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Meteorological Influence on Atrial Fibrillation and Flutter: A Nationwide Observational Study in South Korea (2010–2022)

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Abstract

Background and rationale

The impact of meteorological factors, including atmospheric temperature, humidity, and wind speed, on the incidence of atrial fibrillation and flutter (AF) has been the subject of several studies, but the findings have been inconsistent. Given the complex and multifaceted nature of this relationship, a larger-scale study was necessary to provide sufficient statistical power and elucidate potential associations between them. The aim of this study was, thus, to investigate the potential associations between meteorological factors and the incidence of AF.

Methods

The South Korean government provides open access to national health insurance and weather data for its citizens; the data was available from January 2010 to July 2022. The national health insurance data includes the monthly number of patients diagnosed with a specific condition, reflecting the incidence and prevalence of the condition. Pearson correlation analyses were performed using the statistical analysis software, SAS® OnDemand for Academics (SAS Institute Inc., Cary, North Carolina, United States), to examine the association between each month's national average climate data and the number of patients diagnosed with AF.

Results

The number of patients diagnosed with AF in the total population showed a statistically significant correlation only with average wind speed (correlation coefficient (r)=-0.42, 95%CI -0.55 to -0.28, $p<0.001$) and sunshine duration (r=0.27, 95%CI 0.12 to 0.41, $p<0.001$). Among females aged 20-24 years, there was a statistically significant association with other variables, including average temperature, precipitation, humidity, and atmospheric pressure ($p<0.05$). Diurnal temperature variation showed inconsistent associations across different age and sex groups.

Conclusion

The number of patients diagnosed with AF is negatively correlated with average wind speed and positively correlated with sunshine duration in the general population, particularly among the elderly. There was no significant association between the number of patients diagnosed with AF and average temperature, precipitation, or humidity, except for females aged 20-24 years, who exhibited a significant association with these variables. However, it is important to note that these correlations do not establish causality.

Categories: Cardiology, Environmental Health, Epidemiology/Public Health
Keywords: epidemiology and biostatistics, cardiology research, cardio vascular disease, health related air pollution, sun exposure, air temperature, climate weather, meteorological factor, atrial flutter, atrial fibrillation

Introduction

The incidence of atrial fibrillation and flutter (AF) has been extensively studied in relation to meteorological factors, including atmospheric temperature, humidity, and wind speed. However, these studies have yielded inconsistent findings, necessitating a larger-scale investigation to enhance statistical power and clarify the potential associations between meteorological factors and AF.

Temperature variability has been linked to the risk of cardiac arrhythmias, including AF [1]. Nonetheless, the significance of atmospheric temperatures in relation to AF remains inconclusive [2,3]. Several studies have suggested that low temperatures, rather than high temperatures, increase the risk of AF [4-11]. Colder temperatures are believed to impact microvascular function and resistance, placing strain on the cardiovascular system [12]. Another theory proposes that heat-induced heat shock proteins may offer protection against myocardial remodeling and the development of AF in higher temperatures [13,14]. However, it is important to note that alcohol consumption plays a significant confounding role in cold weather, as it is a well-known major risk factor for AF, and alcohol sales tend to increase during colder seasons [15]. On the other hand, certain studies indicate that high temperatures may also elevate the risk of AF, particularly in the presence of heat stroke risk factors such as high temperature, high humidity, precipitation, and prolonged sunlight exposure [16-18]. Overall, it appears that both extreme cold and hot temperatures increase the risk of AF [19,20].

Other meteorological factors, including humidity, precipitation, wind speed, volatile gases, and fine particles in the air, have also been examined, but the results have been inconsistent. The effect of humidity and precipitation on the risk of AF has been reported as increasing [16,17,20], decreasing [10], or having no significant effect [2,6,21]. Fine particles, such as particulate matter (PM) with a diameter of 2.5 micrometers or smaller (PM2.5), as well as PM10, have demonstrated an increased risk in certain studies [5,11,22-24], while others did not find a statistically significant association with PM2.5 [25] or PM10 [26]. Associations have been observed between elevated levels of other air pollutants, such as ozone (O3) [27], nitrogen dioxide (NO2) [9,22,26], and sulfur dioxide (SO2) [22], and the risk of AF. However, some studies did not find a statistically significant association with O3 [22,24], NO2 [24], or SO2 [24]. The relationship between carbon monoxide (CO) and AF has been inconsistent, with some studies reporting an association [11] and others finding no statistical significance [22,24].

Atmospheric pressure and wind speed significantly influence the concentration and dispersion of air pollutants [28]. Increased atmospheric pressure has been correlated with a higher incidence of AF [20,21]. Low wind speeds can result in the stagnation of air pollutants, leading to elevated levels of PM and nitrogen dioxide, which are known potential contributors to AF [28]. However, different studies have produced conflicting results. One study suggests that high wind speeds, rather than low wind speeds, are associated with an increased incidence of AF [11], while another study reports no significant effect of wind speed on AF [2].

Additionally, it is worth noting that the impact of meteorological factors on humans may be diminishing [2] due to the increasing amount of time spent indoors and the advancements in air conditioning systems, which have effectively reduced the influence of weather on individuals [29].

The aim of this study is to investigate the potential associations between meteorological factors and the incidence of AF. The study seeks to address the inconsistent findings from previous research by conducting a larger-scale investigation, utilizing open-access national health insurance and weather data in South Korea. Specifically, the study aims to explore the relationships between atmospheric temperature, humidity, wind speed, and other meteorological variables with the occurrence of atrial fibrillation and flutter. The ultimate goal is to provide a more comprehensive understanding of the complex and multifaceted nature of the relationship between meteorological factors and AF.

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Materials And Methods

Healthcare data

The Healthcare Big Data Hub [30], operated by the South Korean government, provides open access to national health insurance data for approximately 50 million citizens. This comprehensive dataset includes information on the monthly number of patients diagnosed with specific conditions, categorized according to the Korean Standard Classification of Diseases (KCD). The KCD system is a slightly modified version of the International Classification of Diseases 10 (ICD-10). The data is further segmented by age, in five-year intervals, and sex groups, allowing for detailed analysis. The available data covers the period from January 2010 to July 2022.

Meteorological data

The Korea Meteorological Association [31] offers open access to national climate data, including metrics such as national average temperature, precipitation, humidity, wind speed, and sunshine hours. Additional weather indices, such as the heat index and wind chill index, were calculated using formulas from the United States National Weather Service [32]. Environmental and air pollution data were obtained from the Korea Statistical Information Service [33].

Statistical analysis

Pearson correlation analyses were conducted using the statistical analysis software, SAS® OnDemand for Academics (SAS Institute Inc., Cary, North Carolina, United States), to examine the potential associations between the national average climate data for each month and the number of patients diagnosed with AF.

Results

Healthcare data

In 2010, the National Health Insurance registered a total population of approximately 48.9 million people, consisting of 24.6 million males and 24.3 million females. By 2021, the total population had increased to about 51.4 million, with 25.7 million males and 25.7 million females. Over time, there has been a significant advancement in the age distribution of the population. The median age was 38.1 in 2010 and 44.5 in 2021, while the mean age was 38.1 in 2010 and 43.5 in 2021. Baseline data for 2022 is currently unavailable. Although the total population has not experienced significant growth, there has been a notable increase in the number of patients diagnosed with AF over the years (Figure 1, Table 1).

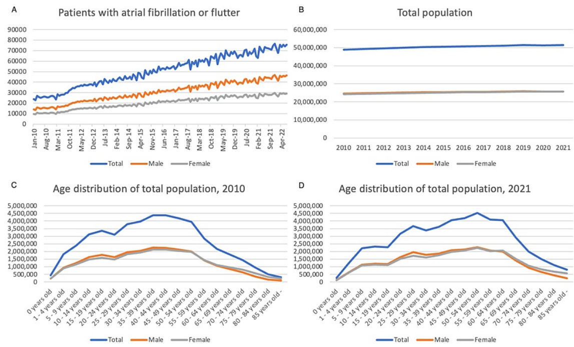

FIGURE 1: Baseline characteristics of total population and the number of patients with AF

(A) Monthly number of patients with atrial fibrillation or flutter who utilized the national health insurance system; (B) Total number of people enrolled in national health insurance each year; (C) Age distribution of the total population in 2010; (D) Age distribution of the total population in 2021, showing the advancement of age over time.

AF: atrial fibrillation and flutter

	2010	2021
Total Population	48,906,765	51,412,137
Male	24,648,532	25,742,882
Female	24,258,263	25,669,255
Male-to-Female Ratio	1.016	1.003
Mean Age	38.1	43.5
Median Age	38.1	44.5

TABLE 1: Baseline characteristics of the total population

Meteorological data

South Korea features a continental climate characterized by very cold, dry winters and very hot, humid summers (Figure 2, Table 2). Spring and autumn are relatively short, and temperatures are mild and generally quite pleasant. There are only minimal regional variations in weather conditions throughout the country. Most air pollutants have been steadily reduced over the years following green energy policy. Of note, weather indices are intended for certain weather conditions. For example, the wind chill index is applied in winter, while the heat index is applied in summer.

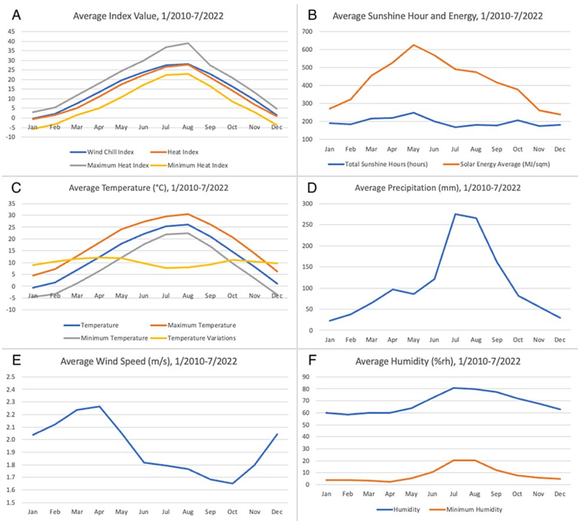

FIGURE 2: Weather variables

(A) Monthly national average values of wind chill index (blue, designed for cold season), heat index (orange, designed for hot season), maximum heat index (gray), and minimum heat index (yellow); (B) Monthly national average of total sunshine hours (blue) and solar energy (orange); (C) Monthly national average of average atmospheric temperature (blue, °C), maximum temperature (orange, °C), minimum temperature (gray, °C), and intraday temperature variation (yellow, °C); (D) Monthly national average of precipitation (blue, mm); (E) Monthly national average of average wind speed (blue, m/s); (F) Monthly national average of average humidity (blue, %rh) and minimum humidity (orange, %rh) from January 2020 to July 2022.

Weather Variables	Mean	Standard Deviation	Median	Minimum	Maximum
Temperature (°C)	13.01	9.28	13.80	-4.80	27.30
Maximum Temperature (°C)	18.43	9.11	20.20	0.50	32.30
Minimum Temperature (°C)	8.33	9.66	7.90	-9.80	23.80
Temperature Variation (°C)	10.10	1.95	10.20	-3.00	13.70
Precipitation (mm)	107.62	99.93	76.30	2.60	498.10
Daily Maximum Precipitation (mm)	255.60	218.93	195.00	14.50	1131.00
Hourly Maximum Precipitation (mm)	40.53	23.59	36.00	5.10	102.70
Humidity (%rh)	67.72	8.77	67.00	50.00	86.00
Minimum Humidity (%rh)	8.32	7.08	6.00	0.00	25.00
Wind Speed (m/s)	1.94	0.28	1.90	1.30	2.70
Maximum Wind Speed (m/s)	22.10	5.54	21.50	12.80	49.00
Maximum Instantaneous Wind Speed (m/s)	29.51	6.05	28.60	19.20	56.50
Sunshine Hours (hour)	197.09	37.69	194.30	96.20	304.20
Solar Energy (MJ/m^2)	421.18	129.05	426.81	172.31	754.45

TABLE 2: Simple statistics of the weather variables over a total of 151 months

Statistical analysis

In the overall population, a statistically significant correlation was observed between the number of patients diagnosed with AF and average wind speed (correlation coefficient (r)=-0.42, 95%CI -0.55 to -0.28, p<0.001), as well as sunshine duration (r=0.27, 95%CI 0.12 to 0.41, p<0.001). Subgroup analysis revealed that these correlations were more pronounced in older males and females, particularly in males aged over 35 and females aged over 55. Regarding diurnal temperature variation or intraday temperature variation, its significance varied across different age and sex groups, resulting in inconsistent but statistically significant correlations. In our analysis, notable correlations with the traditional risk factors were observed only among females, predominantly aged 20-24 years. Females in this age group showed a statistically significant association with other variables, including average temperature (r=0.22, 95%CI 0.06 to 0.37, p=0.007), precipitation (r=0.22, 95%CI 0.07 to 0.37, p=0.006), humidity (r=0.22, 95%CI 0.06 to 0.37, p=0.006), and atmospheric pressure (r=-0.22, 95%CI -0.39 to -0.04, p=0.014). However, similar associations were not observed in other age and sex groups. The results of the Pearson correlation analysis of this study are given in the Appendix.

Discussion

Negative correlation between wind speed and AF

The number of patients diagnosed with AF displayed a negative correlation with average wind speed (r = -0.42, 95%CI -0.55 to - 0.28, p < 0.001). Wind speed has a significant impact on the concentration and dispersion of air pollutants [28]. Lower wind speeds can lead to the stagnation of air pollutants, resulting in higher levels of PM and nitrogen dioxide, both of which are known potential contributors to AF [28]. However, it is worth noting that previous studies have suggested a positive association between higher wind speeds and the occurrence of AF, which is opposite to this study's findings. Researchers have proposed hypotheses suggesting that higher wind speeds may contribute to cardiovascular stress and AF through mechanisms such as atmospheric pressure oscillations [34], as well as wind-induced increases in the intensity of the atmospheric electric field [11]. Nevertheless, it is important to recognize that these connections remain speculative. Further investigation through experimental studies may be necessary to gain a better understanding of these relationships.

Positive correlation between sunlight duration and AF

The number of patients diagnosed with AF showed a positive correlation with monthly sunshine duration (r=0.27, 95%CI 0.12 to 0.41, p<0.001). Prolonged exposure to sunlight may also increase the risk of heat exhaustion or heat stroke, potentially triggering AF [35,36]. However, there are studies suggesting that sunlight may have a protective effect against paroxysms of AF [37,38]. Previous research has indicated a higher incidence of AF during colder months when sunshine duration is typically shorter, rather than longer [4-11]. It is important to consider the close relationship between weather variables in specific locations, which can limit the meaningful interpretation of these findings. For instance, sunshine duration is closely associated with temperature and precipitation. It tends to be longer on high-temperature days and shorter on low-precipitation days, but these relationships can vary depending on the location. For example, in South Korea, sunshine duration can be shorter during the summer due to a higher number of rainy days, whereas in Michigan, United States, it is longer on hot summer days. Hence, higher temperatures might be linked to shorter sunshine duration in South Korea but longer sunshine duration in Michigan. This could potentially lead to misleading and contradictory correlations between sunshine duration and the incidence of atrial fibrillation or flutter across different regions. These region-specific relationships impose limitations on the meaningful interpretation of the correlation between sunlight duration and AF.

Weather susceptibility of the female population aged 20-24 years

Females in the 20-24-year age group exhibited a statistically significant association with traditional risk factors, including average temperature (r=0.22, 95%CI 0.06 to 0.37, p=0.007), precipitation (r=0.22, 95%CI 0.07 to 0.37, p=0.006), humidity (r=0.22, 95%CI 0.06 to 0.37, p=0.006), and atmospheric pressure (r=-0.22, 95%CI -0.39 to - 0.04, p=0.014). Several studies have indicated that females may exhibit higher sensitivity to climate change [39,40]. Positive correlations with average temperature, precipitation, and humidity can potentially be attributed to conditions commonly experienced by young females. Autonomic dysfunction, postural orthostatic hypotension (POTS) [41], multiple sclerosis (MS) [42-44], and various autoimmune diseases are known to be relatively more prevalent in young females. It is known that postural orthostatic tachycardia syndrome (POTS) [41], multiple sclerosis (MS) [42-44], and certain autoimmune diseases [45] tend to worsen in hot and humid conditions. Therefore, it can be hypothesized that stress induced by the exacerbation of these underlying conditions may trigger episodes of atrial fibrillation in young females. While previous studies have shown positive correlations between atmospheric pressure and atrial fibrillation [20,21], our findings indicate a negative correlation in young females. This might suggest that the change or gradient of atmospheric pressure may have a greater effect on atrial fibrillation than the actual pressure itself. Nevertheless, meaningful interpretation is significantly constrained by the absence of a causal relationship due to the observational study design and the presence of strong connections and multicollinearities among the variables.

Limitations

Nature and Accuracy of Data

The data consists of the monthly number of patients recorded for a specific diagnosis under national health insurance. Although it is expected to provide insights into the incidence and prevalence of the condition, it may not necessarily align with the true incidence and prevalence due to various factors. While the data source itself is reliable, insurance claims for a specific diagnosis are often based on initial impressions and medical history. This can introduce potential inaccuracies, as these impressions may not always align with confirmed diagnoses by electrophysiologists or other specialists. Moreover, cases may be underreported, particularly among subgroups with limited healthcare access or those less inclined to seek medical attention, as they won't be accounted for in the total number of patients. Therefore, caution should be exercised when interpreting the data, as it may not fully capture the true prevalence and incidence of the condition.

Scientific Plausibility

This study revealed statistically significant associations between wind speed, sunlight, and the occurrence of AF. Many hypotheses have been proposed as discussed above regarding the impact of various weather variables on cardiovascular stress, including AF, but some of these hypotheses are speculative and lack experimental evidence.

Independence of Events and Meaningless Correlation

The study is retrospective and observational in nature, which limits its ability to establish a cause-and-effect relationship between variables. In the context of an observational study, a statistically significant correlation between two variables does not necessarily indicate a meaningful relationship. Each event can be independent and not directly related to each other. For instance, the increase in AF cases may be influenced by the aging population, while the decrease in air pollutants may be attributed to government initiatives focused on implementing renewable energy policies to reduce emissions. Although statistical analysis may reveal a negative correlation between AF and air pollutants, it does not establish a causal relationship between the two. Each of these factors operates independently, with its own distinct underlying reasons. These confounding factors introduce bias and present challenges in establishing a direct cause-and-effect relationship. To determine the reasons behind the association between a specific factor and a particular outcome, experimental studies would be necessary.

Multicollinearity between Meteorological Variables

Multicollinearity, also known as collinearity, is a phenomenon in which one predictor variable in a multiple regression model can be accurately predicted from the others with a substantial degree of accuracy. For instance, faster winds may disperse airborne dust, potentially resulting in a decrease in PM concentration [28]. Therefore, when statistical analysis is employed to explore potential correlations between wind speed and respiratory disease, the findings do not necessarily imply a direct relationship between wind speed and respiratory disease. Instead, they may indicate a connection between PM concentration and respiratory disease. The interconnected nature of meteorological variables poses challenges in isolating their individual effects and conducting precise multiple regression analyses [29]. Furthermore, the linear relationship between the meteorological variables can significantly vary depending on the specific location, further complicating the interpretation and analysis of their effects. Therefore, to isolate the interconnected nature of meteorological variables and clarify the relationship between these variables and health conditions, a well-designed experimental study in a controlled environment may produce more plausible results than real-life observational studies.

Conclusions

This nationwide study aimed to investigate the potential correlation between meteorological factors and AF using a comprehensive dataset covering over 50 million South Korean citizens from 2010 to 2022. The analysis identified a negative correlation between AF and average wind speed, indicating a potential association with increased AF incidence during lower wind speeds, possibly linked to air pollution stagnation. Additionally, a positive correlation was observed between AF and sunshine duration, particularly in the elderly, indicating a potential link to increased AF incidence with prolonged sunlight exposure in the elderly. Females aged 20-24 exhibited unique susceptibility to climate changes, displaying correlations with temperature, precipitation, humidity, and atmospheric pressure, while no other age and sex groups showed a statistically significant correlation with these variables. Despite these findings, the observational nature of the study restricts causal inferences, necessitating further well-designed experimental research to discern the precise interplay of meteorological variables and AF. This study contributes insights into the complex environmental influences on health, emphasizing the importance of future experimental research and resultant public health strategies.

Appendices

N=151	Total	Male	Male 0-4	Male 5-9	Male 10-14	Male 15-19	Male 20-24	Male 25-29	Male 30-34	Male 35-39	Male 40-44	Male 45-49	Male 50-54	Male 55-59	Male 60-64	Male 65-69	Male 70-74	Male 75-79	Male 80-	Female	Female 0-4	Female 5-9	Female 10-14	Female 15-19	Female 20-24	Female 25-29	Female 30-34	Female 35-39
Temperature	0.05327	0.05055	0.00108	-0.02602	-0.00348	0.0127	-0.09913	-0.04951	0.01106	0.00333	-0.0108	0.02003	0.03758	0.03639	0.03632	0.05126	0.05711	0.06536	0.05353	0.05758	-0.02488	0.04721	0.0428	0.08447	**0.219**	0.08926	0.03878	0.02226
p value	0.5159	0.5377	0.9895	0.7512	0.9662	0.877	0.2259	0.5461	0.8928	0.9677	0.8953	0.8072	0.6469	0.6573	0.6579	0.5319	0.4861	0.4253	0.5139	0.4825	0.7617	0.5649	0.6018	0.3024	**0.0069**	0.2758	0.6364	0.7862
Maximum Temperature	0.06725	0.06422	0.00116	-0.03028	-0.02195	-0.00752	-0.10021	-0.04666	0.01328	0.01821	0.00177	0.03242	0.05054	0.05081	0.04912	0.06396	0.07098	0.0802	0.06653	0.07203	-0.0309	0.02516	0.02191	0.08381	**0.20479**	0.08966	0.03669	0.01619
p value	0.412	0.4334	0.9887	0.712	0.789	0.927	0.2208	0.5694	0.8714	0.8244	0.9828	0.6927	0.5377	0.5355	0.5492	0.4353	0.3865	0.3277	0.417	0.3795	0.7065	0.7591	0.7894	0.3063	**0.0117**	0.2736	0.6546	0.8436
Minimum temperature	0.03178	0.0295	-0.00151	-0.01865	0.0209	0.03457	-0.09868	-0.05154	0.00312	-0.01895	-0.03299	0.00134	0.01488	0.01339	0.01655	0.03171	0.03522	0.04306	0.03432	0.0354	-0.01085	0.08202	0.07492	0.08529	**0.23668**	0.08691	0.04231	0.02955
p value	0.6985	0.7192	0.9853	0.8202	0.7989	0.6734	0.228	0.5297	0.9697	0.8174	0.6876	0.987	0.8561	0.8704	0.8402	0.6991	0.6677	0.5996	0.6757	0.6661	0.8948	0.3167	0.3606	0.2978	**0.0034**	0.2887	0.606	0.7188
Regional Minimum Temperature	0.02603	0.02488	-0.00364	0.03488	0.01759	0.06813	-0.11573	-0.0147	-0.01089	-0.01566	-0.04776	-0.00318	-0.00173	-0.00486	0.01401	0.03004	0.02957	0.03488	0.0369	0.02784	0.04271	0.136	0.13163	0.08259	**0.21073**	0.07873	0.03847	0.04319
p value	0.751	0.7617	0.9647	0.6707	0.8303	0.4059	0.157	0.8579	0.8944	0.8487	0.5604	0.9691	0.9832	0.9528	0.8645	0.7142	0.7186	0.6707	0.6528	0.7343	0.6025	0.0959	0.1072	0.3134	**0.0094**	0.3366	0.6391	0.5985
Precipitation	-0.03737	-0.0369	-0.07037	0.05466	0.08359	0.07701	-0.15366	-0.04856	-0.03196	-0.03383	-0.09876	-0.0608	-0.04822	-0.05538	-0.03946	-0.03471	-0.03817	-0.03062	-0.02453	-0.03808	0.00098	0.1576	0.10794	**0.17421**	**0.2234**	0.08055	-0.09229	0.14119
p value	0.6487	0.6528	0.3906	0.505	0.3075	0.3473	0.0596	0.5538	0.6969	0.68	0.2276	0.4583	0.5566	0.4994	0.6305	0.6722	0.6417	0.7089	0.765	0.6425	0.9905	0.0533	0.1871	**0.0324**	**0.0058**	0.3255	0.2597	0.0838
Daily Maximum Precipitation	-0.02252	-0.024	-0.01459	0.00294	0.07209	0.08138	-0.15554	-0.06666	-0.03687	-0.01072	-0.07122	-0.05044	-0.0299	-0.02442	-0.02958	-0.02549	-0.02719	-0.01113	-0.0197	-0.02012	-0.02403	0.10766	0.03114	**0.16261**	**0.19787**	0.03653	-0.07673	0.11352
p value	0.7837	0.7699	0.8589	0.9714	0.379	0.3205	0.0565	0.4161	0.6531	0.8961	0.3849	0.5386	0.7155	0.766	0.7185	0.7561	0.7403	0.8921	0.8102	0.8063	0.7696	0.1882	0.7043	**0.0461**	**0.0149**	0.6561	0.3491	0.1652
Hourly Maximum Precipitation	0.09056	0.0897	0.00997	0.01914	0.05997	0.02491	-0.08365	-0.0144	0.05479	0.06852	0.02793	0.08021	0.06172	0.08893	0.08332	0.0921	0.07834	0.10036	0.093	0.09181	-0.0433	0.09136	0.07368	0.05537	**0.20975**	0.15114	-0.04553	0.14569
p value	0.2688	0.2734	0.9033	0.8155	0.4645	0.7614	0.3072	0.8607	0.504	0.4032	0.7335	0.3276	0.4515	0.2775	0.3091	0.2607	0.339	0.2202	0.256	0.2622	0.5975	0.2646	0.3686	0.4995	**0.0097**	0.064	0.5788	0.0743
Average Wind Speed	**-0.42535**	**-0.42417**	**0.16837**	**0.22757**	0.10437	0.04729	**-0.21542**	**-0.24015**	**-0.17727**	**-0.34289**	**-0.30341**	**-0.40713**	**-0.36479**	**-0.39326**	**-0.42423**	**-0.42392**	**-0.41828**	**-0.43048**	**-0.41952**	**-0.4267**	0.0323	0.03283	**0.20473**	0.05712	-0.14526	**-0.18718**	0.09247	0.11797
p value	**<.0001**	**<.0001**	**0.0388**	**0.005**	0.2022	0.5642	**0.0079**	**0.003**	**0.0294**	**<.0001**	**0.0002**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.6937	0.689	**0.0117**	0.486	0.0751	**0.0214**	0.2588	0.1491
Average Maximum Wind Speed	-0.0018	0.00044	-0.14043	0.02139	-0.09544	-0.03207	0.04456	-0.00622	-0.03239	0.01311	-0.04284	-0.00201	-0.03327	-0.00545	0.00559	0.00135	-0.00107	-0.00184	0.00878	-0.00539	0.11303	0.0214	0.04305	0.00104	-0.01323	0.04994	-0.12347	-0.05922
p value	0.9825	0.9957	0.0855	0.7944	0.2437	0.6959	0.587	0.9396	0.693	0.873	0.6015	0.9805	0.6851	0.947	0.9457	0.9868	0.9896	0.9821	0.9148	0.9476	0.167	0.7943	0.5997	0.9899	0.8719	0.5425	0.1309	0.4701
Average Maximum Instantaneous Wind Speed	-0.05417	-0.0531	-0.13081	0.02093	-0.07694	0.02027	0.00287	-0.04778	-0.02779	-0.05357	-0.07497	-0.05588	-0.07068	-0.05181	-0.0508	-0.05253	-0.05493	-0.05358	-0.04556	-0.05582	0.08092	0.06696	0.13185	0.01521	0.03788	-0.00444	-0.08794	0.01434
p value	0.5089	0.5173	0.1094	0.7986	0.3477	0.8049	0.9721	0.5602	0.7348	0.5136	0.3602	0.4955	0.3885	0.5276	0.5356	0.5218	0.503	0.5135	0.5786	0.496	0.3233	0.414	0.1066	0.8529	0.6443	0.9569	0.2829	0.8613
Average Humidity	0.09984	0.09933	-0.04704	-0.04599	0.01941	0.00576	0.02302	0.00493	0.08128	0.04004	0.04171	0.07689	0.0937	0.07864	0.09264	0.10282	0.10909	0.10604	0.0957	0.10053	0.01768	0.10388	-0.02286	0.06754	**0.22193**	0.11128	0.00417	-0.0094
p value	0.2226	0.225	0.5663	0.575	0.813	0.9441	0.7791	0.9521	0.3212	0.6254	0.6111	0.348	0.2525	0.3371	0.2579	0.209	0.1824	0.195	0.2425	0.2194	0.8294	0.2043	0.7805	0.4099	**0.0062**	0.1737	0.9595	0.9088
Average Minimum Humidity	-0.0303	-0.02976	-0.01777	-0.08394	0.15734	0.06432	-0.01897	-0.05324	-0.00322	-0.02524	-0.06429	-0.03347	-0.00242	-0.02625	-0.03596	-0.03378	-0.02431	-0.02427	-0.03218	-0.03114	-0.03636	0.17043	0.1032	0.07295	**0.21648**	0.09152	-0.01777	0.00668
p value	0.7119	0.7168	0.8286	0.3055	0.0537	0.4327	0.8172	0.5162	0.9687	0.7584	0.4329	0.6833	0.9765	0.749	0.6612	0.6805	0.767	0.7674	0.6949	0.7043	0.6576	0.0364	0.2073	0.3734	**0.0076**	0.2637	0.8286	0.9351
Sunshine Hours	**0.27233**	**0.26815**	0.08258	-0.03389	**-0.21071**	**-0.18362**	0.05137	0.10377	0.12058	**0.2673**	**0.26949**	**0.25787**	**0.27175**	**0.29152**	**0.25308**	**0.25582**	**0.27124**	**0.2802**	**0.24823**	**0.27869**	-0.10645	**-0.20447**	-0.15636	-0.10998	-0.09765	0.01316	-0.0172	**-0.18299**
p value	**0.0007**	**0.0009**	0.3134	0.6796	**0.0094**	**0.024**	0.531	0.2048	0.1403	**0.0009**	**0.0008**	**0.0014**	**0.0007**	**0.0003**	**0.0017**	**0.0015**	**0.0008**	**0.0005**	**0.0021**	**0.0005**	0.1933	**0.0118**	0.0552	0.1789	0.2329	0.8726	0.834	**0.0245**
Solar Energy	0.14425	0.14311	-0.04578	0.02018	-0.03312	-0.06104	-0.10416	0.09548	-0.00273	0.10866	0.03327	0.08154	0.07405	0.0824	0.13193	0.15115	0.1487	0.14432	**0.17388**	0.14591	-0.0695	-0.10364	0.07233	0.03282	0.07553	**0.16131**	-0.00203	-0.0132
p value	0.0772	0.0796	0.5767	0.8058	0.6864	0.4566	0.2031	0.2436	0.9734	0.1841	0.685	0.3196	0.3662	0.3145	0.1064	0.0639	0.0684	0.0771	**0.0327**	0.0738	0.3965	0.2054	0.3775	0.6892	0.3567	**0.0479**	0.9803	0.8722
Wind Chill Index	0.06058	0.05784	-0.00175	-0.02916	-0.00622	0.01121	-0.09581	-0.04447	0.01418	0.00963	-0.00496	0.02727	0.04402	0.04329	0.04374	0.05847	0.06433	0.07265	0.06067	0.0649	-0.02522	0.04622	0.03803	0.08337	**0.21931**	0.09113	0.03696	0.02068
p value	0.46	0.4805	0.983	0.7223	0.9396	0.8913	0.2419	0.5877	0.8628	0.9066	0.9519	0.7396	0.5914	0.5977	0.5939	0.4758	0.4326	0.3753	0.4593	0.4285	0.7586	0.5731	0.6429	0.3088	**0.0068**	0.2658	0.6523	0.801
Heat Index	0.05329	0.05065	0.00677	-0.04332	0.01311	0.0188	-0.08381	-0.05558	0.01582	0.0006	-0.00518	0.02173	0.0417	0.04199	0.03684	0.05057	0.05631	0.06547	0.05156	0.05746	-0.04171	0.05973	0.03949	0.07795	**0.22196**	0.08298	0.02964	0.01875
p value	0.5158	0.5368	0.9343	0.5974	0.8731	0.8188	0.3063	0.4979	0.8471	0.9942	0.9496	0.7911	0.6112	0.6087	0.6534	0.5375	0.4922	0.4244	0.5295	0.4834	0.6111	0.4663	0.6302	0.3414	**0.0062**	0.3111	0.7179	0.8192
Maximum Heat Index	0.05222	0.04976	0.01052	-0.04152	0.00901	0.03597	-0.08721	-0.05168	0.03008	0.00937	-0.00104	0.02718	0.04808	0.04203	0.03572	0.04943	0.05323	0.06394	0.05046	0.0561	-0.03869	0.06583	0.05867	0.08443	**0.24168**	0.1004	0.04031	0.03905
p value	0.5243	0.544	0.898	0.6127	0.9126	0.661	0.287	0.5285	0.7139	0.9091	0.9899	0.7404	0.5577	0.6083	0.6632	0.5467	0.5162	0.4354	0.5384	0.4939	0.6372	0.4219	0.4743	0.3027	**0.0028**	0.22	0.6231	0.6341
Minimum Heat Index	0.05442	0.0521	-0.00694	-0.03979	0.02327	0.02787	-0.08272	-0.04936	0.0245	0.00485	-0.00354	0.02482	0.04698	0.04113	0.03915	0.05248	0.05852	0.06538	0.05266	0.05809	-0.02507	0.05876	0.04694	0.07542	**0.23828**	0.0987	0.03534	0.02378
p value	0.5069	0.5252	0.9326	0.6276	0.7767	0.7341	0.3126	0.5473	0.7652	0.9528	0.9656	0.7623	0.5667	0.6161	0.6332	0.5222	0.4754	0.4251	0.5207	0.4787	0.7599	0.4736	0.5671	0.3574	**0.0032**	0.2279	0.6666	0.7719
Diurnal Temperature variation	0.15728	0.15443	0.01294	-0.04929	**-0.20666**	**-0.20691**	0.02053	0.03734	0.04676	**0.17941**	**0.17213**	0.14528	**0.16292**	**0.17157**	0.14796	0.14221	0.15768	**0.16193**	0.14128	**0.16167**	-0.09089	**-0.28942**	**-0.26939**	-0.03086	**-0.21584**	-0.01147	-0.03818	-0.07088
p value	0.0538	0.0583	0.8747	0.5478	**0.0109**	**0.0108**	0.8024	0.6489	0.5686	**0.0275**	**0.0346**	0.0751	**0.0456**	**0.0352**	0.0698	0.0815	0.0532	**0.047**	0.0836	**0.0473**	0.267	**0.0003**	**0.0008**	0.7068	**0.0078**	0.8888	0.6416	0.3871
Average Atmospheric Pressure	0.00887	0.01085	-0.02096	0.04369	-0.0189	-0.04303	0.1207	0.11711	0.0049	0.06393	0.0712	0.05236	0.02439	0.02186	0.02828	0.01235	-0.0019	-0.00158	-0.0007	0.00581	0.01363	-0.08995	-0.06592	-0.13341	**-0.22343**	-0.08748	-0.02787	-0.07906
p value	0.9234	0.9064	0.8202	0.6357	0.8376	0.6407	0.1891	0.2027	0.9576	0.4879	0.4397	0.57	0.7915	0.8127	0.7591	0.8935	0.9836	0.9863	0.994	0.9498	0.8825	0.3286	0.4744	0.1463	**0.0142**	0.342	0.7626	0.3907

TABLE 3: Results of the Pearson correlation analysis of this study

Pearson correlation coefficients for each parameter and their corresponding p-values. P-values less than 0.05 are bolded.

Additional Information

Disclosures

Human subjects: Consent was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Zhao Q, Coelho MS, Li S, et al.: Temperature variability and hospitalization for cardiac arrhythmia in Brazil: a nationwide case-crossover study during 2000-2015. Environ Pollut. 2019, 246:552-8. 10.1016/j.envpol.2018.12.063
2. Sawicka KM, Prasał M, Wawryniuk A, Łuczyk RJ, Szych M, Łuczyk M, Daniluk J: Influence of atmospheric conditions on the incidence of atrial fibrillation. J Educ Health Sport. 2017, 7:524-41.
3. Sheehy S, Fonarow GC, Holmes DN, et al.: Seasonal variation of atrial fibrillation admission and quality of care in the United States. J Am Heart Assoc. 2022, 11:e023110. 10.1161/JAHA.121.023110
4. Frost L, Johnsen SP, Pedersen L, Husted S, Engholm G, Sørensen HT, Rothman KJ: Seasonal variation in hospital discharge diagnosis of atrial fibrillation: a population-based study. Epidemiology. 2002, 13:211-5. 10.1097/00001648-200203000-00017
5. Rivera-Caravaca JM, Roldán V, Vicente V, Lip GY, Marín F: Particulate matter and temperature: increased risk of adverse clinical outcomes in patients with atrial fibrillation. Mayo Clin Proc. 2020, 95:2360-9. 10.1016/j.mayocp.2020.05.046
6. Comelli I, Ferro J, Lippi G, Comelli D, Sartori E, Cervellin G: Incidence of acute-onset atrial fibrillation correlates with air temperature. Results of a nine-year survey. J Epidemiol Glob Health. 2014, 4:151-7. 10.1016/j.jegh.2013.12.003
7. Fustinoni O, Saposnik G, Esnaola y Rojas MM, Lakkis SG, Sposato LA: Higher frequency of atrial fibrillation linked to colder seasons and air temperature on the day of ischemic stroke onset. J Stroke Cerebrovasc Dis. 2013, 22:476-81. 10.1016/j.jstrokecerebrovasdis.2013.03.009
8. Zhu X, Chen R, Zhang Y, et al.: Low ambient temperature increases the risk and burden of atrial fibrillation episodes: a nationwide case-crossover study in 322 Chinese cities. Sci Total Environ. 2023, 880:163351. 10.1016/j.scitotenv.2023.163351
9. Ahn J, Uhm T, Han J, et al.: Meteorological factors and air pollutants contributing to seasonal variation of acute exacerbation of atrial fibrillation: a population-based study. J Occup Environ Med. 2018, 60:1082-6. 10.1097/JOM.0000000000001449
10. Nguyen JL, Link MS, Luttmann-Gibson H, et al.: Drier air, lower temperatures, and triggering of paroxysmal atrial fibrillation. Epidemiology. 2015, 26:374-80. 10.1097/EDE.0000000000000284
11. Vencloviene J, Babarskiene RM, Dobozinskas P, Dedele A, Lopatiene K, Ragaisyte N: The short-term associations of weather and air pollution with emergency ambulance calls for paroxysmal atrial fibrillation. Environ Sci Pollut Res Int. 2017, 24:15031-43. 10.1007/s11356-017-9138-7
12. Bhatnagar A: Environmental determinants of cardiovascular disease . Circ Res. 2017, 121:162-80. 10.1161/CIRCRESAHA.117.306458
13. Brundel BJ, Shiroshita-Takeshita A, Qi X, et al.: Induction of heat shock response protects the heart against atrial fibrillation. Circ Res. 2006, 99:1394-402. 10.1161/01.RES.0000252323.83137.fe
14. Liu D, Han X, Zhang Z, Tse G, Shao Q, Liu T: Role of heat shock proteins in atrial fibrillation: from molecular mechanisms to diagnostic and therapeutic opportunities. Cells. 2022, 12:151. 10.3390/cells12010151
15. Kupari M, Koskinen P: Seasonal variation in occurrence of acute atrial fibrillation and relation to air temperature and sale of alcohol. Am J Cardiol. 1990, 66:1519-20. 10.1016/0002-9149(90)90549-g
16. Fujimoto R, Suzuki E, Kashima S, et al.: Heat exposure following the rainy season is associated with an increased risk of cardiovascular emergency among the elderly in Japan. J Am Heart Assoc. 2023, 12:e027046. 10.1161/JAHA.122.027046
17. Paul A, Alex R, Jacob JR, Yadav B: Effects of heat stroke on surface ECG: a study on clinical outcomes . Heart Asia. 2019, 11:e011221. 10.1136/heartasia-2019-011221
18. Zanobetti A, O'Neill MS, Gronlund CJ, Schwartz JD: Susceptibility to mortality in weather extremes: effect modification by personal and small-area characteristics. Epidemiology. 2013, 24:809-19. 10.1097/01.ede.0000434432.06765.91
19. Yarza S, Novack L, Sarov B, Novack V: Ability to adapt to seasonal temperature extremes among atrial fibrillation patients. A nation-wide study of hospitalizations in Israel. Environ Res. 2023, 216:114804. 10.1016/j.envres.2022.114804
20. Michałkiewicz D, Chwiałkowski J, Dziuk M, Olszewski R, Kamiński G, Skrobowski A, Cholewa M: The influence of weather conditions on the occurrence of paroxysmal atrial fibrillation [Article in Polish]. Pol Merkur Lekarski. 2006, 20:265-9.
21. Poletaev V, Antonelli D, Litskevich G, Turgeman Y: Monthly variation in emergency department admission for acute onset atrial fibrillation. Isr Med Assoc J. 2021, 23:302-5.
22. Yue C, Yang F, Li F, Chen Y: Association between air pollutants and atrial fibrillation in general population: a systematic review and meta-analysis. Ecotoxicol Environ Saf. 2021, 208:111508. 10.1016/j.ecoenv.2020.111508
23. Link MS, Luttmann-Gibson H, Schwartz J, et al.: Acute exposure to air pollution triggers atrial fibrillation . J Am Coll Cardiol. 2013, 62:816-25. 10.1016/j.jacc.2013.05.043
24. 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, 41:1441-6. 10.1111/pace.13500
25. Bunch TJ, Horne BD, Asirvatham SJ, et al.: Atrial fibrillation hospitalization is not increased with short-term elevations in exposure to fine particulate air pollution. Pacing Clin Electrophysiol. 2011, 34:1475-9. 10.1111/j.1540-8159.2011.03200.x
26. Saifipour A, Azhari A, Pourmoghaddas A, et al.: Association between ambient air pollution and hospitalization caused by atrial fibrillation. ARYA Atheroscler. 2019, 15:106-12. 10.22122/arya.v15i3.1843
27. Rich DQ, Mittleman MA, Link MS, et al.: Increased risk of paroxysmal atrial fibrillation episodes associated with acute increases in ambient air pollution. Environ Health Perspect. 2006, 114:120-3. 10.1289/ehp.8371
28. Jones AM, Harrison RM, Baker J: The wind speed dependence of the concentrations of airborne particulate matter and NOx. Atmos Environ. 2010, 44:1682-90. 10.1016/j.atmosenv.2010.01.007
29. Arbuthnott K, Hajat S, Heaviside C, Vardoulakis S: Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change. Environ Health. 2016, 15:33. 10.1186/s12940-016-0102-7
30. HIRA Bigdata Open Portal [Webpage in Korean]. (2023). Accessed: October 1, 2023: http://opendata.hira.or.kr/.
31. Korea Meteorological Administration [Webpage in Korean]. (2023). Accessed: October 1, 2023: http://www.kma.go.kr/.
32. National Weather Service: National Oceanic and Atmospheric Administration . (2023). Accessed: October 1, 2023: http://www.weather.gov/.
33. Korean Statistical Information Service [Webpage in Korean]. (2023). Accessed: October 1, 2023: http://kosis.kr/.
34. Čulić V: Triggering of cardiac arrhythmias: the problem of multicollinearity among air pollution and meteorological factors. J Am Coll Cardiol. 2014, 63:1226-7. 10.1016/j.jacc.2013.09.065
35. Wang W, Zhang Y, Li Y, Zhai WH: Electrical cardioversion intervention in a patient with heat stroke accompanied by rapid atrial fibrillation: a case report and literature review. Heliyon. 2023, 9:e15636. 10.1016/j.heliyon.2023.e15636
36. Marchand M, Gin K: The cardiovascular system in heat stroke . CJC Open. 2022, 4:158-63. 10.1016/j.cjco.2021.10.002
37. Gluszak A, Kocon S, Szaniawska E, Zuk K, Aljabali P, Gluza A, Siwek K: May sunshine protect women against paroxysms of atrial fibrillation?. Tohoku J Exp Med. 2009, 219:303-6. 10.1620/tjem.219.303
38. Feelisch M, Kolb-Bachofen V, Liu D, Lundberg JO, Revelo LP, Suschek CV, Weller RB: Is sunlight good for our heart?. Eur Heart J. 2010, 31:1041-5. 10.1093/eurheartj/ehq069
39. Di Nicola M, Mazza M, Panaccione I, et al.: Sensitivity to climate and weather changes in euthymic bipolar subjects: association with suicide attempts. Front Psychiatry. 2020, 11:95. 10.3389/fpsyt.2020.00095
40. Graw K, Sommer M, Matzarakis A: The prevalence of weather sensitivity in Germany derived from population surveys. Atmosphere. 2022, 13:1865. 10.3390/atmos13111865
41. Mathias CJ, Low DA, Iodice V, Owens AP, Kirbis M, Grahame R: Postural tachycardia syndrome--current experience and concepts. Nat Rev Neurol. 2011, 8:22-34. 10.1038/nrneurol.2011.187
42. Elser H, Parks RM, Moghavem N, et al.: Anomalously warm weather and acute care visits in patients with multiple sclerosis: a retrospective study of privately insured individuals in the US. PLoS Med. 2021, 18:e1003580. 10.1371/journal.pmed.1003580
43. Schroth WS, Tenner SM, Rappaport BA, Mani R: Multiple sclerosis as a cause of atrial fibrillation and electrocardiographic changes. Arch Neurol. 1992, 49:422-4. 10.1001/archneur.1992.00530280116034

44. Chagnac Y, Martinovits G, Tadmor R, Goldhammer Y: Paroxysmal atrial fibrillation associated with an attack of multiple sclerosis. Postgrad Med J. 1986, 62:385-7. 10.1136/pgmj.62.727.385
45. Carlin K: Autoimmune disease pH and temperature . J Clin Med Res. 2014, 6:305-7. 10.14740/jocmr1839w