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Effects of Geomagnetic Disturbances on Incidence of Stroke: Identifying Gaps for Future Research

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Abstract

Geomagnetic disturbances (GMDs)—transient variations in Earth's magnetic field driven by solar activity—have garnered increasing attention for their potential impact on cardiovascular and cerebrovascular outcomes, including stroke. A growing body of epidemiological research has documented the correlations between geomagnetic storms and stroke incidence, particularly among high-risk populations. However, mechanistic studies remain scarce and existing findings are often inconsistent across geographic regions, stroke subtypes, and patient-specific variables. This paper presents a comprehensive review of the literature on GMDs and cerebrovascular health, highlights the physiological pathways that potentially link GMDs to stroke, and identifies key gaps in current research. We propose future interdisciplinary directions for integrating space weather forecasting with clinical neurology to inform early-warning systems and stroke prevention strategies.

Keywords: *geomagnetic disturbances, stroke, autonomic nervous system, endothelial dysfunction, space weather, inflammation, cardiovascular risk*

1. 1. Introduction

Stroke remains one of the leading causes of death and disability worldwide, with an estimated 12 million new cases occurring annually Feigin et al. (2022). Traditionally, stroke risk has been attributed to modifiable factors such as hypertension, atrial fibrillation, and smoking, as well as non-modifiable ones like age and genetics. However, emerging research suggests that environmental and geophysical factors—particularly space weather phenomena such as geomagnetic disturbances (GMDs)—may also play a contributing role Palmer et al. (2006); Stoupel et al. (2014). Interest in the health implications of GMDs has grown in recent decades, spurred by observations of increased hospital admissions for cardiovascular and cerebrovascular events during geomagnetic storms Gurfinkel et al. (1998); Cherry (2002). However, despite a number of epidemiological studies linking GMDs to cardiovascular morbidity, there remains a dearth of focused research exploring how these disturbances may influence cerebrovascular physiology specifically. This paper aims to synthesize the current state of knowledge, evaluate potential pathophysiological mechanisms, and highlight key research gaps that warrant further investigation.

2. Geomagnetic Disturbances and Stroke Incidence

GMDs are known to generate electrical currents in the atmosphere and surface of the Earth, which can indirectly influence biological systems through electromagnetic exposure. Several studies have examined the relationship between GMDs and the incidence of stroke, often using indices such as the Ap or Kp index to quantify geomagnetic activityVencloviene et al. (2021); Breus et al. (2015). For example, a multi country case crossover study by Feigin et al. (2014) found that moderate to severe geomagnetic storms (Ap more than 60) were associated with a statistically significant increase in admissions to ischemic stroke. Similarly, studies in Moscow and Kaunas have reported increases in both ischemic and hemorrhagic stroke during periods of heightened geomagnetic activity Shaposhnikov et al. (2014); Stoupel et al. (2012). Despite these findings, there are several inconsistencies in the literature. For instance, while some studies report a stronger

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association with hemorrhagic stroke, others find ischemic stroke to be more affected Stoupel et al. (2014); Vencloviene et al. (2019). Regional differences may also modulate the impact of GMDs. Populations residing at higher geomagnetic latitudes, where geomagnetic fluctuations are more pronounced, often exhibit greater stroke sensitivity Otsuka et al. (2011). Moreover, some large-scale studies, such as those conducted across 263 U.S. cities, found no significant relationship between GMDs and stroke mortality, though associations were noted for cardiovascular deaths overall Vieira et al. (2019). These conflicting results underscore the need for standardized methodologies and longitudinal studies that account for regional geomagnetic exposure, stroke subtype, and comorbid conditions. More granular data on temporal exposure windows—e.g., whether stroke onset clusters during the peak, rise, or recovery phase of geomagnetic storms—is also lacking.

3. Pathophysiological Mechanisms

3.1. Autonomic Nervous System and Hemodynamic Changes

The autonomic nervous system (ANS) is a critical regulator of cardiovascular and cerebrovascular function. Studies suggest that GMDs may alter autonomic balance, leading to reduced heart rate variability (HRV), increased blood pressure, and shifts in vagal and sympathetic tone Cornelissen et al. (2002); Dimitrova et al. (2016). These changes may, in turn, compromise cerebral autoregulation and increase stroke susceptibility. For instance, Cornelissen et al. Cornelissen et al. (2002) reported significant correlations between geomagnetic activity and circadian patterns of HRV, blood pressure, and the incidence of myocardial infarction. Reduced HRV is a known marker of cardiovascular risk, and similar autonomic perturbations could impair cerebrovascular tone, promote vasospasm, and predispose susceptible individuals to ischemic events. Furthermore, fluctuations in baroreceptor sensitivity during geomagnetic storms could lead to impaired regulation of perfusion pressure in the cerebral arteries, especially in patients with compromised vascular integrity Khabarova et al. (2018).

3.2. Coagulation, Inflammation, and Endothelial Dysfunction

GMDs may also influence hemostatic balance by promoting inflammation and endothelial activation. Elevated levels of proinflammatory cytokines such as IL6, TNF alpha, and CRP have been observed during periods of heightened geomagnetic activity Rapoport et al. (2017); Mavromichalaki et al. (2012). These inflammatory mediators contribute to atherosclerosis progression and plaque destabilization, creating a prothrombotic environment conducive to stroke. Exposure to extremely low-frequency electromagnetic fields has been shown to alter platelet aggregation and fibrinolysis, thereby increasing clot formation risk Palmer et al. (2006); Zhang et al. (2020). Melatonin suppression during geomagnetic storms can further exacerbate these effects, as melatonin has known anti-inflammatory and anticoagulant properties Reiter et al. (2013). Together, these changes can impair vascular reactivity, reduce endothelial nitric oxide production, and compromise blood-brain barrier integrity Stoupel et al. (2002).

4. Discussion

4.1. Summary of Current Evidence

Together, the literature supports a plausible link between GMDs and increased stroke risk, mediated through autonomic, inflammatory, and vascular pathways. However, most of the existing studies are ecological in design, with limited individual-level data. Few studies control for confounding variables such as temperature, air pollution, and circadian misalignment, which are also known to influence stroke risk Kyselý et al. (2021). There is also a lack of mechanistic research that directly investigates the biological effects of GMD exposure in humans. Most pathophysiological theories remain speculative, supported by extrapolated data from cardiovascular studies or animal models. Moreover, no study to date has performed real-time monitoring of autonomic or vascular parameters in stroke patients exposed to geomagnetic storms Houdouin et al. (2022).

4.2. Key Research Gaps

1) Geographic and temporal inconsistencies in observed stroke-GMD associations

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2) Lack of stroke-subtype stratification in most epidemiological studies

3) Absence of human biomarker studies measuring endothelial, inflammatory, or coagulation changes during GMDs

4) No integration of space weather forecasting with clinical risk models

5) No clinical trials assessing protective interventions (e.g., melatonin) in GMD-exposed individuals

4.3. Future Research Directions

To address these gaps, we propose the following:

- Conduct multi-site cohort studies integrating geomagnetic data with individual stroke cases Feigin et al. (2022)
- Include stroke subtyping and temporal resolution of geomagnetic exposure windows Vencloviene et al. (2019)
- Implement biomarker sampling during high GMD periods to measure inflammatory and endothelial changes Rapoport et al. (2017)
- Explore the feasibility of geomagnetic storm early warning systems for vulnerable populations Breus et al. (2015)
- Evaluate the protective potential of melatonin, antioxidants, and antihypertensive therapies during geomagnetic events Reiter et al. (2013)

5. Conclusion

While the association between GMDs and cardiovascular events is increasingly recognized, the evidence for their role in stroke remains incomplete and inconsistent. Pathophysiological mechanisms such as autonomic dysregulation, vascular inflammation, and coagulation abnormalities provide a theoretical basis for these associations, but empirical validation is lacking. Addressing these gaps through targeted interdisciplinary research is essential to develop predictive tools and preventive strategies to mitigate the burden of stroke in the context of space weather.

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