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Effect of geomagnetic activity on cardiovascular parameters

E. Stoupel

Multidirectional changes in the natural history of many cardiovascular syndromes have been linked to different levels of daily and monthly geomagnetic activity (GMA). Previous studies have found that in periods of high GMA there were more admissions for acute myocardial infarction and more cases of anterior wall myocardial infarction. Results also indicated: higher outpatient mortality and a trend towards higher hospital mortality from acute myocardial infarction; higher diastolic arterial pressure in healthy subjects and in treated hypertensive patients; higher prolactin and 17-corticosteroid levels in the peripheral blood; more severe migraine attacks and more admissions for CVA and cerebrovascular insufficiency in male patients; changes in many blood coagulation cellular gradients (platelet count, basophils in the peripheral blood), a rise in platelet aggregation, fibrinogen level and a drop in leukocyte adhesiveness.

Periods of low GMA showed a related increase (negative correlation) in in-hospital non-myocardial infarction-related cardiovascular deaths. Only in times of lowest GMA did inferior wall myocardial infarction exceed anterior wall myocardial infarction. Low GMA was also associated with higher levels of growth hormone and 11-ketosteroids in the peripheral blood, more sudden deaths, some increase in electrical heart instability/hourly number of ventricular and supraventricular extrasystoles and higher rate of ventricular tachycardia.

The monthly occurrence of pregnancy-induced hypertension was negatively correlated with GMA level. Gender differences were noted in some of the parameters. Other studied parameters did not show changes related to GMA. These included haemoglobin level, electrolyte level, heart beat and pulse rate. Moreover, some observed cardiovascular fluctuations that were related to the level of GMA also showed differences in the rising and dropping parts of the 11-year cycle of solar activity. It has been suggested that some of the changes observed in many clinical syndromes may be related to the concomitant activation of the serotoninergic system. *J Clin Basic Cardiol 1999; 2: 34–40.*

Key words: geomagnetic activity, myocardial infarction, sudden death, blood pressure, coagulation, arrhythmia, stroke

Everything in nature is a cause from which there flowsome effects.
B. Spinoza, "Ethics"

There is an increasing amount of evidence linking biological effects to solar and geomagnetic conditions. The present article contains a review of studies conducted over the last 20 years on changes in cardiovascular parameters in relation to changes in geomagnetic field activity.

Geomagnetic activity is not necessarily a direct "cause" of the diverse effects with which statistical relationships have been found. It may simply characterize complicated geophysical forces (primarily in the magnetosphere and ionosphere) which also influence the geomagnetic field by a dynamo effect. This effect is generated by different layers of the earth moving at different speeds and with different rates of electrical conductivity in the outer (liquid) and inner (solid) parts of the earth's core. We based our work on geomagnetic activity because it is observed globally (although not necessarily optimally) and may be measured using a reasonably simple, consistent scheme of data reduction – the K and A and associated composite indices.

My colleagues and I have published a series of studies of changes in normal human physical responses and the natural history of various pathological events at different levels of daily and monthly geomagnetic activity. As a clinical cardiologist, I have concentrated here on cardiovascular disease and related risk factors (ie, central nervous system changes) potentially involved in the behavioral and clinical dynamics of the human heart and blood circulation.

Gradation of geomagnetic activity (GMA)

GMA is measured by the A and K indices, as defined by the National Oceanic Atmospheric Administration (USA) Classification. "A" refers to the 24-hour index observed at a geomagnetic observatory, such as that in Fredericksburg, Virginia (middle latitude) or Anchorage, Alaska (high latitude). "K" refers to the 3-hour index derived from the most disturbed horizontal component of the local geomagnetic field. K is a quasi-logarithmic index, ranging from 0 (very quiet) to 9 (highly disturbed – stormy).

Table 1 shows the relationship between GMA (nanotesla units), K values and characteristics of the day. The amplitude is given for a middle latitude station.

In our studies we used the daily A and K indices for the middle latitude, describing quiet (Io), unsettled (IIo), active (IIIo), and stormy (IVo) days, and monthly K indices from the NOAA Space Service [1] and Geophysical Data Centers, Boulder, Colorado [2].

These data were compared with observations published monthly in Cosmic Data, published by the Izmiran Institute

Table 1. Geomagnetic activity gradation

Category	"A" index range	Typical "K" values	Amplitude (Nanotesla)
1. Quiet (I)	0< A<8	Usually not > 2	0–20
2. Unsettled (II)	8< A<16	Usually not > 3	21–40
3. Active (III)	16< A<30	Few indices of 4	41–70
4. Minor storm (IV)	30< A<50	Mostly 4 & 5	71–120
5. Major storm (IV)	50< A<100	Some indices 6 or >	121–200
6. Severe storm (IV)	100< A	Some indices 7 or >	201–>550

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of the Academy of Sciences of the USSR (now Russia) [3]. The Space Environment Service Center Glossary of Solar-Terrestrial Terms (1988, revised 1992) was used as well [4].

Relationship of GMA to cardiovascular parameters

Acute myocardial infarction (AMI)

In a separate study, the number of admissions for AMI (n = 1744) to a single ICCU over a 48 month period was correlated with daily GMA level [5, 6]. For men, $r = 0.97$, $p < 0.03$; for women, $r = 0.947$, $p < 0.05$; for all patients, $r = 0.977$, $p < 0.02$. This work was based on an earlier one showing that the number of AMIs increases on days just before, on and after stormy (IVo) geomagnetic days [5, 7].

Localization of AMI

The two principal coronary arteries are regulated by different vegetative innervation: the left by sympathetic, the right by both sympathetic and parasympathetic. The right artery supplies most of the inferior-posterior heart wall, the left supplies the anterior wall and, in most cases, the lateral wall. We learned from experience that incoming patients show some "irregularity" in the localization of AMI. Sometimes the irregularity appears on certain days only; in some cases, predominantly one area appears damaged at certain times and an opposite area at other times.

The same 1744 patients mentioned above served as the population in a previous study which investigated whether irregularities in the site of AMI (anterior wall versus inferior-posterior wall) occur in accordance with the seasons of the year and whether the changes differ on days of different GMA levels [5]. It was found that in 28 of the 48 months of the study (58.3 %), more than 10 % of one of these two AMI locations dominated. Anterior wall AMI occurred more frequently than inferior-posterior wall AMI in all four seasons, although the differences were small and not significant (winter 51.14 %, spring 52.9 %). The GMA came into play only when inferior-posterior wall AMI occurred more frequently than anterior wall AMI. On these days, GMA was at its lowest level (Io), with a ratio of 0.96. This ratio increased concomitantly with an increase in GMA. The ratio of the two studies on Io days was different from that on days of the higher (IIo–IVo) GMA levels (chi square = 9.4226, $p < 0.05$), whether the findings for all three higher levels were taken together or compared individually.

Eighty-seven patients had isolated lateral wall AMI, a separate and generally benign form of AMI which is related mainly to the lesion of the circumflex branch of the left coronary artery. This type of AMI showed an inverse and strong correlation with GMA level (Io–IVo) ($r = -0.951$, $p < 0.01$) [5].

Deaths from AMI

In one study, AMI was confirmed as the cause of death on postmortem examination in 164 outpatients with a very poor prognosis before admission. When the relationship between AMI mortality and GMA was investigated, results indicated 0.161 deaths/day for IIIo–IVo days and 0.096/day for Io–IIo days (n = 123) ($p < 0.02$). When inpatient deaths were examined (n = 650), a trend became apparent (t = 1.6–1.7) for higher daily mortality on IIIo–IVo days, although statistical significance was not achieved (679 days of Io, 836 of IIo, 499 of IIIo and 121 of IVo were studied).

In another 180-month correlative study (1974–1988) of 15,601 hospital deaths, including 1573 from AMI which were linked to ten cosmophysical parameters, a non significant correlation was shown between the monthly index and the number of ICCU deaths from AMI [8]. However, highly significant links with some parameters of solar activity were seen. These supported earlier observations of daily GMA and the distribution of in-hospital deaths from AMI in the years 1974 to 1980, which constituted the first, or rising, part of solar cycle 21, and 1981 to 1986, the second, or declining, part of solar cycle 21 [9]. In the first part of the cycle (increasing solar activity), a positive correlation was noted between the number of in-hospital deaths from AMI and GMA level ($r = 0.827$, $p = 0.05$). In the second part (decreasing solar activity), a significant negative correlation was registered ($r = 0.949$, $p < 0.01$). Almost no difference between the two solar activity periods was noted for days of lower (Io) GMA.

We concluded that the ongoing advances in cardiovascular diagnosis, early treatment and improved intensive care and resuscitation techniques may have affected hospital mortality and morbidity, as reflected in admissions of AMI patients and the distribution of outpatient deaths from AMI. Moreover, the cyclic changes in the effects of GMA may also partially explain the absence of a significant correlation between GMA level and long-term hospital mortality from AMI. In our recent study with J. Petraukiene, E. Abramson, R. Kalediene and J. Sulkes considering 8-year (1990–97) monthly mortality from ischaemic heart disease (n = 129,913) a significant correlation with 3 GMA monthly indices was found, more prominent for male and at age < 65 and > 74 and non significant for age group 65–74 (unpublished data).

Sudden Death

Sudden death refers to death that occurs within 6 hours of overt critical symptoms without previous signs of a life-threatening situation. Cardiologists tend to agree that the shorter the interval between onset of critical symptoms and death, the higher the chances of a cardiac origin.

Two groups of sudden death patients were investigated with regard to GMA activity in three separate studies. Group 1 included 651 patients who died on the way to the hospital or in the admissions room, over a 1782 consecutive-day period [10–12]. In 95 % of these patients, death occurred within 1 hour or less of onset of critical symptoms. Of the 1782 days covered by the study, 666 were quiet (Io), 660 unsettled (IIo), 375 active (IIIo) and 81 stormy (IVo). We found that 0.146 sudden deaths/day occurred on Io days, 0.108 on IIo and IIIo and 0.106 on IVo. The daily number of sudden deaths correlated adversely with the GMA level ($r = -0.804$, $p = 0.057$), Group 2 included 46 non hospitalized sudden death patients with postmortem confirmation of atherosclerotic heart disease [13]. The patients had shown no signs of AMI. Results showed 0.55 deaths/day on Io–IIo days and 0.018 deaths/day on IIo and IVo days ($p < 0.001$). When acute vascular events were excluded, the main cause of death in most of the patients was related to electrical heart instability and heart rhythm disturbances (ventricular tachycardia, fibrillation, complete atrioventricular block, electromechanical dissociation).

Heart rhythm disturbances

To check these results, 4363 in-hospital deaths from cardiovascular disease, excluding myocardial infarction, were studied over 180 consecutive months (1974–1989) [8]. The monthly number of deaths in this group showed a negative correlation with the monthly K index ($r = -0.23$, $p < 0.05$). At the same time, studies were made to check the distribution of some types of heart rhythm disturbances in accordance with different GMA levels.

In 211 cardiac patients checked for heart arrhythmias, no significant differences were seen in heart rhythm frequency among four levels of daily GMA. Extrasystolic premature heart contractions - electrical depolarizations were studied by 24-hour Holter electrocardiographic monitoring. Results were as follows:

(a) *Supraventricular extrasystoles (APCs):* 23.42 ± 13.04 APCs on Io days; 19.06 ± 6.7 on IIo; 11.04 ± 6.88, IIIo; and 17.87 ± 5.8, IVo. The number of APCs/hour was significantly higher on Io days compared with IIIo ($p < 0.02$) and IVo ($p < 0.05$) days. Statistical significance was not achieved in comparison with IIo days.

(b) *Ventricular extrasystoles (VPCs):* 55 ± 16.21 VPCs on Io days, 33.5 ± 11.11, IIo; 34.6 ± 14.3, IIIo; and 44.2 ± 13.79, IVo. The number of VPCs/hour was significantly higher on days of Io GMA compared with every other daily GMA level ($p < 0.05$ for each).

Ventricular tachycardia (VT)

Long and frequent episodes of VT (ie, more than three consecutive VPCs) are related to a high risk of sudden death. Thus, in a separate study, 17 of 233 patients in whom VT was registered in more than 5000 24-hour Holter monitoring studies underwent repeat studies at a different GMA level [14].

Observations were made over 910 consecutive days (excluding holidays). A trend was indicated toward more VT occurrences on Io–IIo days compared with IIIo–IVo days (0.247 versus 0.225 daily), although the difference was not statistically significant. An accompanying trend was observed toward a higher frequency of VTs on Io and IIo days compared with IIIo and stormy IVo days (150.67 ± 29.056 versus 142.16 ± 27.79, $t = 1.78$, $p = 0.077$). On the most active GMA days (IVo), the VT rate was lowest (132 ± 21.38). The total number of VPCs registered in patients with VT by Holter monitoring was 3271 ± 710 ($n = 31$) on Io–IIo days and 1301 ± 1558 ($n = 16$) on IIIo–IVo days.

Paroxysmal atrial fibrillation (PAF)

In a study of admissions for PAF ($n = 653$) in 1990–1993 (1185 consecutive days) a trend was again observed of the highest daily admissions Io GMA (0.65); the numbers of daily admissions were 0.549 (IIo), 0.508 (IIIo) and 0.356 (IVo). On days of lowest GMA, significantly more PAF patients were admitted than on days of highest GMA ($p = 0.0004$) [15]; it was a significant negative correlation between daily number of patients admitted with PAF and GMA level ($r = -0.976$, $p = 0.024$). This was observed in both male and female patients.

In conclusion

1) There is a negative correlation between GMA level and nonmyocardial infarction-related cardiovascular deaths in hospital and all cardiovascular deaths.
2) There is an adverse correlation between GMA level and the daily and monthly number of sudden deaths.
3) A greater number of electrical heart instability events may be noted in affected patients on days of low GMA.

Neuroendocrine markers

The influence of the central nervous system (CNS), especially the hypothalamus, on the cardiovascular system, whether directly or through the endocrine system, is well known [16–19]. To study the relationship of these systems with changing GMA, the levels of human growth hormone (GH) and prolactin (PRL), both markers of hypothalamic activity, were studied, as were those of 17-ketosteroids (KS), 17-oxyhydroketosteroid (17-OHKS) and 11-hydroxyketosteroid (11-OHKS), are secreted by the adrenal glands as part of the stress situation response process and also involved in the regulation of vascular tonus, arterial blood pressure, and general reactivity.

GH levels were studied using 1752 samples in 967 males and 785 females. A trend was seen towards decreased plasma GH levels on IVo days ($t = 1.85$). Levels ranged from 4.8 ± 0.2 (SE) on Io days to 4.0 ± 0.4 on IVo days. This tendency achieved significance (in males) when GH levels on IVo days were compared with levels on Io ($p < 0.05$) and IIo ($p < 0.025$) days.

Prolactin levels were higher on IIIo ($p < 0.025$) and IVo ($p < 0.02$) days compared with Io and IIo days. Levels increased from 10.3 ± 0.4 (Io) and 9.8 ± 0.4 (IIo) to 12.0 ± 0.7 (IIIo) and 13.0 ± 0.3 (IVo).

The level of 17-KS rose on IIIo–IVo days compared to Io–IIo days ($p < 0.001$–0.05), whereas the level of 11-OHKS showed a significant, concomitant decrease ($p < 0.01$–0.05). Changes in 17-OHKS were not significant [20].

Laboratory cardiovascular risk factors

Plasma cholesterol level was measured in 1215 patients suffering from atherosclerotic heart disease and 2205 healthy subjects (blood donors) [21]. The only significant change observed was the decrease in cholesterol level in the patients, from 253.3 ± 43.8–257.16 ± 42.5 (SD) on I–IIIo days to 244.0 ± 48.0 on IVo days ($p < 0.05$). The levels of triglycerides, glucose, and uric acid did not show significant changes in the patient group. In the healthy subjects, a decrease in triglyceride levels from 118.4 ± 67.62 (Io-IIo) to 109.35 ± 59.6 (IIIo) and 107.67 ± 63.02 (IVo) ($p < 0.02$) was the only significant change related to GMA.

Arterial blood pressure

Systolic and diastolic arterial blood pressure was measured in 870 hypertensive patients under drug therapy and 550 healthy blood donors [13]. Data were observed over 1419 days: 417 Io, 589 IIo, 339 IIIo and 74 IVo. There was a tendency in the hypertensive group for diastolic blood pressure to be significantly higher on IIIo-IVo days (99–100 mmHg) than on Io-IIo days (97.26–97.33 mmHg) ($p < 0.05$–0.07).

In the healthy volunteers, diastolic blood pressure was higher on IIo–IVo days than on Io days ($p < 0.01$–0.02). Pulse pressure (difference between systolic and diastolic arterial pressure) showed a tendency to be lower on IVo than on Io days ($p < 0.01$); a slight decrease in systolic pressure on Io–IIIo days was seen (from 154–157 to 150 mmHg) concomitant with the increase in diastolic pressure. In an additional study [22] it was shown by 24-hour ambulatory blood pressure monitoring of treated hypertensive patients significantly higher 1) daytime systolic blood pressure ($p = 0.04$); 2) diastolic blood pressure at strong trend level ($p = 0.08$); 3) highest daytime systolic pressure ($p = 0.04$); 4) highest daytime diastolic pressure ($p = 0.018$), when results in Io ($n = 35$) and IVo ($n = 39$) of daily GMA were compared.

Pregnancy-induced hypertension (PIH)

PIH is a common life-threatening disorder of unclear pathogenesis with multiorgan involvement. Of 19,843 deliveries studied, 628 were associated with PIH (3.2 %). A negative correlation between the monthly GMA index and the number of monthly cases of pregnancy-induced hypertension over a 60-month period was shown ($r = 0.4$; $p < 0.01$) [23].

Some plasma electrolytes

Only partial conclusions can be drawn from observation of plasma electrolyte levels, because some electrolytes (potassium, magnesium) are concentrated mainly intracellularly, and the plasma level is insufficient for consideration of their dynamics. The function of the cellular membranous pumps, degree of permeability, and gradients of potassium, sodium, calcium, and magnesium on both sides of the membrane is very important in the pathogenesis of heart failure, rhythm disturbances, conduction defects, ischaemic adaptation to hypoxia, acidosis, etc.

We studied 2835 ambulatory persons examined for chloride, 2834 for sodium and 2986 for potassium plasma concentration [21]. No differences in plasma levels of these three electrolytes were observed at different daily GMA levels.

Blood coagulation parameters

The blood coagulation system is essential in human homeostasis, and its role in the pathogenesis of most cardiovascular diseases is the subject of intensive study. This field received renewed attention with the successful introduction of thrombolytic agents for the treatment of vascular thrombosis.

Part of our study of this subject consisted of the measurement of changes in some blood coagulation parameters at different GMA levels. The observations were made in hospital on large groups of patients and on healthy subjects (blood donors) [13, 24, 26]. In some cases, in addition to daily GMA level, the level just before active and stormy GMA days and two days after were also considered in the analysis. The data collected included: 1) platelet count; 2) prothrombin time (INR); 3) ADP platelet aggregation (a key factor in vascular thrombosis, myocardial infarction, atherogenesis); 4) Plasma fibrinogen level; 5) fibrinolytic activity; 6) clotting time and 7) bleeding time. For more complex observations, and in consideration of the close connection between blood coagulation and viscosity, additional parameters were included in the protocol: 1) red blood cell count; 2) haemoglobin; 3) haematocrit; 4) plasma viscosity; 5) total leukocyte count and leukocyte fractions, with special attention to basophils, which are white blood cells associated with some elements (heparinoid, serotonin, histamine) involved in coagulation and microcirculation [27, 28]. A separate study was performed for leukergy (leukocyte aggregation) [29], which is involved in reperfusion damage, arrhythmias after natural and therapeutic thrombovascular lysis, etc. [30, 31].

Results were as follows:

1) Platelet count (1053 individuals) increased from an average of 177,000 ± 90,000/mm³ during Io–IIo days to 191,000 ± 82,000/mm³ on IIIo–IVo days ($p < 0.025$) and to 213,000 ± 85,000/mm³ on the two days after the active days ($p < 0.001$); levels measured 205,064 ± 101,448/mm³ on IVo days and 195,025 ± 69,040/mm³ on the days before and after the active days ($p < 0.02$ compared to Io days).

2) Plasma prothrombin time (INR) (1331 individuals) on Io days averaged 75.7 ± 7.1 % compared to 79.8 ± 8.1 % on IIIo ($p < 0.01$) and 80.0 ± 11.9 % on IVo days ($p < 0.025$ compared to Io).

3) ADP platelet aggregation (1 min. values) (162 individuals) averaged 33.8 ± 15.5 % on Io–IIo days, compared to 44.0 ± 17.0 % on days, just before and after the active days ($p < 0.005$).

4) Plasma fibrinogen 441.56 ± 160.0 mg/dl in Io (n = 100) and 500.445 ± 182.88 mg/dl in IVo GMA, (n = 100), ($p = 0.002$).

5) Mean capillary clotting time was 296 ± 51 sec. on Io days (163 individuals) compared with 320 ± 72 sec. on IIIo days and 314 ± 71 sec. on summarized IIIo and IVo days (123 individuals) ($p < 0.01$ compared with Io days); however, in 41 observations on IVo days, the results equaled those on Io days (296 ± 60 sec).

6) Bleeding time (activated partial thromboplastin time, APTT) tended to be lower on high level GMA days (511 individuals) ($t = 1.85$), but not to a significant degree.

With regard to the additional parameters,

7) mean peripheral blood basophil levels dropped significantly from average values of 0.51 ± 0.31 % to 0.20 ± 0.26 % (n = 584) on IVo days ($p < 0.0025$). On Io days, the basophil percentage was 0.55 ± 0.27 % (n = 422) of the white cell count. A negative correlation was found between basophil values (4359 evaluations) and the integrated GMA daily A index ($r = -0.538$, $p < 0.01$). Leukergy, examined in 233 persons over 2169 days, decreased on IVo days (3.9 %) compared with Io–IIIo days (5.36–6.8 %, $p < 0.001$).

Plasma viscosity, studied in 945 persons, was higher on IIo and IIIo days compared with Io days. On IVo days, viscosity decreased to a level equal to that shown on Io days. Values recorded were: 1.43 ± 0.01 (n = 489) for Io and IVo days (n = 25); 1.44 ± 0.01 for IIo days (n = 274); and 1.48 ± 0.01 for IIIo days (n = 157). On days just before or after active or stormy GMA days, a strong tendency to higher plasma viscosity was observed ($t = 1.909$, $p = 0.07$) [32]. To these changes, the cellular component of blood viscosity (blood cell count, aggregability, mentioned above) must be added in order to obtain the complete picture.

Haemoglobin, haematocrit and euglobulin time comparisons did not show significant changes with changes in GMA.

The two parallel trends of increased coagulation and heightened bleeding may explain the high incidence of bleeding in atheromatous plaques during platelet aggregation [33].

This was stressed by Falk [34] and other investigators as one of the important mechanisms in the pathogenesis of AMI and sudden cardiac death, in which the critical coronary vessel obstruction (more than 90 % of the lumen) is largely a consequence of platelet aggregation and intraplaque bleeding. In obstructions that occur gradually, the platelet aggregation around the atheromatous plaques or at the rupture (erosion) site of the unstable plaque is predominant [35–37].

Cerebrovascular Syndromes

This section includes studies of cerebral vascular accidents (CVA) – stroke, cerebrovascular insufficiency with dizziness, and mostly, vertebrobasilar insufficiency that required admission to hospital, and migraine attacks, as a syndrome closely related to cerebrovascular disturbances.

Stroke was analyzed over two periods, 1974–1977 and 1974–1988 in four separate studies. In the first study (1974–1977), the daily number of in-hospital deaths from cerebrovascular syndrome was compared in accordance with different GMA level [13, 25].

Of a total of 269 deaths over 1339 consecutive days, 0.160 occurred on Io–IIo days and 0.234 on IIIo–IVo days and on days just before and after IIIo and IVo days ($p < 0.005$). In the second, comparative, study conducted over 180 months (1974–1988), the monthly number of in-hospital deaths from CVA (n = 910) was compared according to ten cosmophysical activity parameters, including the monthly K index [8]. A negative correlation was shown between the monthly number of deaths and the K index. The third study covered only the most severe patients (n = 27) (1974–1977) who died on the way to the hospital or in the admissions room [13]. Cause of death was confirmed by postmortem examination. Results showed 0.120 deaths daily on Io–IIo days and 0.273 deaths daily on IIIo–IVo days ($p < 0.01$). It is noteworthy that in this group, modern therapeutic techniques, especially artificial respiration, were not applied. In most CVA patients, ie, those who reach the hospital and are admitted, the fatal outcome is delayed by such procedures, and often death occurs at the point at which many critical parts of the CNS are no longer functioning. Finally, in a large study including the whole population of Lithuania [38], a significant negative correlation (r = -0.297, p = 0.04) was seen between monthly stroke deaths number (n = 19,399) and GMA, but only at age below 74. For the age > 74 and the whole stroke victims this relationship was not significant.

Migraine

Migraine is associated with dilatation of certain cranial arteries, plasma extravasation, severe headache and other neurovascular disorders; it often serves as a model for other kinds of vascular pathology. For the cardiologist, migraine is a prototype of vascular spasm-related angina pectoris, so called Prinzmetal or variant angina. The interest in migraine is rising together with the recent interest in the rate of serotonin (5-hydroxytryptamine) metabolism in physiological and pathological migraine, cluster headache, coronary spasm, peripheral vascular insufficiency, arterial hypertension, depression, food intake, circadian rhythms, etc. [39, 40].

In a study with a group of neurologists [41], we rated the intensity of 486 migraine headaches from 1 (mild) to 3 (severe) in 30 patients (23 females and 7 males; migraine occurs more often in women) over 15 months. Scores were recorded in general, and in accordance with GMA levels. Although we were unable to demonstrate changes in the frequency of migraine attacks with GMA level, a clear and strong correlation between the severity of the attack and GMA level was shown. Of all the migraine episodes recorded, 30.2 % were severe. Their distribution was as follows: 25.9 %, Io; 28.3 %, IIo; 34.3 %, IIIo; and 43.75 %, IVo. The correlation coefficient between severe pain and GMA level was 0.96 (p < 0.002).

Serotonin metabolism and cardiovascular parameters

Experience with new, active anti-serotonin drugs (such as Sumatripan) in aborting migraine and cluster headache [42, 43] confirmed the close relationship between humoral vascular regulation and the pathogenesis of migraine attack. Previously, Sulman [44] had demonstrated a close relationship between the level of serotonin and climatic changes (hot dry winds) and air ionization.

At the end of 1991, a multicenter study was published showing the important prognostic value of depression following AMI for cardiovascular death and reinfarction, surpassing even many "proper" cardiological signs, such as extrasystoles and late potentials [45].

Depression and suicide attempts have been associated with a decrease in the level of serotonin and prolactin [39, 46, 47]. A recent study confirmed that the concentration of serotonin and its metabolites in the central nervous system were much lower in suicide victims than in victims of road accidents and other control groups [48].

We examined the number and types of activities conducted by the National First Aid Service of Israel and of one of the central mental health centers during one week in March 1989 that included a very severe magnetic storm. For the first aid service, data from the storm week were compared with those from the week before the storm; for the mental health center, storm week data were compared with data from the same week in the years 1987 and 1988. We found an increase in almost all activities in the week of the geomagnetic event. The only type of pathology that decreased were suicide attempts [49]. The monthly number of deaths from myocardial infarction and ischaemic heart disease were negative correlated with the number of fatal suicides [38, 50, 51].

In our study with Raps et al. [52, 53] an adverse correlation was noted between the number of primary admissions of psychiatric patients in an 11-year period (monthly) and the monthly GMA index.

Peripheral blood basophils [13, 24, 26] beside their role in heparin production as noted earlier are also involved in serotonin, histamine and other neurotransmitter metabolism [27]. It is not clear if the observed disappearance of basophils from the peripheral circulation on stormy GMA days was the result of cell destruction (accompanied by the release of some vasoactive factors) or the transfer of these cells to mast cells [27, 28]. The drastic drop of the basophile count is more likely linked with sequestration rather than destruction but this point should be tested.

Gender differences

Gender differences in physiology and pathology have recently gained renewed interest. This phenomenon was investigated in many areas of cardiovascular medicine in relation to GMA. A number of examples are described.

Site of myocardial infarction

As noted above, in a study of 1700 cases of AMI, isolated lateral wall myocardial infarction was found to occur significantly less frequently in women [7, 8]. The male to female ratio for lateral wall AMI was 6.1, for anterior wall AMI 2.6 and for inferior/posterior wall AMI 2.8. There was a trend in men for a higher number of AMIs on IIIo–IVo days (0.85) compared with Io-IIo days (0.64). In women, the picture was reversed: 0.37 on Io–IIo days and 0.21 on IIIo–IVo days.

In the same study, 100 men and 100 women were chosen at random from all patients who underwent coronary angiography at Beilinson Medical Center for chest pain or ischaemia possibly indicative of severe coronary artery disease. Results showed that such critical (99–100 %) occlusions occurred more frequently in men. The ratio for occlusion of the left anterior descending artery (LAD) was 1.36; for the right coronary artery (RCA), 1.04. For the left circumflex coronary artery (CRX), the ratio was 2.3, higher than for the LAD or RCA (for CXR chi square M/F = 4.554; p = 0.03). It was concluded that some gender differences in the regulation of the three major coronary arteries probably exist [7].

Heart rhythm disturbances

Two types of heart rhythm disturbances were studied with regard to gender differences at different levels of GMA.

a) *Ventricular tachycardia (VT):* VT measured by 24-hour Holter monitoring increased in male patients (n = 157) on days of highest (IVo) GMA (0.22 daily) and decreased on days of lowest Io GMA (0.14). In females, a trend toward higher VT on Io–IIo GMA days was noted (n = 76) [14].

b) *Paroxysmal atrial fibrillation (PAF):* On days of Io–IIo GMA (total, 768 days) the male/female ratio was significantly higher (94/54) than on IIIo–IVo days (total 393) (43/44; p = 0.024) [15].

As a possible partial explanation for these differences, we suggest that the influence of the sympathetic nervous system is predominant in women [53].

Neuroendocrine markers

The concomitant increase in prolactin level with an increase in GMA levels was more prominent in females throughout (p < 0.0025–0.01). For males, the increase in prolactin was significant when results of Io and IVo days were compared (p < 0.02) [19].

Cerebrovascular syndromes

A three-year study (1990–1993) of 977 cases of CVA showed a significant and strong negative correlation of male stroke admissions with daily GMA level, but only for 65 and less age group (n = 137; r = -0.9720, p = 0.027). The male/female ratio for all stroke patients also was negatively correlated to the level of daily GMA (r = -0.99, p = 0.0008). The male/female ratio on Io GMA days at age 65 (42/18) was higher than for the older stroke patients (106/96; p = 0.016). On higher GMA days these differences were not significant [15].

For cerebrovascular insufficiency with predominant dizziness, the number of males admitted was higher on IIIo–IVo days (0.23–0.22 daily) than on Io-IIo days 0.18–0.19 (n = 429). In female patients, this trend was not seen, but again, like in CVA, the lowest number of daily admissions (0.14) was noted on IVo days. For lower level days, there were 0.16–0.19 admissions daily (n = 373) [55].

Blood coagulation factors and serotonin

Changes in platelet count and serotonin level were manifested more often in men older than 50 years [39].

These data are only a small part of the continuing research on gender differences in studies of the natural history of diseases and human reactions to environmental influences.

Discussion

Changes in the GMA level are related to fluctuations in solar activity and are involved in climate regulation and various animal and human behaviors. The biological effects of geomagnetic fields have emerged in recent years as an important factor in, for example, sea mammal (cetaceans) and turtle (reptile) navigation [56, 57]. What becomes clear in all these studies is that the living species examined, including man, have adapted to normal variation in GMA.

However, when the GMA provokes biological changes that exceed the threshold of human reserves or adaptation ability, our regulatory (homeostatic) activities are upset at different levels: central nervous system, hormonal-humoral, neurotransmitter, cellular, electrophysiological, membrane-related and others. This may result in critical conditions, such as heart rhythm disturbances and related sudden death, cerebrovascular accidents, cerebrovascular insufficiency and vascular thrombosis, including myocardial infarction. Some differences in the development of these conditions are the result of differences in neural control of the major cardiac arteries (right versus left coronary artery) or in gender difference in reactions to environmental activity.

As noted in the introduction, GMA is not an isolated factor. Other studies have shown strong effects of solar and other cosmic influences (radiation, corpuscular), which may also play a role in the natural history of cardiovascular diseases [8, 58, 59]

It remains unclear whether the key factor is GMA or whether GMA is itself affected by other physical forces that may or may not act concomitantly with it. Our studies considering solar activity, space proton flux, radiowave propagation support such an approach. Clearly, there is much room for further, more intensive study.

We suggest that the observed GMA-related changes in the levels of some neurohormones and neurotransmitters, such as serotonin or endothelin, may be part of the bridge between morphological cardiovascular changes and such secondary local and general complications as thrombosis and plaque instability, vasospasm, shock, cardiac arrhythmia (including cardiac arrest); different "behavior" or parts of the vascular bed, the receptor network and neurohormonal regulation under varying environmental conditions. Findings in these areas have given a new face to the old concepts of psychosomatic links, the brain-heart relationship, the body and the soul.

In conclusion

1) The level of GMA is connected with changes in many pathogenetic mechanisms and risk factors in cardiovascular pathology and their time distribution.

2) The multidirectional changes of the studied parameters are of interest in the overall study of the interaction between people and their environment.

3) It is premature to extend specific recommendations to patients, excluding some more careful preventive measures in the field of antithrombothic and antihypertensive therapy at days of predicted high GMA.

The motto of this review, "Everything in nature is a cause from which there flow some effects" (B. Spinoza), was and remains a basis for the deterministic attitude to each active force in the surrounding world. "The human will is free only within the bounds of a determined cosmic system" [60].

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