – 4%. In the next few years, a 2–3-fold increase in the incidence of AF is expected due to the increasing life expectancy and extensive search for previously unrecognized causes of atrial fibrillation. The mechanism underlying atrial fibrillation is multifactorial: advanced age, male gender,

✉ Address for correspondence: Robert Tomasz Błaszczyk, Medical University, Jaczewskiego 8, 20-954 Lublin, Poland
E-mail: robert.blaszczyk@umlub.pl

Received: 05.07.2022; accepted: 06.12.2022; first published: 02.01.2023

arterial hypertension, diabetes, and underlying heart disease are important factors for the development of arrhythmia. Environmental and habitual risk factors, such as sleep apnoea, obesity, alcohol abuse and hyperthyroidism, have also been suggested to promote the development of atrial fibrillation [6, 7, 8]. Some studies have demonstrated a triggering effect of exposure to air pollution on acute exacerbation of atrial fibrillation. Evidence for the long-term effect of air pollution exposure on atrial fibrillation episodes is even more limited or scarce [9].

The study aims to present current knowledge on short- and long-term exposure to air pollution, including particulate matter (PM2.5 and PM 10), and the occurrence of atrial fibrillation.

Review method. In order to implement the research assumptions, PubMed and related databases were searched for relevant studies using the following key words: air pollution, particulate matter, short-term exposure, long-term exposure, atrial fibrillation, and their combination. The inclusion criteria were: studies examining the short- or long-term effects of ambient air pollution (PM2.5, PM10, nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone) on atrial fibrillation; studies providing the relative risks (RR), odds ratio (OR) or hazard ratio (HR), and the corresponding 95% confidence intervals. The exclusion criteria were studies that did not include atrial fibrillation as an endpoint; letters and conference abstracts or materials.

The role of air pollutants on the functioning of the circulatory system. The mechanism of the harmful effect of particulate matter on the cardiovascular system is very complicated and not yet fully explained. It is claimed that the finest fractions of a particular matter can penetrate the peripheral parts of the respiratory system, and then into the circulatory system. This may lead to a pro-inflammatory effect through an increase in the synthesis of inflammatory factors, an increase in oxidative stress, imbalance of the autonomic nervous system, increase in arterial blood pressure, increase in pulmonary vascular resistance, endothelial cell dysfunction, increase in platelet aggregation, and increase in the synthesis of vasoconstrictive factors. Particulate matter increases the production of such inflammatory agents as C-reactive protein, fibrinogen, interleukin 1β (IL-1β), interleukin 6 (IL-6), Granulocyte-Macrophage Colony Stimulating Factor (GM-CSF), and Tumour Necrosis Factor-α (TNF-α), the concentration of which depends on environmental pollution. Particular matter is also associated with the emergence markers of oxidative stress, including compounds leading to atherosclerosis, such as oxidized lipids [10]. It has been demonstrated that particulate matter also induced the synthesis of prothrombotic factors, such as fibrinogen, von Willebrandt factor, sCD62P and sCD40L, which may lead to thromboembolic events (myocardial infarction, ischemic/thrombotic cerebrovascular events, deep venous thrombosis). Additionally, tissue Plasminogen Activator (t-PA) is inhibited, and the synthesis of Plasminogen Activator Inhibitor-1 (PAI-1) is increased [11, 12]. Several studies have shown an association between exposure to air pollution and the occurrence of arterial hypertension. There is evidence that exposure to PM may increase the risk of gestational hypertension and pre-eclampsia. Studies show that long-term exposure to PM can lead to left and right ventricular hypertrophy, left ventricular diastolic dysfunction and cardiac fibrosis as a consequence of the increased release of the vasoconstrictive factor angiotensin II [13, 14]. Finally, the effect of particular matter on the heart muscle leads to increased heart rate, electric instability, ectopic beats, and ST-T segment changes including depression, repolarization irregularities and change in heart rate variability (HRV) [15].

Currently, three mechanisms are postulated in which particulate matter causes cardiovascular disorders. The first assumes that the inhalation of particulate matter activates the inflammatory process in the lungs, leading to systemic inflammation, and consequently initiating thrombosis, endothelial dysfunction and atherosclerosis. The second suggested mechanism is the activation of sensor receptors in the lungs, leading to autonomic nervous system imbalance in the form of increased sympathetic activation, and thus an increased resting heart rate, vasoconstriction, endothelial dysfunction and arterial hypertension. The third most controversial mechanism assumes that the smallest particles, called ultrafine particles, i.e. smaller than 0.1 μm (PM 0.1), enter from the lungs into the circulatory system and then to the target tissues [16].

It is known that particulate matter exerts biological effects by stimulating the production of reactive oxygen species (ROS) and by intensifying oxidative stress. Mitochondrial ROS production is an important regulator of cellular response to PM. Many types of cells respond to *in vitro* PM exposure with elevations in cellular ROS levels and oxidative stress (nasal, airway, lung epithelial cells, cardiomyocytes, corneal epithelial cells, gastrointestinal epithelial cells, macrophages, epidermal keratinocytes and endothelial cells). Elevated ROS levels are necessary for PM-induced biologic effects. Inhibition of oxidant production and antioxidant treatment is sufficient to inhibit downstream pathways, such as pro-inflammatory cytokine production and induction of apoptosis [17]. When PM is adsorbed to cells, this leads to free radicals inside the cells. In response to cells generating ROS as signalling molecules, mitochondrial morphology and function are altered? [18].

Alveolar macrophages in the luminal epithelial surface of alveoli play an important role in transmitting signal effects of PM to the heart and vessels. Treatment of alveolar macrophages in vitro with particulate matter elicits a transcriptional upregulation of inflammatory cytokines, such as TNF-α, IL-1β, IL-6, IL-8 and GM-CSF. In a study in mice, alveolar macrophages were eliminated by liposomal clodronate which led to inhibition of the pulmonary and systemic accumulation of IL-6 or TNF-α after exposure to PM [19]. Pro-inflammatory cytokines (IL-6 and TNF-α) expression is induced in alveolar macrophages and lung epithelial cells after exposure to particulate matter [20].

Air pollution can affect the balance between the sympathetic and parasympathetic nervous systems. A recent study found a correlation between elevated exposure to PM with increased serum levels of stress hormones: norepinephrine and epinephrine. Animal studies showed that long-term PM exposure leads to increased adipocyte size and increased visceral fat mass. PM exposure induced genes associated with lipogenesis in adipose tissue and change in serum levels of leptin and adiponectin [21, 22]. Figure 1 shows current evidence for the mechanisms by which PM air pollution causes cardiovascular health effects [10].

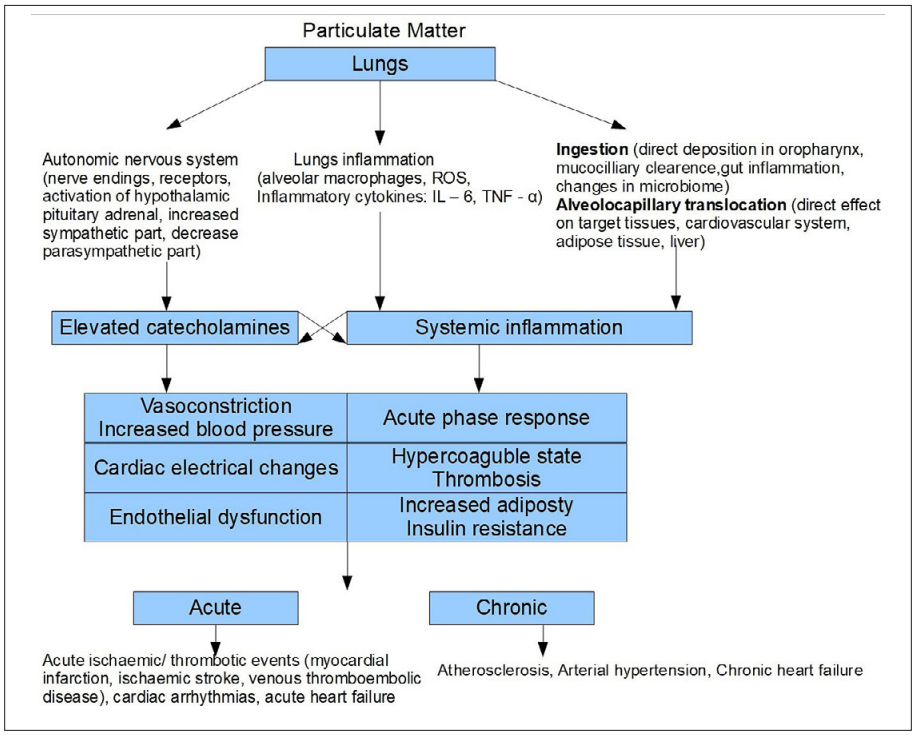

Figure 1. Current evidence for the mechanisms by which PM air pollution causes cardiovascular health effects [10]

Despite limited research data, air pollution exposure has been shown to affect multiple epigenetic mechanisms, including alterations in DNA methylation and histone modifications. Madrigano et al. found that hypomethylation in DNA repetitive elements has been observed in circulating leukocytes after exposure to particles. Baccarelli et al. demonstrated that hypomethylation of LINE-1 element correlates with increased risk for ischaemic heart disease, stroke, and all-cause mortality [23, 24].

Short-term exposure to air pollution. In recent years, some epidemiological studies have assessed the association between short-term exposure to air pollution and atrial fibrillation in two ways: analysing hospital admissions or analysing the history of patients who had their heart rhythm monitored. The latter group belonged to patients with implantable cardiac devices, such as pacemakers or cardioverter-defibrillator, and patients who had undergone a Holter screening.

In the already by Wichmann et al., the authors assessed the impact of environmental pollution in a short-term observation on the risk of arrhythmias, reporting that during the increased smog in 1985 in Germany, the number of patients visiting hospitals due to arrhythmias was about 50% higher compared to the period in which the smog was not particularly intense [25].

One of the most important studies confirming that short-term exposure to PM2.5 causes an increase in cardiovascular mortality was a study using data from the MINAM registry (Myocardial Ischaemia National Audit Project). The research was a case-crossover study, which is particularly used for assessing short-term environmental factors. Each subject is assigned a period in which the effect occurred (case window) and the period with no apparent effect on health (control window). The health risk is assessed by comparing the exposure to a harmful environmental factor in both separate periods. Two million emergency admissions and 600,000 cardiovascular deaths were analysed. Each event was compared with the average daily PM2.5 concentration. During the analysis, factors disturbing or modifying the state of health, such as gender, age, smoking and concomitant disease, were also taken into account. It was found that a relevant increase in PM2.5 concentration was responsible for a 21% increase in arrhythmia-related mortality, and a similar 21% increase in the incidence of atrial fibrillation (95% CI: 3.5–39.7%) [26].

Link et al. investigated the relationship between air quality and the occurrence of AF in patients with implantable cardioverter-defibrillator. They found that the greatest risk of arrhythmias was with short-term exposure to the particulate matter before an episode of atrial fibrillation (less than two hours). The risk of an arrhythmic episode increased by 26% (95% CI; 8–47%) for each 6 μg/mm3 increase in PM2.5 [27]. Liu et al. in their study also used information from the memory of implantable devices: pacemakers, cardioverter-defibrillator, and cardiac resynchronization therapy defibrillators. The research was a case-crossover study in which the air pollutants included: PM2.5, PM10, nitrogen dioxide (NO2), sulphur dioxide (SO2), carbon monoxide (CO) and ozone (O3). It was found that a 10 μg/mm3 increase of PM2.5 and PM10 was associated with a 3.8% (95% CI: 1.4–6.2) and 2.7% (95% CI: 0.6–4.8) increase, respectively, in the risk of atrial fibrillation occurrence. There was no statistically significant association with nitrogen dioxide (NO2), sulphur dioxide (SO2), carbon monoxide (CO) and ozone (O3) [28]. In the next study, patients were selected from the ARIA study cohort, a multicentre prospective study. A Firth Logistic Regression model was used to evaluate the association between atrial fibrillation and daily exposure to PM2.5 and PM10. Association was found between daily exposure to PM2.5 (OR: 1.8; 95% CI: 1.34–2.40) and PM10 (OR: 2.48; 95% CI: 1.44–4.28) and atrial fibrillation

incidence in patients with no medical history of arrhythmia [29, 30].

Cakmam et al. analysed data obtained from 24-hour Holter recordings which were compared with the level of environmental pollution expressed as an air quality index (AQHI – Air Quality Health Index). It took into account not only the concentration of particulate matter, but also the presence of ozone and nitrogen dioxide. It was found that the increase in maximum average daily AQHI in the extent of the interquartile range (IQR) was associated with a 0.17% increase in the frequency of atrioventricular conduction disturbances (95% CI: 1.07–1.29%) and with a 0.9% increase in the maximum heart rate (95% CI: 0.3–1.5%) [31].

A Korean study conducted between 2007–2015 examined patients who had an emergency visit for atrial fibrillation. The daily average concentrations of PM2.5 were 25 μg/mm3 and PM10 -49.1 μg/mm3. The mean age of patients reporting for the emergency visit was 68 years, with a slight majority of men (52.9%). It was noted that patients with AF had a high cardiovascular risk and had concomitant diseases, such as arterial hypertension, ischaemic heart disease and heart failure. A 10 μg/mm3 increase in PM2.5 was shown to significantly increase emergency admissions by 4.5% at lag day three (RR – 1.045; 95% CI: 1.002 – 1.089; p – 0.038). Carbon monoxide showed a marginal trend towards increased risk for arrhythmia, and no other pollutants showed a significant increase with emergency atrial fibrillation admission. When analysing the subgroup, it turned out that the short-term effect of PM2.5 increase affecting the incidence of AF was more prominent for men and the non-elderly (< 65 years old) [32].

The results of studies by Polish authors examining the effect of short-term exposure to PM2.5/PM10 and sudden exacerbations of selected cardiovascular and respiratory system diseases based on emergency ambulance services registries, are interesting. The strongest influence of particulate matter was observed in the case of atrial fibrillation and atrial flutter. The authors concluded that people less than 65 years of age are more prone to developing atrial tachycardia when the particulate matter concentration increases. This was explained by the fact that people over the age of 65 have more comorbidities and take medications, including antiarrhythmic drugs [33].

Interesting information comes from an Icelandic study that searched for a relationship between traffic-related ambient air pollution in Reykjavik, and emergency hospital visits for cardiovascular conditions – particularly atrial fibrillation and atrial flutter. It was found that each 10 μg/mm3 increase in NO2 (24-hour mean NO2 was 20.7 μg/mm3) was associated with an increased risk (OR 1.030; 95% CI: 1.011–1.049) of AF on the same day. Females had higher risk of arrhythmia (OR 1.051; 95% CI: 1.019–1.083 at lag 0; OR 1.050; 95% CI: 1.019–1.083 at lag 1), especially females at younger age (< 71 years; OR 1.077; 95% CI: 1.025–1.131) [12]. In addition to the correlation between NO2 and the occurrence of AF, a relationship between PM2.5 and arrhythmia was found – each 10 μg/mm3 increase of PM2.5 positively correlated with AF incidence (OR 1.029, 95% CI: 1.007–1.052) at lag 3 [34]. Several studies reported a positive association between NO2 and the prevalence of atrial fibrillation [26, 35]. In a recent multicentre study, the authors reported a link between NO2 level and cardiovascular mortality most prominently at lag 1 (but not at lag 0) [36].

Some authors indicate the possibility of synergistic effects of PM2.5 and NO2. During an experiment in which a group of young people were subjected to controlled exposure to both pollutants, followed by assessment of ECG and laboratory tests, it was found that the effect (occurrence of atrial fibrillation) was most prominent with the combined exposure to PM2.5 and NO2. In this study the increase in the mean T wave amplitude, free components of HRV (heart rate variability) and index LF/HF (low frequency/high frequency) were also observed, which may indicate an increased susceptibility to arrhythmias [37].

It has been proven that atmospheric conditions may contribute to the occurrence of atrial fibrillation, including low temperature and low air humidity. In a study performed in Boston, USA, which enrolled 200 patients, there were 328 episodes of atrial fibrillation lasting at least 30 seconds in 49 patients. This was due to the low air temperatures in the previous 48 hours. Moreover, lower absolute air humidity had the strongest correlation: each reduction of 0.5 g/m3 in the last 24 hours increased the probability of an atrial fibrillation episode by 4% (95% CI: 0–7%) and by 5% (95% CI: 2%-8%) for exposure in the last two hours. Lower absolute humidity showed a significant relationship with atrial fibrillation, especially in elderly patients and those with a clinical history of arrhythmia. Nguyen et al. concluded that exposure to drier air and lower temperatures were associated with the onset of AF among patients with known cardiac disease, supporting the hypothesis that meteorological conditions trigger acute cardiovascular episodes [38]. Głuszak et al. examined the relationship between AF occurrence and several meteorological conditions, but found no association with temperature, air pressure and relative humidity. They observed, however, a considerable influence of a meteorological cold front on increased admissions to the cardiology care unit for paroxysmal atrial fibrillation. There was no significant relationship between other meteorological elements and episodes of atrial fibrillation. The absence of arrhythmia for many consecutive days was noted during the presence of stationary high atmospheric pressure areas. The author explained this effect by the influence of low-frequency electromagnetic waves occurring in the zone of atmospheric changes which can penetrate buildings. Considering the translocation speed of the electromagnetic waves (300,000 kilometers per second), the effects may be felt many hours before the approach of an atmospheric front. However, the mechanism which leads to the onset of arrhythmia: pathological automatism, triggered activity, early depolarisation, dispersion of the refractory periods in the atrial myocytes or inidirectional block, is not clear [39]. Culic et al. studied supraventricular tachycardia and supraventricular premature beats and found an association between higher relative humidity and higher air pressure [40].

How the mechanisms causing outdoor ambient meteorological conditions affect human physiologic responses remain unknown, although it is considered that colder temperatures and drier air induce a thermoregulation process that activates the sympathetic nervous system and the coagulation system. In the case of the temperature or water content in the inspired air changes results in the degree of airway cooling and drying. A sympathetic reflex-mediated vasoconstriction limits heat loss by redistributing blood to the core, and causes an increase in cardiac output. This increases blood pressure, peripheral arterial resistance,

central blood volume and ventricular filling pressure. As a consequence, the left atrium dilates, leading to fibrosis in long-time observation. This shows that temperature, wind, light wind, precipitation and low air humidity did not lead to an increase in the presence of particular matter (PM2.5, PM10) in the atmospheric air [41, 42, 43]. Knezović et al. showed a very weak positive correlation with air humidity and concentration of air pollutants in an area with a humid continental climate [44]. Rivera-Caravaca et al. clearly acknowledged that in patients with AF taking Vitamin K antagonists (VKAs), high PM10 and low temperature were associated with an increased risk of ischaemic stroke and cardiovascular events, respectively. Both factors increased both major bleeding and mortality risks, which were higher during colder months and seasons [45]. In a very interesting publication, Vencloviene et al. proved that the impact of weather and air pollution on the occurrence of AF depended on the time of day. An increased level of carbon monoxide between 08:00–13:59 in the previous 2–6 days was associated with paroxysmal atrial fibrillation. Between 14:00–21:59 a significant effect of lower temperatures on AF occurrence was observed. During this time interval, no relationship was found between PM concentration and incidence of atrial fibrillation. The risk of an atrial fibrillation episode between 22:00–08:00 was associated with an increased wind speed over the period of 2–4 days before arrhythmia, and decreased PM10 concentration within 2–5 days preceding paroxysmal atrial fibrillation. The impact of pollutants was observed only in patients over the age of 65 [46].

Interestingly, the short-term effects of ambient air pollutants on atrial fibrillation differed by region, with Asia showing the more prominent trend. This may be due to the different levels of air pollutants in different regions. Future research is needed to establish the concentration-response function between the levels of air pollutants and the risk of arrhythmia.

Long-term exposure to air pollution. Long-term exposure to air pollution, including particulate matter, increases respiratory and cardiovascular mortality [2]; however, data on long-term exposure to particulate matter is less well defined. It is not clear which components of air pollution are the most harmful, and which time window of exposure is most relevant. In the publication already cited, Kwon et al. found that long-term exposure to air pollution, including PM2.5, did not affect the development of new-onset atrial fibrillation in healthy patients. Subgroup analyses suggested that long-term effects of PM2.5 were present in patients with heart disease, which is a hypothesis-generating finding [32].

Kim et al. analysed a cohort of 432,587 subjects from the general population who had not been diagnosed with atrial fibrillation, and selected via the Korean National Health Insurance Service – National Sample Cohort from 2009–2013. Medical records were screened from January 2002 to investigate the disease-free baseline period of each subject, and were followed until December 2013. The authors matched each subject's residential ZIP code with hourly measurements of air pollutant (particulate and gaseous) concentration and meteorological (temperature and humidity) data during the study period. They found significant association between incidents of atrial fibrillation and long-term exposure to PM2.5 (HR-1.179 (1.176–1.183) for 10 μg/mm3 increments; p<0.001), PM10 (HR-1,034 (1.033–1.036) for 10 μg/mm3 increments; p<0.001) and gaseous air pollutants during the study period. After sub-analysis, the effect of long-term exposure of PM2.5 regarding atrial fibrillation incidence was more significant in males (HR – 1.187 (1.183–1.192), p<0.001), older subjects (aged ≥ 60 years; HR-1.194 (1.183–1.199), p<0.001), subjects with prior myocardial infarction (HR-1.203 (118.6–1.221), p<0.001), with obesity defined as body mass index (BMI) ≥ 27.5 kg/m2 (HR-1.191 (1.183–1.199), p<0.001) and with a history of arterial hypertension (HR-1.191 (1.185–1.197); p<0.001). In subgroup analysis, higher exposure of cigarette smoking subjects showed a smaller association, compared to non-smokers. This was explained by the fact that air pollution effects might be diminished in subjects with chronic pulmonary diseases [47].

Nevertheless, the long-term effects of exposure to PM2.5 on atrial fibrillation incidence in the general population have not yet been well-established. Monrad et al. investigated the association between long-term exposure to traffic-related air pollution and incident atrial fibrillation in the general population. However, they found no significant association and PM2.5 concentrations were not analysed. In this study, a 10 μg/mm3 increase in 10-year time-weighted mean exposure to NO2 was associated with an 8% higher risk of atrial fibrillation (incidence rate ratio 1.08; 95% CI: 1.01–1.14). The authors found no clear tendencies regarding effect modification of the association between NO2 and atrial fibrillation by gender, smoking, arterial hypertension and myocardial infarction. There were some indications of a stronger association among participants with arterial hypertension, suggesting the hypertensive subjects are more susceptible to air pollution-triggered atrial fibrillation. Interestingly, even though myocardial infarction is a risk factor for arrhythmia, such as atrial fibrillation, the history of myocardial infarction did not increase the incidence of AF [48, 49, 50]. The association between exposure to air pollution and risk of arrhythmias is less when compared to already established risk factors, e.g. obesity or alcohol consumption, although a relatively small association with atrial fibrillation may have a relevant impact on the population given the widespread nature of air pollution [51, 52]. Another important study showed no association between incident atrial fibrillation and exposure to particulate and gaseous air pollutants (PM2.5, PM10, SO2, NO2, CO). The authors analysed two Swedish cohorts (PPS cohort and GOT-MONICA cohort) to investigate the effects of total and source-specific particulate matter on incidents of cardiovascular disease (ischaemic heart disease, stroke, heart failure and atrial fibrillation) for different time windows of exposure (lag 0 – last year of exposure, lag 1–5 years and exposure of study start). During the studied period, there were 1,712 new-onset atrial fibrillation cases [53]. Table 1 shows the Hazard ratio (95% confidence interval) for total PM10, PM 2.5 and BC (black carbon) exposures, and incidents of atrial fibrillation for the last year of exposure (lag 0), an average of the previous five years (lag 1–5), and the exposure in 1990 (at study start) in the cohort, using the main confounder model.

A previous study showed a decreased correlation between air pollution and atrial fibrillation in chronic lung disease. Kim et al. analysed two groups of patients: former smokers, and current smokers who smoked at least 20 pack-years and smokers who smoked less than 20 pack-years. The first group had a lower association between PM2.5 and PM10 exposure and incident of atrial fibrillation [54]. In a meta-analysis

Table 1. Hazard ratio (with 95% confidence interval) for total PM10, PM 2.5 and BC (black carbon) exposures and incident of atrial fibrillation for the last year of exposure (lag 0), an average of the previous 5 years (lag 1–5) and the exposure in 1990 (at study start) in the cohort, using the main confounder model [51]

Exposure (increment)	Lag (years)	PPS	GOT-MONICA
PM10 (10 µg/mm^3)	0	0.91 (0.75–1.10)	0.91 (0.60–1.38)
	1–5	1.07 (0.83–1.39)	0.63 (0.37–1.08)
	1990	1.04 (0.78–1.38)	1.03 (0.60–1.77)
PM2.5 (5 µg/mm^3)	0	0.92 (0.77–1.10)	0.78 (0.54–1.14)
	1–5	1.09 (0.84–1.42)	0.46 (0.28–0.75)
	1990	1.02 (0.79–1.32)	0.87 (0.53–1.43)
BC (1 µg/mm^3)	0	1.01 (0.86–1.18)	0.95 (0.64–1.40)
	1–5	0.98 (0.83–1.17)	1.17 (0.82–1.66)
	1990	1.03 (0.88–1.21)	1.07 (0.79–1.45)

published by Chen M. et al., long-term exposure to all air pollutants (PM2.5, PM10, SO2, NO2, CO) was associated with increased AF incidence in a healthy population [55].

Stroke is one of the most serious complications of atrial fibrillation, and there is growing evidence that exposure to PM2.5 and PM10 may increase its risk. Yang et al. demonstrated that a 10 µg/mm3 increase of particulate matter concentration led to increased risk of stroke by 1.20% (95% CI; 0.22–2.18%) for PM2.5 and 0.58% (95% CI; 0.31–0.86%) for PM10 [56]. An increased risk of ischaemic strokes has been documented in response to the increase in PM2.5; however, single observations indicate an increased risk of haemorrhagic strokes due to exposure to nitrates (RR – 1.19; 95% CI; 1.07–1.032) [57].

Data on long-term exposure to particulate matter and the incidence of atrial fibrillation are inconclusive and often contradictory. To determine the extent to which air pollution contributes to cardiac arrhythmia and other specific causes of cardiovascular morbidity and mortality, a significant amount of data still needs to be accumulated.

Limitations. The discussed studies have several limitations. The source of air pollutants was different in regions where the selected studies were performed. Most of the studies reported the effect of single air pollutants, and only some of them provided the information for multiple-pollutant models. The presented research was carried out in many countries with different levels of medical registers, different air quality, and using various research models and methods for estimating the dose-health effect relationship.

CONCLUSIONS

Literature data indicate that human exposure to air pollution is associated with an increased risk of arrhythmias, particularly atrial fibrillation. Considering the increased risk of stroke and all-cause mortality related to atrial fibrillation, further efforts to reduce air pollution exposure should be undertaken worldwide to decrease the negative health effects on the general population. Laden et al. showed that with a decrease in the concentration of PM by 10 µg/mm3 after 10 years, observed a 27% decrease in the number of deaths due to diseases of the cardiovascular system [58]. To better understand the effects of air pollution on the incidence of atrial fibrillation and its related impact on public health in the most polluted regions of the world, more high-quality studies are needed. Future investigations will help to expand our knowledge related to toxicities of different components of air pollution and their arrhytmogenic potential when action alone and in combination. Therefore, it is important to reduce airborne emissions as much as possible which may lead to an improvement in the quality and length of life without disease.

REFERENCES

1. Forouzanfar MH, Aleksander L, Anderson HR, et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries. 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 2015;386(10010):2287–2323. doi:10.1016/S0140-6736(15)00128-2
2. EEA. Air quality in Europe – 2014 Report. EEA Report No 5/2014. European Environment Agency, Copenhagen. doi:10.2800/22775
3. Zivin JG, Neidell M. Air pollution's hidden impacts. Science. 2018;359(6371):39–40. doi:10.1126/science.aap7711
4. Brook RD, Newby DE, Rajagopalan S. The global threat of outdoor ambient air pollution to cardiovascular health: time for intervention. JAMA Cardiol. 2017;2(4):353–354. doi:10.1001/jamacardio.2017.0032
5. Krzeszowiak J, Pawlas K. Particulate matter (PM2,5 and PM10), properties and epidemiological siginificance for respiratory and cardiovascular diseases. A review of the literature on the effects of short- and long-term exposure. Med Srod. 2018;21(2):7–13. doi:10.19243/2018201
6. Nattel S, Harada M. Atrial remodelling and atrial fibrillation: Recent advances and translational perspectives. J Am Coll Cardiol. 2014;63(22):2335–2345. doi:10.1016/j.jacc.2014.02.555
7. Gorenek B, Pelliccia A, Benjamin EJ, et al. European Heart Rhythm Association (EHRA)/European Association of Cardiovascular Prevention and Rehabilitation (EACPR) position paper on how to prevent atrial fibrillation endorsed by the Heart Rhythm Society (HRS) and Asia Pacific Heart Rhythm Society (APHRS). Europace. 2017;19(2):190–225. doi:10.1093/europace/euw242
8. Larsson SC, Drca N, Wolk A. Alcohol consumption and risk of atrial fibrillation: A prospective study and dose – response meta – analysis. J Am Coll Cardiol. 2014;64(3):281–289. doi:10.1016/j.jacc.2014.03.048
9. Shao Q, Liu T, Korantzopoulos P, et al. Association between air pollution and development of atrial fibrillation: A meta-analysis of observational studies. Heart Lung. 2016;45(6):557–562. doi:10.1016/j.hrtlng.2016.08.001
10. Hamanaka RB, Mutlu GM. Pariculate Matter Air Pollution. Effects on the Cardiovascular system. Front Endocrinol. 2018;9:680. doi: 10.3389/fendo.2018.00680
11. Liu C, Cai J, Qiao I, et al. The acute effects of fine particulate matter constituents on blood inflammation and coagulation. Environ Sci Technol. 2017;51(14):8128–8137. doi:10.1021/acs.est.7b00312
12. Lucking AJ, Lundback M, Mills NL, et al. Diesel exhaust inhalation increases thrombus formation in man. Eur Heart J. 2008;29(24):3043–3051. doi: 10.1093/eurheartj/ehn464
13. Dadvand P, Ostro B, Amato F, et al. Particulate air pollution and preeclampsia: a source-based analysis. Occup Environ Med. 2014;71(8):570–577. doi: 10.1136/oemed-2013-101693
14. Leary PJ, Kaufman JD, Barr RG, et al. Traffic – related air pollution and the right ventricle. The multi-ethnic study of atherosclerosis. Am J Respir Crit Care Med. 2014;189:(9)1093–1100. doi: 10.1164/rccm.201312-2298OC
15. Cakmak S, Dales R, Kauri LM, et al. Metal composition of fine particulate air pollution and acute changes in cardiorespiratory physiology. Environ Pollut. 2014;189:208–214. doi:10.1016/j.envpol.2014.03.004
16. Franklin BA, Brook R, Arden P. Air pollution and cardiovascular disease. Curr Probl Cardiol. 2015;40(5):207–238. doi:10.1016/j.cpcardiol.2015.01.003
17. Tripathi P, Deng F, Scruggs AM, et al. Variation in doses and duration of particulate matter exposure in bronchial epithelial cells results in upregulation of different genes associated with airway disorders. Toxicol In vitro. 2018;51:95–105. doi:10.1016/j.tiv.2018.05.004
18. Jin X, Xue B, Zhou Q, et al. Mitochondrial damage mediated by ROS incurs bronchial epithelial cell apoptosis upon ambient PM2,5 exposure. J Toxicol Sci. 2018;43(2):101–111. doi:10.2131/jts.43.101.

19. Marchini T, Wolf D, Michael N A, et al. Acute exposure to air pollution particulate matter aggravates experimental myocardial infarction in mice by potentiating cytokine secretion from lung macrophages. Basic Res Cardiol. 2016;111(44):1–14. doi:10.1007/s00395-016-0562-5
20. Hunter CA, Jones SA. IL – 6 as a keystone cytokine in health and disease. Nat Immunol. 2015;16(5):448–457. doi:10.1038/ni.3153
21. Li H, Cai J, Chen R, et al. Particulate matter exposure and stress hormone levels: a randomized, double-blind, crossover trial of air pollution. Circulation. 2017;136(7):618–627. doi:10.1161/CIRCULATIONAHA.116.026796
22. Xu X, Liu C, Xu Z, et al. Long-term exposure to ambient fine particulate pollution induces insulin resistance and mitochondrial alteraration in adipose tissue. Toxicol Sci. 2011;124(1):88–98. doi:10.1093/toxsci/kfr211
23. Madrigano J, Baccarelli A, Mittleman MA, et al. Prolonged exposure to particulate pollution, genes associated with glutathione pathways, and DNA methylation in cohort of older man. Environ Health Perpsect. 2011;119(7):977–982. doi:10.1289/ehp.1002773
24. Baccarelli A, Wright RO, Bollati V, et al. Rapid DNA methylation changes after exposure to traffic particles. Am J Respir Crit Care Med. 2009;179(7):572–578. doi:10.1164/rccm.200807-1097OC
25. Wichmann HE, Mueller W, Allhoff P, et al. Health effects during a smog episode in West Germany in 1985. Environ Helath Perspect. 1989;79:89–99. doi:10.1289/ehp.897989
26. Milovjevic A, Wilkinson P, Armstrong B, et al. Short-term effects of air pollution on a range of cardiovascular events in England and Wales: case – crossover analysis of the MINAP database, hospital admissions and mortality. Heart. 2014;100(14):1093–1098. doi:10.1136/heartjnl-2013-304963
27. Link MS, Luttman-Gibson H, Schwartz J, et al. Acute exposure to Air Pollution Triggers Atrial Fibrillation. J Am Coll Cardiol. 2013;62(9):816–825. doi:10.1016/j.jacc.2013.05.043
28. Liu X, Kong D, Liu Y, et al. Effects of the short-term exposure to ambient air pollution on atrial fibrillation. Pacing Clin. Electrophysiol. 2018;41(11):1441–1446. doi:10.1111/pace.13500
29. Folino F, Buja G, Zanotto G, et al. Association between air pollution and ventricular arrhythmias in high-risk patients (ARIA study): A multicenter longitudinal study. Lancet Planet Health. 2017;1:e58-e64. doi:10.1016/S2542-5196(17)30020-7
30. Gallo E, Folino F, Buja G. Daily exposure to air pollution particulate matter is associated with atrial fibrillation in high-risk patients. Int J Environ Res Public Health. 2020;17(17):6017. doi:10.3390/ijerph17176017
31. Cakmak S, Kauri L, Shutt R, et al. The association between ambient air quality and cardiac rate and rhythm in ambulatory subjects. Environ Int. 2014;73:365–371. doi:10.1016/j.envint.2014.08.015
32. Kwon OK, Kim S-H, Kang S-H, et al. Associate of short- and long-term exposure to air pollution with atrial fibrillation. Eur J Prev Cardiol. 2019;26(11):1208–1216. doi:10.1177/2047487319835984
33. Krzeszowiak J, Pawlas K, Rabczenko D. Effect of short-term exposure to particulate matter (PM2,5 and PM10) and its impact on sudden exacerbations of selected cardiovascular and respiratory diseases in Wrocław during 2009–2013 based on registers of ambulance emergency calls. Med Srod. 2018;22(3–4):49–56. doi:10.26444/ms/132865
34. Halldorsdottir S, Finnbjornsdottir RG, Elvarsson BT, et al. Ambient nitrogen dioxide is associated with emergency hospitals visits for atrial fibrillation: a population-based case – crossover study in Reykjavik, Iceland. Environ Health. 2022;21(2):1–12. doi.10.1186/s12940-021-00817-9
35. Solimini AG, Renzi M. Association between air pollution and emergency room visits for atrial fibrillation. Int J Environ Res Public Health. 2017;14(6):661. doi:10.3390/ijerph14060661
36. Meng X, Liu C, Chen R, et al. Short term association of ambient nitrogen dioxide with daily total, cardiovascular and respiratory mortality: multilocation analysis in 398 cities. BMJ. 2021; 372:n534. doi:10.1136/bmj.n534
37. Huang YC, Rappold AG, Graff DW, et al. Synergistic effects of exposure to concentrated to ambient the pollution particles and nitrogen dioxide in humans. Inhal Toxicol. 2012;24(12):790–797. doi:10.3109/08958378.2012.718809
38. Nguyen JL, Link MS, Luttmann-Gibson H, et al. Drier air, lower temperatures, and triggering of paroxysmal atrial fibrillation. Epidemiology. 2015;26(3):374–380. doi:10.1097/EDE.0000000000000284
39. Głuszak A, Kocoń S, Żuk K, et al. Episodes of atrial fibrillation and meteorological conditions. Kardiol Pol. 2008;66(9):958–963.
40. Culić V, Silić N, Hodzić M. Triggering of supraventricular tachycardia by physical activity and meteorologic factors. Int J Cardiol. 2013;168(4):4295–4300. doi:10.1016/j.ijcard.2013.04.195
41. Giesbrecht GG. The respiratory system in a cold environment. Aviat Space Environ Med. 1995;66(9):890–902.
42. Larsson K, Tornling G, Gavhed D, et al. Inhalation of cold air increases the number of inflammatory cells in the lungs in healthy subjects. Eur Respir J. 1998;12(4):825–830. doi:10.1183/09031936.98.12040825
43. Kupari M, Koskinen P. Seasonal variation in occurence of acute atrial fibrillation and relation to ait temperature and sale of alcohol. Am J Cardiol. 1990;66(20):1519–1520. doi:10.1016/0002-9149(90)90549-g
44. Knezović M, Pintarrić S, Jelavić MM, et al. Correlation between concentration of air pollutants and occurence of cardiac arrhythmias in a region with humid continental climate. Acta Clin Croat 2017;56:3–9. doi:10.20471/acc.2017.56.01.01
45. Rivera-Caravaca JM. Roldan V, Vicente V, et al. Particulate matter and temperature: Increased risk of adverse clinical outcomes in patients with atrial fibrillation. Mayo Clin Proc. 2020;95(11):2360–2369. doi:10.1016/j.mayocp.2020.05.046
46. Vencloviene J, Babarskiene R M, Dobozinskas P. et al. The short-term associations of weather and air pollution with emergency ambulance calls for paroxysmal atrial fibrillation. Environ Sci Pollut Res. 2017;24:15031–15043. doi:10.1007/s11356-017-9138-7
47. Kim I S, Yang P S, Lee J, et al. Long-term exposure of fine particular matter air poluution and incident atrial fibrillation in general population: A nationwide cohort study. Int J Cardiol. 2019;283:178–183. doi:10.1016/j.ijcard.2018.12.048
48. Monrad M, Sajadieh A, Christensen JS, et al. Long-term exposure to traffic-related air pollution and risk of incident atrial fibrillation: a cohort study. Environ Health Perspect. 2017; 125(3):422–427. doi:10.1289/EHP392
49. Schnabel RB, Yin X, Gona P, et al. 50 year trends in atrial fibrillation prevalence, incidence, risk factors, and mortality in the Framingham Heart Study. Lancet. 2015;386(9989):154–162. doi:10.1016/S0140-6736(14)61774-8
50. Wolf K, Schneider A, Breitner S, et al. Association between short-term exposure to particulate matter and ultrafine particles and myocardial infarction in Augsburg, Germany. Int J Hyg Environ Health. 2015;218(6):535–542. doi:10.1016/j.ijheh.2015.05.002
51. Wanahita N, Messerli F H, Bangalore S, et al. Atrial fibrillation and obesity-results of a meta-analysis. Am Heart J. 2008;155(2):310–315. doi:10.1016/j.ahj.2007.10.004
52. Samokhvalov AV, Irving HM, Rehm J. Alcohol consumption as a risk factor for atrial fibrillation: a systematic review and meta-analysis. Eur J Cardiovasc Prev Rehabil. 2010;17(6):706–712. doi:10.1097/HJR.0b013e32833a1947
53. Stockfelt L, Andersson EM, Molnar P, et al. Long-term effects of total and source-specific particulate air pollution on incident cardiovascular disease in Gothenburg, Sweden. Environ Res. 2017;158:61–71. doi:10.1016/j.envres.2017.05.036
54. Kim IS, Sohn J, Lee SJ, et al. Association of air pollution with increased of incidence of ventricular tachyarrhythmias recorded by implantable cardioverter – defibrillators: vulnerable patients to air pollution. Int J Cardiol. 2017;240:214–220. doi:10.1016/j.ijcard.2017.03.122
55. Chen M, Zhao J, Zhuo C, et al. The association between ambient air pollution and atrial fibrillation. A systematic review and meta-analysis. Int Heart J. 2021;62(2):290–297. doi:10.1536/ihj.20-523
56. Yang WS, Wang X, Deng Q, et al. An evidence-based appraisal of global association between air pollution and risk of stroke. Int J Cardiol. 2014;175(2):307–313. doi:10.1016/j.ijcard.2014.05.044
57. Chen SY, Lin YL, Chang WT, et al. Increasing emergency room visits for stroke by elevated levels of fine particulate constituents. Sci Total Environ. 2014;473–474:446–450. doi:10.1016/j.scitotenv.2013.12.035
58. Laden F, Schwartz J, Speizer FE, et al. Reduction in fine particulate air pollution and mortality. Extended follow-up of the Harvard Six Cities Study. Am J Respir Crit Care Med. 2006;173(6):667–672.doi.org/10.1164/rccm.200503-443OC