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Correlation of Geomagnetic Activity with Implantable Cardioverter Defibrillator Shocks and Antitachycardia Pacing

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Abstract

Objective—Small-scale observational studies have suggested that geomagnetic activity (GMA) may negatively correlate with the frequency of life-threatening arrhythmias. We investigated a potential relationship between implantable cardioverter defibrillator (ICD) therapies and daily GMA recorded in a large database.

Patients and Methods—The ALTITUDE database, derived from the Boston Scientific LATITUDE remote monitoring system, was retrospectively analyzed for the frequency of ICD therapies. Daily GMA was expressed as the planetary K-index and the integrated A-index and graded as Levels I – quiet, II – unsettled, III – active, and IV – storm.

Results—A daily mean of $59,468 \pm 11,397$ patients were monitored between 2009 and 2012. The distribution of days according to GMA was: Level I 75%, Level II 18%, Level III 5%, Level IV 2%. The daily number of ICD shocks received per 1000 active patients in the database was 1.29 ± 0.47 , 1.17 ± 0.46 , 1.03 ± 0.37 , and 0.94 ± 0.29 on Level I, Level II, Level III, and Level IV days respectively; the daily sum of shocks and antitachycardia pacing (ATP) therapies was $9.29 \pm$

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Disclosures

All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest.

2.86, 8.46 ± 2.45 , 7.92 ± 1.80 , and 7.83 ± 2.28 on quiet, unsettled, active and storm days respectively. A statistically significant inverse relationship between GMA and the frequency of ICD therapies was identified, with the most pronounced difference between Level I and Level IV days ($p < .001$ for shocks, $p = .008$ for shocks + ATP).

Conclusion—In a large scale cohort analysis, ICD therapies were delivered less frequently on days of higher GMA, confirming the previous pilot data and suggesting that higher GMA does not pose an increased risk of arrhythmias using ICD therapies as a surrogate marker. Further studies are needed to gain an in-depth understanding of the underlying mechanisms.

Introduction

While many advances have been made to identify the pathophysiological processes which predispose to clinically significant ventricular arrhythmias (including ischemic, infiltrative, or dilated cardiomyopathies), their initiation often depends on additional proarrhythmic factors, including those found in the environment (physical or mental stress leading to catecholaminergic surge, changes in myocardial electrical conductivity due to electrolyte disturbances or medication changes).^{1–3} The identification of additional environmental factors relevant in ventricular arrhythmogenesis could further our understanding of ventricular arrhythmia pathophysiology, as well as targets for therapies and intervention.

Earth's geomagnetic field is essential for life, as it provides protection from charged particles emitted from the sun (solar wind). Disturbances of the solar wind influence the geomagnetic field. Solar eruptions (solar flares and coronal mass ejections) can lead to dramatic changes via geomagnetic storms. Of concern, these geomagnetic storms can impact the function of electronic instruments, like computers or power grids.⁴ Whether solar activity and the resultant changes in Earth's geomagnetic field could influence occurrence of ventricular arrhythmias remains unclear. Limited evidence from small studies suggests that an inverse relationship between geomagnetic activity (GMA) and the incidence of malignant arrhythmias in humans exists.^{5–11}

We investigated the potential correlation between GMA and arrhythmias through monitoring the frequency of implantable cardioverter defibrillator (ICD) therapies as recorded in the LATITUDE database.

Methods

The ALTITUDE project¹² is a clinical science initiative formed to prospectively analyze data from clinically indicated ICDs and cardiac resynchronization therapy-defibrillators (CRT-D) followed on a remote monitoring system (LATITUDE, Boston Scientific Corp., Natick, Massachusetts).¹³ In the ALTITUDE study, remote transmission occurs an average of 4 ± 2 and 3 ± 2 times monthly for CRT-D and ICD, respectively. The remote system consists of a communicator at the patient's home which interrogates the device. A patient may also initiate the transmission on demand. ICD and CRT-D device data are transmitted on a regular basis over a secure network to a central server. Data regarding this population have been published previously.¹² We retrospectively retrieved data for analysis for ICD therapies and GMA levels between January 1, 2009, and May 15, 2012. On each day during

this period, we recorded the sum of all ICD shocks received by the patients who were active in the monitoring system and indexed this to the number of active patients for each day. An additional variable analyzed was the daily sum of ICD shocks + antitachycardia pacing (ATP) therapies delivered to the active patients in the monitoring system. Data were expressed as daily ICD shocks per 1000 patients, and daily ICD shocks + ATP per 1000 patients, respectively.

Geomagnetic activity was expressed as the K-index and the integrated A-index, which numerically quantify the disturbances in the horizontal component of Earth's geomagnetic field. Planetary K- and A-indexes were obtained from the United States Space Weather Prediction Center.¹⁴ Each day within the studied period was assigned to one of the following four categories according to previously published criteria⁸: quiet days (Level I), unsettled days (Level II), active days (Level III) and storm days (Level IV) (Table 1).

Statistical analysis

The analysis of variance was utilized in the initial evaluation of the differences in the number of ICD shocks (dependent variable) among the groups stratified by the level of GMA (independent variable). Similar analysis was done for the endpoint of daily ICD shocks + ATPs as the dependent variable. To explore the inter-group differences and their significance, we utilized Student's t-test for 2-group comparisons, and to take into account multiple comparisons among the groups and remain conservative, Bonferroni correction was used for adjustment of type I error (4 comparisons performed; therefore, for the *p* value to reach statistical significance a value less than 0.01 was required). Mean, standard deviation and confidence interval (95% CI) were reported. For the assessment of correlation between GMA (A-index was used as the independent variable, transformed by natural logarithm to achieve normal distribution) and the daily proportion of patients who received ICD shock (dependent variable) a simple linear regression was employed. Similar analysis was done for the mean daily ICD shocks + ATPs as the dependent variable.

Results

Our analysis was performed on a daily mean of $59,468 \pm 11,397$ patients from the total of 69,556 patients followed on the ALTITUDE network (mean age of the ALTITUDE network population was 67 ± 12 years, with 74% of participants being male; mean device implantation duration was 29 ± 15 months).¹² The distribution of days stratified according to GMA scheme was: quiet days (Level I) 75%, unsettled days (Level II) 18%, active days (Level III) 5%, and storm days (Level IV) 2%. A total of 86,427 ICD discharges were recorded on the 1231 days included in the study period. The frequency of ICD shocks per day was 1.29 ± 0.47 (95% CI: 1.26–1.31) of every 1000 persons on Level I days, 1.17 ± 0.46 (95% CI: 1.11–1.23) on Level II days, 1.03 ± 0.37 (95% CI: 0.91–1.15) on Level III days, and 0.94 ± 0.29 (95% CI: 0.75–1.14) on Level IV days. A total of 631,193 instances of ICD shocks and ATP therapies were delivered during these 1231 days. The daily mean of ICD shocks or ATP therapies delivered per 1000 patients followed in the database was 9.29 ± 2.86 (95% CI: 9.11–9.48) on Level I days, 8.46 ± 2.45 (95% CI: 8.14–8.78) on Level II

days, 7.92 ± 1.80 (95% CI: 7.45–8.39) on Level III days, and 7.83 ± 2.28 (95% CI: 6.79–8.87) on Level IV days.

The analysis of variance revealed a significant difference in the frequency of ICD shocks among the various GMA level days ($p < .001$), and similar findings were shown regarding the combined endpoint of ICD shocks + ATPs ($p < .001$). An inverse relationship between GMA level and the number of recorded ICD therapies for both ICD shocks and ICD shocks + ATPs was found, with the greatest difference being between Level I and Level IV GMA days. Comparisons among the relevant groups in terms of both ICD shocks and ICD shocks + ATP therapies are summarized in Tables 2 and 3 and Figure 1. Additionally, we tested this relationship employing GMA as a continuous variable (transformed A-index), and similar inverse relationships between GMA and the frequency of ICD shocks ($p < .001$, $R = 0.22$), as well as between GMA and the frequency of the ICD shocks + ATPs ($p < .001$, $R = 0.23$) were identified.

Discussion

We identified an inverse correlation between the levels of GMA and the frequency of ICD shocks, and between the GMA and ICD shocks + ATP therapies. These findings are consistent with prior pilot data and suggest that higher GMA does not pose an environmental risk of increased arrhythmias when using ICD therapies as a surrogate marker.

Magnets and ICDs

It is well known that electromagnetic interference can pose a danger to patients with an ICD;^{15,16} ventricular oversensing with subsequent delivery of inappropriate therapies, temporary or definitive suspension of all antitachycardia therapies or hardware damage can pose as possible mechanisms.^{17–19} In other situations the use of magnets is desirable, for example when an ICD needs to be voluntarily inhibited from delivering therapies in surgical patients when tools that can interfere with the ICD are used. Magnets are also employed in emergency situations to terminate therapy delivery in cases of inappropriate arrhythmia detection.²⁰

Recently, concerns have risen about possible interference to ICDs from electromagnetic fields that exist in certain work environments.²¹ Usually a magnetic flux density of 100 micro-Tesla is considered to be the safety level for pacemakers and ICDs,²² and studies of static magnetic fields have shown that no changes in terms of rate or rhythm of the heart were seen in experiments with animals or humans with the use of up to 8 Tesla.²³

Environmental Factors and ICDs

The Earth's geomagnetic field is an example of cosmic influence on our environment. Even if the geomagnetic field energy level fluctuates constantly as a consequence of interactions between solar and terrestrial energy changes, its absolute energy level is low,⁵ on the order of nano-Teslas. Exposure to cosmic radiation has been shown to interact with electronic devices.²⁴ Cosmic radiation is influenced by altitude, latitude, solar activity, and solar proton events. A few case reports have hypothesized an association between the high

altitude reached on airline flights and ICD software electrical resets.^{24,25} Moreover, there have been a few, modestly powered studies conducted in the last 20 years, which have raised speculation regarding a potential association of cardiac events and change in cosmo-physical factors, suggesting a possible inverse relationship between GMA and the incidence of malignant arrhythmias.^{5-7,9,10}

Forensic medicine and Holter monitoring data reported a higher incidence of sudden cardiac death in patients without acute myocardial infarction and a higher incidence of premature ventricular complexes and ventricular tachycardia on days with lowest GMA levels.^{5,6, 26} Furthermore, in patients admitted for acute myocardial infarction, cardiac arrhythmic events were more frequent on lower GMA days.²⁷ This was met with skepticism and dismissed as a merely coincidental relationship possibly due to the limited scope of these pilot data, therefore underscoring the need for confirming those findings in a larger sample sized population. Another smaller study involving 25 patients showed a significant inverse correlation between GMA and ICD shocks, supporting the notion of GMA as a protective shield or a possible interaction between GMA levels and activation of other additional arrhythmogenic physical factors like cosmic rays or high-energy proton flux.⁹

The results of our study are consistent with this inverse correlation between ICD therapies and GMA levels in a larger scale population study of over 59,000 patients with ICDs. However, these results must be taken in the proper context for further clarity of what these data mean. Although the differences in ICD shocks and ATP therapies were statistically significant, with the extremely large sample sizes employed in this study, it is possible that we have detected a statistically but not clinically significant difference. Further investigation is necessary to gain a deeper understanding for the pathophysiology behind these findings. Moreover, taking into account the possible latency of GMA effect provides an important basis for future investigation. Indeed, the effect of low GMA days may not be seen immediately, and events related to low GMA days may be theoretically noted a few days later rather than on the same calendar day. However, in our studied period, the distribution of the high GMA days was such that they tended to cluster on some occasions, and commonly the period of relatively low GMA prior to the storms was interceded by a few days of relatively higher activity, so we presumed that the consequence of GMA level variation on the devices exerted an immediate effect (Figure 1, Panel C).

In our analysis we considered 4 categories of GMA. Work from Stoupe et al.⁸ further separated Level IV days into 3 subcategories: “Minor Storm,” “Major Storm,” and “Severe Storm.” We decided not to break down Level IV days further because of the relatively infrequent presence of these days during our study period (N = 21), and such investigation deserves to be the focus of future prospective studies. In our population, as showed in Table 2 and 3, the most pronounced difference existed between Level IV days compared to Level I days, (high vs low GMA), rather than within each category.

Limitations

Our study has many limitations, which include all of the inherent biases of a retrospective study, especially one of this magnitude. Additionally, our study could not assess the

appropriateness or inappropriateness of shocks or ATP therapies, as adjudication on such a large scale was not available in the database used. We also could not correlate these changes in GMA to Holter monitoring data or clinical events such as sudden cardiac death, arrhythmias, or myocardial infarctions, and thus were limited to a surrogate marker of arrhythmia activity such as ICD therapies. This surrogate marker could be influenced by the possibility that several patients who would be more sensitive to the potential role of GMA would influence the overall group, as we are adding the number of shocks delivered on each day, rather than the number of patients who received these shocks (as this data was not available to us from the database). The majority of the study subjects were male (74%), and given that being male could be considered a risk factor for arrhythmias, future studies need to explore potential interaction between GMA and various arrhythmia etiologies (for example ischemic cardiomyopathy), which are more prevalent in men. It must also be noted that during our 3-year study period the number of patients in this registry did not stay constant, as patients dropped out of the registry or died, and there was enrollment of new patients. Despite these limitations, the hereby presented study represents the first large-scale assessment of the relationship between surrogate markers for arrhythmias and GMA, and to mitigate the limitations, a prospectively designed study is needed.

Future directions

Our analysis has been possible because of the unique opportunity to access data on a remote monitoring basis. Studies such as this are critical for answering many questions with regard to monitoring ICD therapies such as shocks and ATPs in a prospective controlled cohort fashion. The utility of remotely collected data may provide earlier detection of life-threatening events. It is our hope that studies based on remote monitoring can be used to test hypotheses regarding arrhythmias, sudden cardiac death and appropriateness of shocks in the future, particularly in the matter of variables changing on a day to day basis such as GMA. Ideally these trials will be designed with endpoints to characterize effects on cardiovascular morbidity and mortality.

Conclusion

We identified a relationship between GMA and ICD therapies. In a large-scale cohort analysis followed with a remote monitoring system, ICD therapies, both in terms of shocks and ATPs, were delivered less frequently on days of higher GMA. These findings confirm the previous small-scale observational studies, suggesting that, using ICD therapies as a surrogate marker, higher GMA does not pose an increased risk of arrhythmia. However, further studies are needed to gain an in-depth understanding of the underlying mechanisms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

ATP	Antitachycardia pacing
CRT-D	Cardiac resynchronization therapy - defibrillator
GMA	Geomagnetic activity
ICD	Implantable cardioverter defibrillator

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Figure 1.

Panel A: Scatter-plot showing the daily frequency of ICD shocks delivered per 1000 persons against the level of GMA. Panel B: Scatter-plot showing the daily frequency of ICD shocks plus ATP therapies delivered per 1000 persons against the level of GMA. Panel C: Graphical depiction of the distribution of GMA versus the daily intervals analyzed during the study period.

Table 1

GMA gradation

Category	Typical “K - index” Values	“A - index” Range	Amplitude (nano-Tesla)
Quiet (Level I)	Usually>3	0<A<8	0–20
Unsettled (Level II)	Usually>3	8 A<16	21–40
Active (Level III)	Few indices of 4	16 A<30	41–70
Storm (Level IV)	Mostly 4 and 5, >5	A 30	>70

Table 2

Daily frequency of ICD shocks per 1,000 persons – comparison among groups

	Quiet (Level I) 75%	Unsettled (Level II) 18%	Active (Level III) 5%	Storm (Level IV) 2%	<i>p</i> value
Quiet vs. Storm	1.29 ± 0.47	-	-	0.94 ± 0.29	<i>p</i> < .001
Unsettled vs. Storm	-	1.17 ± 0.46	-	0.94 ± 0.29	<i>p</i> = .003
Active vs. Storm	-	-	1.03 ± 0.37	0.94 ± 0.29	<i>p</i> = .28
All vs. Storm	1.25 ± 0.47			0.94 ± 0.29	<i>p</i> < .001

Comparison among groups: quiet vs. storm; unsettled vs. storm; active vs. storm; quiet + unsettled + active vs. storm. *p* value has been considered statistically significant when < .01 (due to the Bonferroni correction of comparison among groups).

Table 3

The frequency of ICD therapies (shocks and ATP) per 1,000 persons – comparison among groups

	Quiet (Level I) 75%	Unsettled (Level II) 18%	Active (Level III) 5%	Storm (Level IV) 2%	<i>p</i> value
Quiet vs. Storm	9.29 ± 2.86	-	-	7.83 ± 2.28	<i>p</i> = .008
Unsettled vs. Storm	-	8.46 ± 2.45	-	7.83 ± 2.28	<i>p</i> = .23
Active vs. Storm	-	-	7.92 ± 1.80	7.83 ± 2.28	<i>p</i> = .86
All vs. Storm	9.02 ± 2.77			7.83 ± 2.28	<i>p</i> = .02

Comparison among groups: quiet vs. storm; unsettled vs. storm; active vs. storm; quiet + unsettled + active vs. storm. *p* value has been considered statistically significant when < .01 (due to the Bonferroni correction of comparison among groups).