Review Article

The Influence of Geomagnetic Storms on the Risks of Developing Myocardial Infarction, Acute Coronary Syndrome, and Stroke: Systematic Review and Meta-analysis

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Abstract

The aim of this study was to determine the influence of geomagnetic storms (GS) on the risks of developing myocardial infarction (MI), acute coronary syndrome (ACS), and stroke. The systematic review was conducted by searching PubMed database from March 16, 2023, to March 18, 2023, independently by two researchers. Out of 644 articles, a total of 6 studies were selected based on the inclusion/exclusion criteria and included in the systematic review. This systematic review confirmed the effect of GS on the risks of MI/ACS (mean relative risk [RR] 1.3–1.5) and stroke (mean RR 1.25–1.6). At the same time, it is worthnoting the limitations of this systematic review: small number of included studies and their differences in methodology, statistical analysis, and methods for assessing geomagnetic activity. The main mechanism of the negative impact of GS on the functioning of the cardiovascular system and the risk of cardiovascular complications was associated with influence on circadian biological rhythms, heart rate variability, blood pressure, and microcirculation. The authors believe that when planning further research in this area, it is necessary to correctly choose the type of local, regional or planetary geomagnetic index, depending on the goals of the study. It is also necessary to take into account the influence of concomitant somatic pathology, drug therapy, as well as the peculiarities of the individual temporary reaction of the human body to GS.

Keywords: Circadian rhythms, geomagnetic indices, geomagnetic storms, myocardial infarction, relative risk, stroke

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Introduction

Considerable attention has been paid to the influence of fluctuations in the Earth's magnetic field on human health for at least 100 years. The leading role in this direction has always belonged to Russian (Soviet) scientists, starting from the early works of A. L. Chizhevsky to publications at the end of the 20th century, carried out during a space flight on the Soyuz transport ship.[1,2]

Despite the large number of works published over the past decades, their diversity, diverging goals, and in some cases, contradictory results, have disoriented the scientific community as to how this problem should be further studied.[3-19]

In many early works on this topic, attention is drawn to the incorrect approach to data analysis, as well as somewhat outdated methods of their statistical analysis,[3,6,8,14,20,21] which could lead to bias in the results or even to false conclusions from the standpoint of the modern approach to data analysis.[22]

Therefore, in this review, we would like to focus on more specific hard endpoints of the impact of geomagnetic storms (GS) on human health to determine the true impact on major outcomes.

Aim of the study

This study aims to determine the influence of GS on the risks of developing myocardial infarction (MI), acute coronary syndrome (ACS), and stroke.

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Materials and Methods

The authors conducted a systematic review of scientific articles published in the PubMed database, which included observation of patients with cardiovascular diseases regarding the risk of MI, ACS, and stroke depending on the disturbance of the Earth's geomagnetic field (confirmed GS). The authors selected works that had a representative sample and correctly conducted the statistical data analysis.

The search was conducted from March 16, 2023, to March 18, 2023, independently by two researchers using the keywords "geomagnetic storms." Six hundred and forty-four articles were identified, from which 76 articles were selected that discussed the biological effects of GS and their impact on humans. Of these, 16 publications did not meet the inclusion criteria (suicide – 3, schizophrenia/bipolar disorder – 3, depression – 1, migraine – 1, multiple sclerosis – 1, trauma – 1, cancer – 2, appendicitis – 1, epilepsy – 2, and glaucoma – 1) 3–19. The lack of access on the Internet to the full-text version of a number of articles required obtaining their original versions by personally contacting the Russian State Library for subsequent analysis. Ultimately, a total of 60 full-text articles were reviewed. Finally, after further review, only 6 studies were included in the systematic review [Figure 1].[23-28]

Statistical analysis

The systematic review was conducted in accordance with PRISMA standards (http://www.prisma-statement.org).[29] Additional statistical analysis was required to analyze the data from the two studies to ensure consistency in the results presented in the review. For this purpose, the Comparing 2 Person-Time Rates module of the OpenEpi statistical program was used.[30] The results are presented as RR, 95% confidence interval (CI) and significance level ($P < 0.05$ is taken as a statistically significant level).

Results

All studies included in the final systematic review and meta-analysis are presented in Table 1.

Feigin *et al*. used a time-stratified study design to analyze the data from included participants and daily geomagnetic activity (assessed by the planetary A (Ap)-index). The study collected the data from from several large population-based stroke incidence studies from Australia, New Zealand, France, the UK, and Sweden, conducted between 1981 and 2004 (n = 11453).[23] The total follow-up time for the study participants was 16,031,764 person-years of observation. GS (Ap index 60+) was associated with a 19% increased risk of stroke (95% CI, 11%–27%). The triggering effect of GS was greatest in individuals aged <65 years for all types of stroke, increasing the risk of stroke by more than 50%. However, moderate GS (Ap index 60–99) was associated with an increased risk of stroke by 27% (95% CI, 8%–48%) and severe GS (Ap index 100–149) increased the risk by 52% (95% CI, 19%–92%).

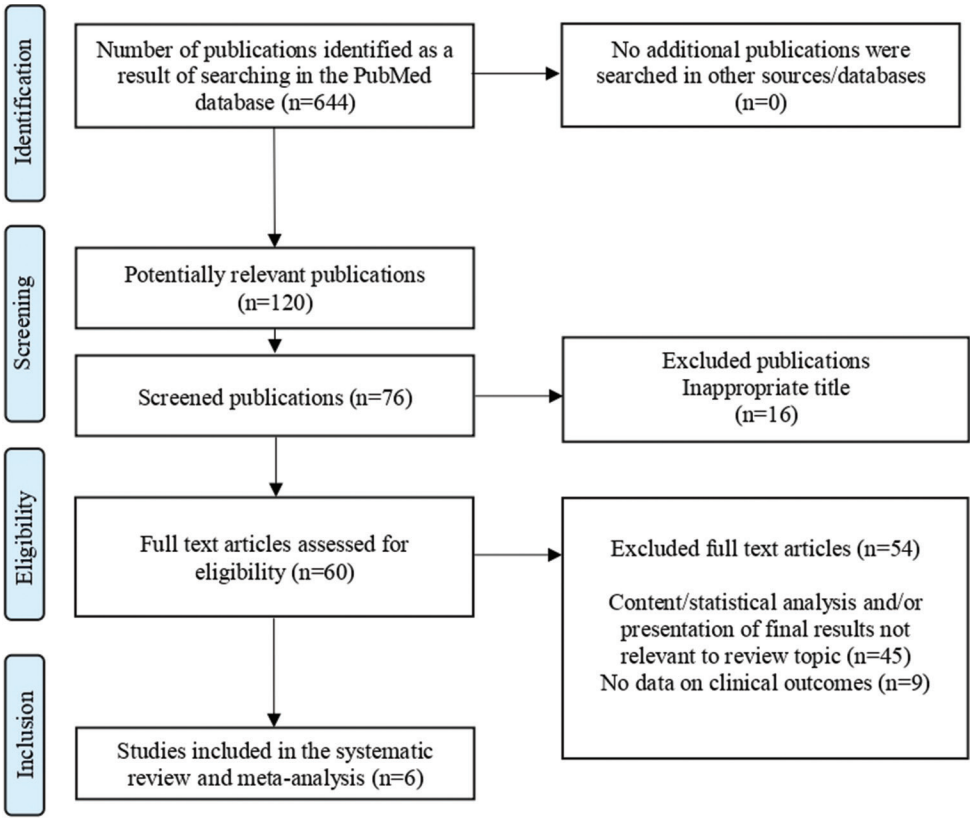

Figure 1: PRISMA scheme: Search, screening and inclusion of studies in a systematic review

Table 1: Relative risks of myocardial infarction, acute coronary syndrome and stroke according to studies included in the systematic review and data analysis

First author, year of publication (number of study participants)	Analyzed sign/outcome due to the impact of GS	RR, 95% CI, significance level
Feigin VL, 2014 (11,453)[23]	Development of any type of stroke regardless of age	1.12 (1.06–1.19), *P*<0.001
	Development of any type of stroke before the age of 65 years	1.33 (1.19–1.49), *P*<0.001
	Development of hemorrhagic stroke before the age of 65 years with a severe GS	2.76 (1.42–5.40), *P*<0.001
Kiznys D, 2020 (4076)[24]	Development of ACS in the presence of	
	Arterial hypertension	1.40 (1.10–1.78), *P*=0.006
	Obesity	1.72 (1.15–2.04), *P*=0.008
	Permanent atrial fibrillation	1.39 (1.03–1.88), *P*=0.03
Shaposhnikov D, 2014 (2833)[25]	Risk of MI	1.29 (1.19–1.40), *P*<0.001
Shaposhnikov D, 2014 (1096)[25]	Risk of stroke	1.25 (1.10–1.42), *P*=0.001
Vencloviene J, 2013 (1979)[26]	Risk of developing STEMI if the patient has	
	History of MI	1.47 (1.00–2.14), *P*=0.048
	Stable angina	1.53 (1.15–2.24), *P*=0.027
	Chronic kidney disease	2.65 (1.20–5.84), *P*=0.016
	COPD	1.95 (1.04–3.66), *P*=0.017
Kleimenova NG, 2007 (85,700)[27]	Increase in the number of emergency calls for MI	1.06 (1.04–1.08), *P*<0.001*
Villoresi G, 1998 (15,543)[28]	Risk of developing MI	1.39 (0.41–2.36), *P*=0.004*

*Additional statistical analysis was required to process the study data in order to obtain consistency in the results presented in the review. MI: Myocardial infarction, CI: Confidence interval, RR: Relative risk, GS: Geomagnetic storms, ACS: Acute coronary syndrome, STEMI: ST elevation MI, COPD: Chronic obstructive pulmonary disease

In another study, Kiznys *et al*. examined the association between space weather events and cardiovascular events in patients hospitalized with ACS (n = 4076).[24] Multivariate logistic regression was used to data analysis. The risk of events in patients was assessed using the odds ratio (OR), adjusted for age, sex, smoking status, week day, and seasonality. The risk of developing ACS on GS days increased in obese patients (OR = 1.72, P = 0.008). The following geomagnetic phenomena were analyzed in the study: (1) Fast solar wind (FSW) - Solar wind speed above 600 km/s; (2) stream interaction region (SIR) - The appearance in the solar wind of interacting streams with different speeds; (3) days of solar proton events (SPE) - Days when a large number of protons and high-energy ions arrive at the Earth.

The risk of developing ACS in patients with chronic atrial fibrillation was associated with FSW days (lag 0–3 days, OR = 1.39, P = 0.030) and with days of combination of SPE and SIR (lag 0–3 days, OR = 2.06, P = 0.021). FSW was associated with risk of ACS in patients with kidney disease (OR = 1.71, P = 0.008) on days that were not classified as GS (lag −3–3 days).

It should be noted that since the solar wind interacts with the Earth's magnetic field, wind speed changes lead to field fluctuations. SPE affect electrical currents in the magnetosphere and change the Earth's magnetic field. Thus, despite the different nature of the studied indices, geomagnetism supposedly has a direct influence on humans in all these cases.

Shaposhnikov *et al*. assessed the effect of geomagnetic activity on hospitalization of patients with MI and stroke.[25] The authors analyzed hospitalizations for MI (n = 2833) and stroke (n = 1096) in two Moscow hospitals between 1992 and 2005. Daily event rates were related to meteorological and geomagnetic conditions, which were confirmed using a generalized linear model based on week day and seasonal trends. The number of hospitalizations for MI and stroke increased on days with high geomagnetic activity. The relative risk of MI and stroke during GS days was 1.29 (95% CI 1.19–1.40) and 1.25 (95% CI 1.10–1.42), respectively. At the same time, the study authors noted that the influence of barometric pressure on hospitalizations was relatively greater than the influence of geomagnetic activity (GMA), and the influence of temperature fluctuations was greater than the influence of atmospheric pressure changes.

Vencloviene *et al*. examined the association between characteristics of patients with ST elevation MI (STEMI) and GMA (including SPE and meteorological variables at the time of admission).[26] Data from 1979 patients hospitalized at the Lithuanian University Hospital (Kaunas) were analyzed. The authors concluded that 2 days after GS, the risk of STEMI was increased by more than 1.5 times in patients with a history of MI, stable angina, kidney or lung disease. A dose-response relationship was observed between GMA levels and STEMI risk in patients with a history of kidney disease. Patients with stable angina had increased risk of STEMI more than 1.5 times 2 days after SPE (adjusted for GMA levels).

Kleĭmenova *et al*. in their work analyzed ambulance calls for MI (85,000 events) in Moscow in 1979–1981 and showed their seasonal dynamics with a deep summer minimum.[27] A number of previously performed studies have confirmed an increase

in the incidence of MI during geomagnetic disturbances, which have a maximum occurrence during the equinox period. The authors of the study suggested that geomagnetic micropulsations (Pc1) are one of the geomagnetic factors affecting the functioning of the human cardiovascular system. Pc1 has a frequency comparable to the frequency of heart rate contractions and the winter maximum of their occurrence. Data from ambulance calls in Moscow for MI and sudden death (SD) were compared with the Pc1 registration catalog from the Borok geophysical observatory. It was shown that geomagnetic micropulsations were recorded in 70% days with abnormally high number of ambulance calls for MI. The probability of the simultaneous occurrence of MI and Pc1 in the winter season was 1.5 times higher than their random coincidence.

The relationship between various GMA parameters and medical statistics regarding MI was also previously studied by Villoresi *et al*.[28] They analyzed the daily incidence of MI ($n = 15,543$) and deaths from MI ($n = 3065$), extracted from 14 largest hospital's registers in St. Petersburg (1989–1990). The analysis showed a statistically significant increase in the frequency of MI during severe geomagnetic disturbances associated associated with the so-called Forbush effect. The Forbush effect is a decrease in cosmic ray flux in the Earth's vicinity with the arrival of large emissions of solar matter. The overall estimate of the average increase in MI incidence during severe GS was calculated taking into account previous results and it was 10.5% ± 1.2%. It was also found that the heart attack incidence rate remained fairly constant from Monday to Friday and dropped sharply by about 1.25 times on Saturday and Sunday.

Discussion

The possible influence of the geomagnetic field on human health has been discussed by scientists over the past decades.[31] Some epidemiological studies have shown that extremely high or low GMA levels may have adverse health effects in susceptible populations.[32] Human is born, grows, constantly resides and develops in the natural electromagnetic fields of the Earth. Studies show that certain physiological processes and functions of the human body have circadian rhythms, and the Earth's magnetic field can affect them. Cyclical processes in solar activity, such as the appearance and disappearance of sunspots, as well as seasonal weakening of the geomagnetic field, can affect human health through influencing to physiological circadian rhythms.[33,34] At the same time, many cardiovascular parameters demonstrate daily variations corresponding to the circadian rhythm.[35] Geomagnetic fluctuations, especially GS, negatively affect (disturb) the synchronization of the body's normal biological rhythms.[36] Therefore there is evidence of the relationship between GMA and heart rate variability.[37,38]

Kleĭmenova *et al*. showed in her work[27] (citing Rapoport *et al*. study[39]), that a comparative analysis of ambulance calls and hospitalizations for MI in Moscow and Bulgaria reached maximum values on GS days. This may indirectly indicate the planetary nature of the negative geomagnetic impact on people and the functioning of their cardiovascular system in different countries at one point of time. At the same time, it is logical to expect an even greater influence from local and/or regional disturbances of the magnetic field. Assumptions of Kleimenova about the negative impact of geomagnetic micropulsations (Pc1), having a frequency comparable to the heart rate[27], was continued in other scientific works.[40,41]

The purpose of the above-mentioned Rapoport's work was to find out the role of Pc1 influence on the risk of developing MI and SD.[39] Researchers analyzed MI incidence in Moscow for 1979–1981, the incidence of MI and SD in Bulgaria for 15 years and statistical data on geomagnetic micropulsations (Pc1). It was noted that the number of cases of MI increased both in Moscow and in Bulgaria when the above-described micropulsations were recorded during the geomagnetic disturbances. Seasonal changes in the incidence of MI and SD in this study were associated with a seasonal trend in the duration of Pc1 with their winter maximum.

In this regard, the authors suggested that a factor enhancing the influence of geomagnetic disturbances in winter may be low melatonin production caused by light deficiency, which served as a prerequisite for subsequent studies.[42]

The authors of other studies also noted that the effect of GMA was observed specifically in individuals with reduced melatonin levels. Dominguez-Rodriguez *et al*. found in their work that patients with coronary artery disease with low melatonin levels had a higher risk of developing MI and SD.[43]

It is important to note the peculiarities of the individual response to GS, which was reflected in the work of Kiznys *et al*.[24] The authors suggested that individuals may respond differently to space weather events (the day before they occur, on the day they occur, or 1–3 days after they occur), and this may be related to the cardiovascular characteristics of the patients. Usenko *et al*.[7] give their own detailed explanation for this and connect the response time with the type of psychological personality and the characteristics of the reaction of the nervous system of a particular person to any stressful influences, including GS. The debut of the body's reaction was noted 1 day before the development of a magnetic storm in cholerics; sanguines reacted on the 1st–2nd day of GS; the body's magnetic reaction to the storm was noted much later in phlegmatics and melancholics (on days 3–4).

In conclusion, we would like to state that this systematic review confirms the influence of GS on the risks of developing MI, ACS and stroke. At the same time, it is worth noting the limitations of this study – Only 6 studies were included in the systematic review, which differed in methodology and features of statistical analysis. Additional statistical analysis was required to process two studies in order to obtain uniformity of the results presented in the review. It is important to note that the studies differed in the geomagnetic indices used to confirm the GS. Daily geomagnetic activity was assessed on a representative sample

based on the registration of the Ap-index in a methodologically well-planned Feigin *et al*. study (n = 11,453).[23] GS degree clearly validated by Ap-index score (Ap <60, 60–99, 100–149, 150>). However, given the significant geographical differences between the countries participating in this study (New Zealand, Australia, Great Britain, France, Sweden), it can be assumed that an analysis of local or regional indices would be useful and at the same time more correct. Since it is known that the Earth's magnetic field (in nT) significantly depends on the distance of the measurement point from the equator. Measurements at a geographic latitude of 50° and at the equator can differ by 1.5–2 times.

Kiznys *et al*. in their study, along with generally accepted indices, also used FSW and SPE[24] (as well as in the work of Vencloviene *et al*.[26]). Shaposhnikov *et al*. in their work used local and planetary K and Ap indices to evaluate GMA,[25] which seems more justified. Kleĭmenova *et al*. and Villoresi *et al*. used completely different indicators in their works – Geomagnetic micropulsations (Pc1)[27] and days of the descending phase of the Forbush decline of cosmic rays.[28] Moreover as we have already noted, all these indicators are directly or indirectly related to fluctuations in the magnetic field, and geomagnetism remains the basis of the physical impact in all these cases.

Conclusion

This systematic review confirmed the effect of GS on the risks of MI, ACS and stroke. Summarizing the data of all the works mentioned in this publication, it can be noted that the main mechanism of the negative impact of GS on the functioning of the human cardiovascular system is their effect on circadian (biological) rhythms, heart rate variability, which affects changes in blood pressure and microcirculation.

We assume that when assessing the impact on humans and when planning further research in this area, it is necessary to correctly choose the type of local, regional or planetary geomagnetic index, depending on the goals of the study.

Currently, a wide variety of indices are presented in the literature:[44] A-index, K-index, geomagnetic Auroral Electrojet (AE-index), disturbance storm time (DST index) and many others. This diversity is associated with the complex dynamics of the Earth's magnetic field, in particular its dependence on geographic coordinates. It is believed that the AE index gives more correct results for high latitudes and in the aurora region. On the contrary, the DST index is more correct for the equatorial zone. In this situation, the idea of using local indices measured in a specific geographic region seems attractive. However, in this case, there is a risk of local "noise" of the data with false signals, which for planetary indices is solved by comparing data from a large number of measurement centers. We believe that insufficient attention has so far been given to this issue and correct consideration of these factors in the future can significantly increase the accuracy of the analysis and the reliability of the conclusions.

It is also necessary to take into account the problem of multimorbidity, the influence of concomitant somatic pathology, the use of drugs with a protective effect and the age of patients when analyzing the influence of geomagnetic field fluctuations on them. A separate unresolved issue is the determination of the characteristics of the individual temporary reaction of a particular person to the fact of the development of a GS (the day before, on the day, or the next day after the storm). We assume that clarification of this issue requires a separate specially designed study.

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Conflicts of interest

There are no conflicts of interest.

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