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Effect of geomagnetic storms upon blood sedimentation dynamics in ischemic heart disease patients

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ABSTRACT

The sedimentation properties of blood of 13 ischemic heart disease patients and 2 healthy volunteers have been analyzed using a special computerized optical device for high temporal resolution tracing of red blood/plasma boundary movement rate (ESR-graphy). The kinetic curves of red blood sedimentation are substantially nonmonotonic and exhibit multiple accelerations, decelerations and even backwards movement of the red blood/plasma boundary. The intensity of blood sedimentation rate oscillations is significantly higher in the blood of patients and voluteers on days of enhanced geomagnetic activity than on quiet days. In healthy donors, blood oscillations were also observed on active geomagnetic days, however, their intensity was lower, the sedimentation rate started to oscillate after a longer time upon pipette installation, and the oscillation frequency was lower than in the patients' blood. Thus, blood is highly responsive to changes in geomagnetic field activity. Possible oscillatory behavior mechanism of blood sedimentation rate and the diagnostic and prognostic merits of the ESR graphs are discussed.

INTRODUCTION

One to four days after a solar flare or eruptive prominence occurs, a slower cloud of solar material and magnetic fields reaches Earth, buffeting the magnetosphere and resulting in a geomagnetic storm. These storms are extraordinary variations in Earth's surface magnetic field. During a geomagnetic storm, portions of the solar wind's energy is transferred to the magnetosphere, causing Earth's magnetic field to change rapidly in direction and intensity [33].

There are indications [1,2,3,29-32] that patients with pathologies of the cardiovascular system often suffer from hypertensive crises, insults, angina attacks, and myocardial infarction complications during geomagnetic disturbances and storms.

Although the primary acceptors of this weak physical field variations are still unknown, there must be physiological mechanisms responsible for the enormous amplification of initial reactions that result in a sharp aggravation of the health of sick people. Blood can well be such an amplifier, because of its important vital functions. Critical changes in blood properties may play a significant role in many complications of cardiovascular and other chronic diseases.

It has been observed that the rate of capillary blood flow decreases during geomagnetic disturbances and storms [4], and numerous large erythrocyte aggregates and sludges appear in the capillaries of cardiovascular disorder patients [5]. The correlation between solar-geomagnetic activity and changes in blood clotting properties [6] and blood formula [7] has been reported. Analysis of 730 000 hematological data items collected over 25 years worldwide has shown that predominantly ESR shows significant fluctuations on different time scales, and some parallelism between ESR fluctuations and the number of sun spots has been noted [8]. Thus, environmental changes seem to affect the general physiological and physical-chemical properties of blood. In particular, ESR data demonstrate that some environmentally induced changes persist in anticoagulant treated blood once it has been taken away from the body.

Although it is considered that the complex nature of the factors that affect the test results precludes the adequate treatise of ESR data [9], ESR, unlike most other hematological methods, is still the only one test that reflects the integral, tissue-related properties of blood. According to the founder of heliobiology A. Chizhevsky, "...there are serious reasons to believe that ESR is potentially very informative, but our ability to decode this information depends upon the profundity of the theoretical and experimental analysis of this phenomenon" [10].

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Recently we developed a variant of the ESR test, designated "ESR-graphy", in which the position of the descending red blood/plasma boundary is recorded at a high temporal resolution (for example, every 30 sec). The process of red blood sedimentation turned out to be essentially nonmonotonic: the red cells/plasma interface movement exhibits numerous accelerations and decelerations. The plots of fractional sedimentation rate vs. time since blood placement into the pipette (ESR graphs) reflect the individual features of blood for each particular donor and their changes due to disease [11, 12, 13]. Using an automatic device allowing one to record ESR graphs at a high accuracy, we compared the ESR graphs for blood of ischemic heart disease patients on days of different geomagnetic activity. The results show a strong correlation between the geomagnetic activity and the behavior of blood.

EXPERIMENTAL

The ESR-graphy of blood of 13 patients with ischemic heart disease (9 women, 48-83 years old, and 4 men, 63-83 years old) and two healthy volunteers (54 and 55 years old) was performed on at least 2 different days with different geomagnetic activity for each case. Ischemic heart disease was often complicated by cardiac insufficiency, diabetes, and/or arterial hypertension. All the patients were examined within 10 days after a heart attack. Myocardial infarction was confirmed in 11 patients.

The blood was obtained by means of venous or finger puncture and stabilized with 3,2% sodium citrate (9:1). In parallel experiments with venous or finger blood of the same donor no significant differences in blood behavior was noted. The stabilized blood was used within 2 hours after the extraction. The blood was placed into glass pipettes with an internal diameter of $1 \pm 0{,}1$ mm to make a 100 mm high blood column. The pipettes were fixed in special holders in which the bottom opening of the capillary was tightly closed. The holders were placed into the device for multi-channel high temporal resolution of blood sedimentation rate, the "ESR scan" [14]. Schematic of the ESR scan is presented in Fig. 1. A pipette filled with blood is illuminated with a luminescent microtube. The light passes through the transparent plasma layer and is absorbed by the red blood. The optical system focuses it onto a 100-mm ruler with 4050 CCDs. An image of a capillary recorded by the ruler is sent to a PC. Every 30 seconds a new image is recorded and, as the red blood/plasma boundary moves, the software compares the successive images. The course of blood sedimentation can be observed in real time mode as a plot and as a table on the computer monitor. The data are stored in a database and can be obtained as digital files for further statistical analysis. The data are presented as two curves: one, the ESR-graph, is the time series of fractional blood sedimentation rates (within 30 sec or 1 min intervals) recalculated as mm/hr vs. time after pipette installation; the other curve shows the movement of the red blood/plasma interface.

The data presented as ESR-graphs were analyzed statistically using the STATISTICA for Windows commercial software. In the analysis of the oscillation intensity of fractional sedimentation rates, the general trend was subtracted after the curve approximation to a 3rd (4th, 5th) degree polynom ($y = C_0 + C_1*x + C_2*x^2 + C_3*x^3$). The oscillation intensity was evaluated as a standard deviation from the mean.

The local K- and A-indices were obtained from the Institute of Terrestrial Magnetism, Ionosphere and Wave Propagation, Troitsk, Moscow Region.

RESULTS

The ESR graph patterns of all the blood samples are strongly geomagnetic activity dependent. A typical set of the ESR graphs for blood of myocardial infarction patient D-a obtained on days of different geomagnetic activity is presented in Fig. 2 (information on the diagnosis of this and other patients and numerical data on the oscillation intensity and ESR values are presented in the Table 1). It can be seen from Fig. 2 that the intensity of blood sedimentation rate oscillations is strikingly higher on 30.01.1998, a day of the geomagnetic activity (A-index = 22), than on any other day. This ESR graph exhibits a lot of "negative sedimentation rate" events. Thus, besides the abrupt descending of the red blood/plasma boundary (positive sedimentation rate peaks), upward movements of the red cells/plasma boundary against the gravity force are observed. The latter phenomenon is a new, formerly unknown property of blood.

Data on the sedimentation behavior of blood of this and other patients in relation to geomagnetic activity also are presented in the Table 1. For all the patients, the highest oscillation intensity coincides with the high and the highest A-indices, though there is no direct correlation between oscillation intensity and the intensity of a geomagnetic storm. For example, on the day of the most intense geomagnetic storm (case $n = 11$, A-index = 79, 25.09.1999) the oscillation intensity was lower than on 18.09.1999, when a weaker geomagnetic storm occurred (A-index = 35). On the other hand, the rate oscillations for the blood of two different patients (cases $n = 3$ and $n = 4$) on the same "stormy" day were about 7 times those for the quiet day before, when the geomagnetic activity was less perturbed. In two cases ($n = 3$ and $n = 5$), the oscillation intensities and the ESR values decreased sharply immediately after streptase (a fibrinolytic enzyme) infusion. One can see that, with the

exception of these two cases, changes in the oscillation intensity did not correlate with the ESR values. The oscillation intensity increased on almost every geomagnetically active day, whereas the ESR values for the blood of different patients did not change from day to day in a consistent manner.

The ESR-graphy revealed also an increase in the intensity of sedimentation rate oscillations in the blood of 2 healthy volunteers. Fig. 3 illustrates the typical differences in the patterns of blood sedimentation of one of them on a quiet day (04.05.1999, A-index = 6) and on more active day (06.05.1999, A-index = 14). It can also be seen that oscillations emerge in the blood of a healthy donor much later (more than 1 hour after blood placement into the pipette) and that their frequency and amplitude are lower than those in the patients' blood on active geomagnetic days.

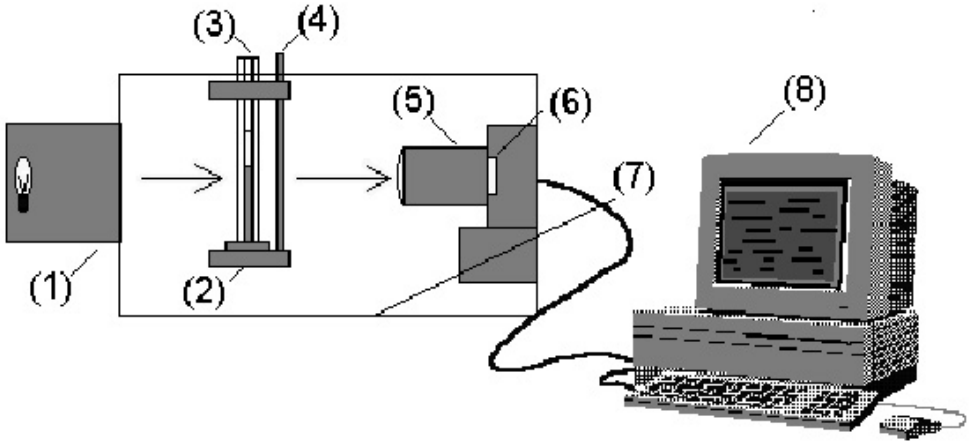

FIGURE 1. Schematic of the ESR scan, the device for high temporal resolution of red blood sedimentation dynamics. (1) light source, (2) the stand at which pipettes filled with blood (3) are fixed, (4) the lens, (5), (6) elements of light detecting and scanning system, (7) ambient light protecting case, (8) PC.

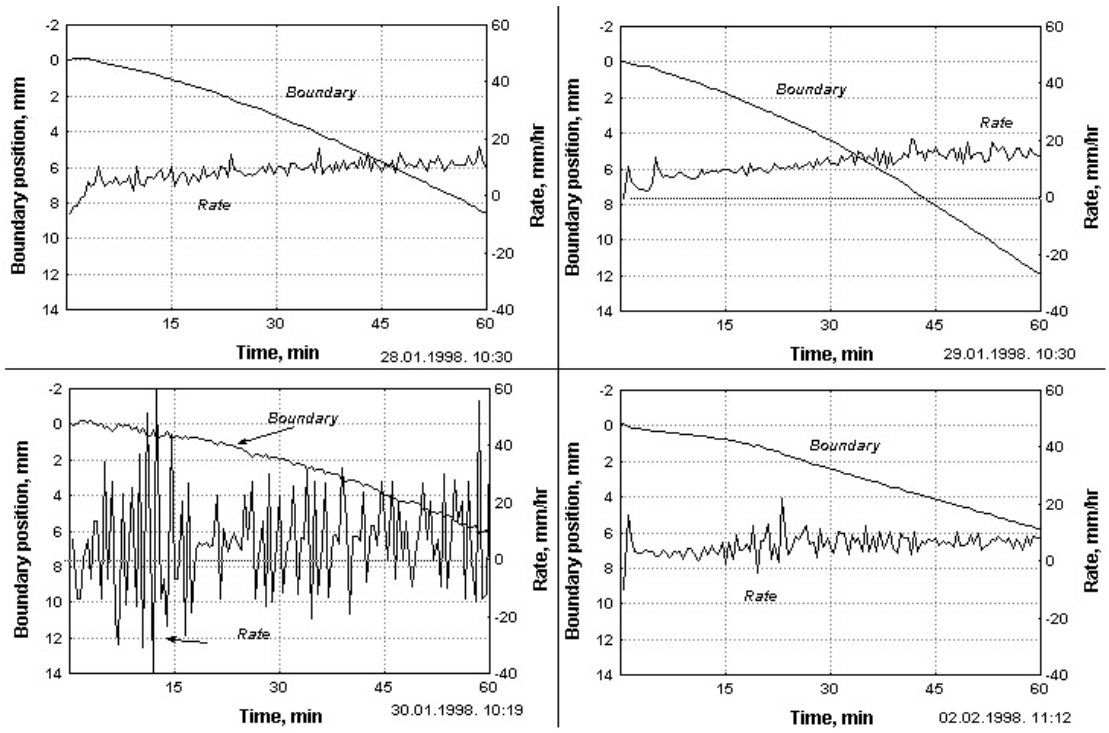

FIGURE 2. ESR graphs (rate) and plots showing the change in the position of the boundary between the red blood and the plasma (boundary) on 4 different days for patient D-a (case #1 in the Table). Note the change in the pattern of the ESR graph on 30.01.1998, a day of a geomagnetic storm.

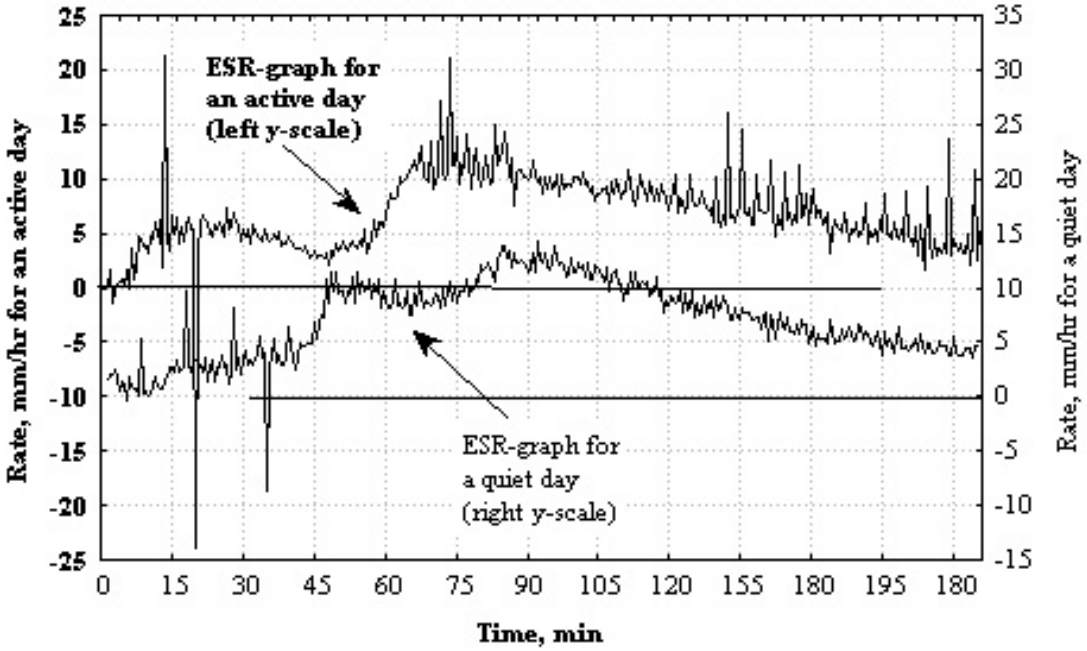

FIGURE 3. ESR graphs on a quiet day (A-index=6) and on day with A-index=14.

Table 2. Correlation between patients blood sedimentation behavior and geomagnetic activity

Patient, sex age	Diagnosis	Date	A-index	Pulsation intensity*	ESR, mm/hr
1. D-a, f	M.I. on	28.01	4	2.0	8,6
61	28.01.1998	29.01.	12	1.9	12,0
	A.H.	30.01	**22**$^{+}$	**18.7**$^{+}$	6,3
		02.02	5	3.2	5,8
2.V-v, m	M.I. on	13.02	9	0.2	12.2
83	13.02.1998	16.02	3	0.9	23.2
		17.02	**18**	**1.3**	23.4
3. S-a, f	M.I. on	11.03	24		
48	21.03.1998	12.03a	**17**	**10.9**	9.8
		12.03b**		1.3	4.5
		20.03	13	3.7	12.0
		21.03	**40**	**27.2**	23.2
4. Z-a, f	M.I. on	20.03	13	3.0	8.1
68	11.03.1998	21.03	**40**	**21.3**	9.3
5. A-a, f	T/m M.I. on	08.04a.	8-7	30.6	10.2
61	08.04.1998	08.04b**		1.4	2.7
	rel. 22.04	09.04	12	1.6	5.6
	A.H.	10.04	**31**		
	Diab.	11.04	**18**	**32.4**	23.9
	Ins(-)	14.04	13		
		15.04	***10***	***34.5***	56.8

Patient, sex age	Diagnosis	Date	A-index	Pulsation intensity*	ESR, mm/hr
		17.04	17	18.4	55.4
		18.04	9	19.4	61.6
		19.04	9	15.2	54.8
		20.04	11	13.3	50.5
		22.04	6	19.6	49.9
		27.04	14	16.9	53.4
6. S-v, m 63	M.I. on 21.03.98	07.05	12	7.1	15.8
		08.05	**27**	**16.7**	10.9
		12.05	**16**	**17.5**	29.7
7. G-o, f 61	T/m M.I. on 23.05.98 A.H., Diab. 2, Ins(-)	26.05	**15**	**30.6**	31.5
		27.05	14	7.5	33.8
		29.05	20		
		30.05	**17**	**29.6**	13.9
		31.05	7	9.1	42.4
8. G-b, f. 53	U.A., f.c. 3 A.H.	31.07.98	**32**	**2.7**	2.6
		03.08	9	1.0	2.1
		13.08	11	1.0	2.5
9. B-i, m, 62	M.I. on 31.07.1998 rel. 01.08	10.08	**25**	**2.1**	**3.7**
		11.08	12	0.9	3.7
		13.08	***11***$^{++}$	***2.6***	4.2
10. P-a, f. 83	M.I. on 21.08.98 U.A. f.c.-2, A.H. Diab., Ins.(+)	21.08	12	1.0	3.4
		22.08	**27**	**9.40**	3.1
		24.08	14	1.94	5.4
		26.08	***45***$^{++}$*****	***1.6***	6.0
11. I-a, f. 68	U.A., f.c. 2 A.H. Diab. 2, Ins(-)	14.09.98	14	1.6	3.3
		15.09	13	1.5	2.5
		18.09	**35**	**8.8**	3.5
		25.09	***79***	***2.8***	4.6
		26.09	22	1.7	3.7
12. K-a, f 73	M.I. on 17.12.1998	23.12	10		23.6
		26.12	15	6.5	32.8
		29.12	**30**	**15.5**	39.4
13.L-m, m 68	M.I. on 31.03.99 A.H.	08.04	15	0.8	11.8
		09.04	17	1.2	4.2
		10.04	19	0.3	6.2
		13.04	9	0.8	6.5
		14.04	10	1.6	7.6
		15.04	7	0.5	9.3
		17.04	**29**	**3.9**	6.1
		19.04	20	0.7	9.5

Abbreviations: m – male, f – female, M.I. – myocardial infarction, T/m – transmural, A.H.- artherial hypertension, U.A. – unstable angina, f.c. – functional class, Diab. – diabetes, ins.(+) or (-) – insulin dependent or independent, rel. – relapse.
Notes: *ESR pulsation intensity was calculated as S.D. of fractional ESR values subtracted from the ESR graph trend. $^{+}$ Bold typeface marks notable elevations of the pulsation intensity on geomagnetic storm. $^{++}$ Bold italic typeface marks lack of correlation between the level of geomagnetic activity and pulsation intensity. **Data are presented before and immediately after i/v streptase infusion to the patient. *$^{++}$ In this case, the high A-index is due to a sudden storm in the evening, while blood test analysis was performed in the morning.

DISCUSSION

Literary data on changes in the general properties of extracted blood in relation to environmental factors are scarce. As has been mentioned in the Introduction, some positive correlation between the ESR values as obtained by conventional methods and the solar activity was revealed from the analysis of a large scope of data (more than 730 000 items) [8]. The correlation of the ESR values with geomagnetic activity was not studied in that work, though it is well-known that solar activity variations are soon followed by geomagnetic activity disturbances. Our study revealed no correlation between conventional ESR values and geomagnetic activity, probably, because a limited number of observations were made. On the other hand, the application of the new method of ESR-graphy, which allows one to study the detailed dynamic picture of red blood sedimentation, showed an evident correlation between geomagnetic activity and blood properties. The general conclusion that can be drawn from our observations is that the oscillation intensity of fractional red blood sedimentation rates increases generally on the days of high geomagnetic activity in comparison to quiet days. A relatively wide range of changes in the oscillation intensity of blood may be explained by the individual sensitivity of different patients to the geomagnetic perturbations, as well as by specific parameters of different geomagnetic storms.

Comparison of blood sedimentation dynamics for healthy and sick persons regardless of geomagnetic situation show that the oscillation intensity of blood sedimentation rate correlates with the general state of health of a person [11-13]. Thus, the appearance of unusually strong oscillations in the blood sedimentation rate is an objective symptom of probable worsening of the patient's health that should attract the attention of a physician.

The non-monotonic character of blood sedimentation has already been noted by those few authors who studied the detailed kinetics of whole blood sedimentation [15, 16]. Our results also show that red blood/plasma boundary movement is characterized by accelerations and decelerations, and that this boundary can even ascend against the gravity force. This behavior of red blood is not explained by the current theories of erythrocyte sedimentation in whole blood based on the Stokes law.

Recently one of us (VLV) suggested the "'phase hypothesis" to explain the dynamic patterns of red blood sedimentation [17]. Within the framework of this hypothesis, blood is considered a colloidal system, and some phenomena specific for aqueous colloids should apply to it. In particular, it is well-known that in colloid solutions of two or more water-soluble polymers, phase separation may occur if the solute concentrations exceed critical values. If such a multiphase system is agitated or stirred so the shear stress in the liquid exceeds a critical value, the phase separation is removed, and the mixture turns into a real solution. As the agitation rate decreases, phase separation occurs again. All these phenomena take place at moderate concentrations of the polymers (a few percents w/v). The larger the molecular weights (molecular dimensions) of the polymers, the lower their concentrations at which phase separation occurs [18, 19].

Blood is an aqueous bio-colloidal system that contains "solutes" of widely different dimensions, from proteins to cells. It is also well-known that, as soon as blood flow is halted, erythrocytes associate to form long "piles of coins", or rouleaux, and the latter unite with one another to build a 3-dimentional network [20, 21]. This network should also form in blood shortly after its placement into a pipette for ESR measurements.

Thus, we suggest that the erythrocyte association that takes place in still blood is a kind of phase separation similar to the one observed in aqueous solutions of water-soluble polymers. In blood, one phase consists of associated cells and the other is the cell-free plasma. Our assumption is alternative to the common treatise of erythrocyte aggregation as binding with one another by plasma proteins. In fact, there are a lot of data contradictory to this assumption [22, 23]. On the other hand, by a close analogy to the situation observed in two- and multiphase aqueous polymer solutions, relatively low molecular weight proteins and water-soluble polymers prevent erythrocyte association, while high molecular weight substances, irrespective of their chemical nature, net charge, and the degree of hydrophobicity, enhance the rouleau formation [24-27]. In our opinion, the movement of the boundary between the red cells and the plasma reflects a shrinkage of the cellular network rather than simple sedimentation of individual particles. Obviously, each event of network reorganization involves a great number of cells simultaneously, and if blood is held in a narrow capillary, this event should show itself as an abrupt change in the red blood/plasma boundary position. An example of series of regular oscillations in the boundary movement can be seen from the ESR graph for blood of a healthy donor on a geomagnetically active day (Fig. 3).

What are the immediate reasons for network reorganization? To answer this question, one should consider that extracted blood is still a living biological tissue in which active metabolic processes occur. In particular, it was demonstrated by a chemiluminescent study of whole non-diluted blood that its leukocytes actively consume oxygen to produce reactive oxygen species [28]. Under the anoxic conditions of an ESR measurement, oxygen is only available from erythrocytes. It is plausible that the state of the erythrocyte network depends strongly upon the level of oxygen saturation of erythrocytes and that its consumption is followed by network shrinkage. As the movement of the red cells/plasma boundary is often macroscopically non-monotonic, cooperative processes in blood may account for the sharp downward movement of this boundary. From this viewpoint, the upward boundary movement can be caused either by transient "swelling" of the

network, or by an active upward movement of the leukocytes. Anyway, the upward movement of the boundary is impossible without an active work performed by the blood against the gravity force at the expense of its own energy resource.

In conclusion, the patterns of blood sedimentation on geomagnetically active days are characterized by intense oscillations of red blood/plasma boundary which presumably reflect the stressful response of the body and blood to the transient variations of the geomagnetic field. Detailed molecular and cellular mechanisms of the oscillations that occur during blood sedimentation are still to be determined.

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