EXPERIMENTAL STUDY

Changes of decartograms under gravitational acceleration and microgravity

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Abstract

The Decarto technique was used to study the orthogonal ECGs recorded in 23 subjects during parabolic flights (44 records). A parameter of the instantaneous decartograms, namely the activation area (AA), which is the total area of the depolarization front projection on the image sphere, was analyzed. We compared the values of AA during the periods of horizontal flight, upward parts of all parabolas, and the initial 10 s of microgravity of all parabolas.
According to the characteristics of the vectorcardiograms and AA, all subjects were subdivided into 3 groups: with increased electric activity of the right ventricle (I), the left ventricle (II) and both ventricles (III). Changes of AA with change of gravitational levels in these groups showed some differences.
In groups I and II, the AA of the initial part of the QRS complex increased during microgravity and decreased during hypergravity. In group III it decreased during microgravity and changed variously during hypergravity. The AA of the middle part of the QRS complex decreased during microgravity and increased during hypergravity, and these changes were more pronounced in group III. The changes of AA in groups I and II may be explained by the Brody effect. In group III, AA seems to be influenced by some additional factors, possibly by changes in the intramyocardial or intraventricular blood volume.
The AA of the last part of the QRS complex increased during microgravity and decreased during hypergravity in all groups. This may be explained by an effect of mutual neutralization of depolarization fronts related to the changes of the QRS duration. ***(Fig. 3, Ref. 4.)***
Key words: weightlessness-simulation, orthogonal electrocardiography, electrocardiographic mapping.

Electrocardiography is a simple technique often used for assessment of cardiac physiology in subjects working under the special conditions. The redistribution of blood, changes of arterial pressure and other parameters under gravitational acceleration and microgravity lead to changes of the electric activity of the heart. These changes can be estimated by measuring the electric potentials on the body surface (1, 2, 5).

The use of corrected orthogonal leads seems to be especially promising. These lead systems are highly informative, biophysically substantiated, simple and convenient to use. However, at the present time these features of orthogonal leads are not used in full measure. The choice of parameters being analysed is often motivated only by the simplicity of their calculation. Electrophysiological interpretation of such results often involves some difficulties.

Theoretical and experimental studies show that the accuracy of assessment of the heart state with the use of orthogonal leads may be improved by new approaches to signal parameterization based on mathematical models of cardioelectric generator for an orthogonal electrocardiogram (ECG) (3).

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Dipole electrocardiotopography (abbreviated as DECARTO, or decartography) allows us to represent the bioelectric process in the heart in a map-like form. The so-called decartograms represent in a descriptive form the main electrophysiological states of the ventricular wall projected onto a sphere enclosing the heart along with the anatomical landmarks.

The aim of this work is to reveal the regularities of decartogram changes under gravitational accelerations and microgravity during parabolic flights.

Methods

The Decarto technique was used to study the orthogonal ECG recorded in 23 subjects during parabolic flights (44 records). Each ECG represented a PQRST complex derived as a mean value of 8 to 15 consecutive beats during the following periods of all parabolas: horizontal flight ("1 g period"), the upward part of the parabola with gravitational acceleration 1.8 g ("2 g period") and the initial 10 s of microgravity ("0 g period").

The Decarto technique allows a representation of the signals of orthogonal leads in a map-like form. Decartograms represent the projection of the main electrophysiological states of the heart onto the image sphere. The image sphere is a sphere enclosing the heart and having its centre at the midpoint of the heart.

For constructing decartograms we use simplified models of the cardioelectric generator, which are adequate to the restricted data set from three orthogonal leads. For example, during the ventricular depolarization phase it is a uniform double layer with a circular edge which changes its size and orientation over time.

The distribution of electrophysiological states on the image sphere at a given time instant is referred to as the instantaneous map of cardiac excitation, or instantaneous decartogram. For the depolarization period, these main electrophysiological states are 1) resting state, 2) activation state (presence of the depolarization front), and 3) completely depolarized state.

The depolarization front is projected onto the image sphere in the form of a spherical segment. The direction and magnitude of the heart vector define, respectively, the position of the centre and the size (radius) of the depolarization front projection. Here, the heart vector D is a vector with components proportional to the corresponding signals X, Y, Z of the orthogonal leads.

For quantitative analysis of the instantaneous decartograms, a set of parameters is calculated. One of these parameters is the activation area (AA) presenting the total area of the depolarisation front projection. The absolute or relative (percent) number of the image sphere points in the corresponding state may represent AA. The total number of such points on the sphere, or the number of equal-area elements of the map is 3660.

The image sphere radius is taken to be equal to the maximum radius of the depolarisation front projection, which is defined by the maximum magnitude of the heart vector over the QRS period. The use of the maximal QRS vector as a scale helps us to understand more clearly the internal interrelationships between different parts of the QRS complex.

We studied the AA characteristics of different subjects at the initial period of horizontal flight and the changes of AA with variations of the gravitational level. AA values were calculated for each 5 ms of the QRS period.

In order to reveal the changes of AA with the variation level of gravitation we compared the values of AA of every subject during the following periods of all parabolas: horizontal flight, the upward part of the parabola, and the initial 10 s of microgravity.

For comparing the groups, the Mann-Whitney U test was used. The results obtained were thought to be statistically significant if $p<0.05$.

Results

The characteristics of AA at the initial period of the horizontal flight allowed us to divide the subjects into three groups.

In the 1st group, AA had two maxima during the QRS period: one at 30 or 35 ms from the QRS onset and the other at 50 or 60 ms from the QRS onset, and one minimum at 40 or 45 ms from the QRS onset.

In the 2nd group, AA had one maximum at 40—60 ms from the QRS onset, and then its value rapidly decreased.

In the 3rd group, AA had one maximum at 35—50 ms from the QRS onset and then in the period 45 to 75 ms from the QRS onset there was a slowing or a decrease of its value.

One subject could not be assigned to any group. In this subject AA had three maximums at 20, 45 and 70 ms and two minimums at 30 and 60 ms from the QRS onset.

The 1st group included 3 subjects (8 flights), the 2nd group — 7 subjects (13 flights), and the 3rd group — 12 subjects (22 flights).

After a comparison of these data with common vectorcardiographic signs, it was found that the subjects of the 1st group had increased electrical activity of the right ventricle, the subjects of the 2nd group had increased activity of the left ventricle and subjects of the 3rd group had approximately equal activities of both ventricles.

With the change of the gravitational level during one flight and in different flights the distribution of subjects in the aforementioned groups was the same. But in the subject with three maxima of AA in the last file, the AA curve changed its form and had only one maximum.

Changes of AA with the variations of the gravitational level in the three groups considered showed some differences.

In 0 gravity period as compared with 1 gravity period:

1. The AA in the initial part of the QRS complex (0—40 ms from the QRS onset) in the 1st and 2nd groups increased and in the 3rd group decreased (Fig. 1).

2. The AA in the middle part of the QRS complex (40—70 ms from the QRS onset) decreased in all groups (Fig. 2). These changes were more pronounced in the 1st and 3rd groups, and in the 2nd group they were present only in one-half of the number of flights (66 % of subjects).

3. The AA in the last part of the QRS complex (70—90 or 100 ms from the QRS onset) increased in all groups.

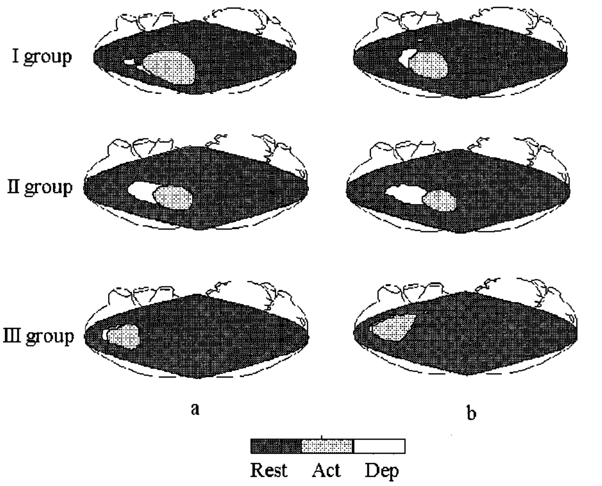

Fig. 1. Instantaneous decartograms from representative cases. Changes of the activation area at 20 ms from the QRS complex onset during a) weightlessness, and b) horizontal flight.

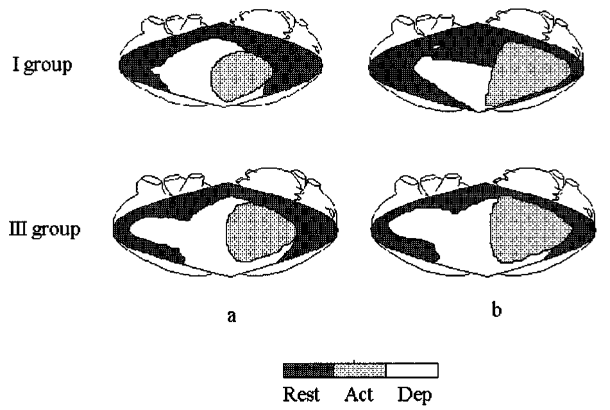

Fig. 2. Instantaneous decartograms from representative cases. Changes of the activation area at 45 ms (group I) and 60 ms (group III) from the QRS complex onset during a) weightlessness, and b) horizontal flight.

In the 2 gravity period as compared with 1 gravity period:

1. The AA in the initial part of the QRS complex (0—40 ms from the QRS onset) in the 1st and 2nd groups decreased and in the 3rd group changed variously in different subjects.

2. The AA in the middle part of the QRS complex (40—70 ms from the QRS onset) increased in all groups. These changes were more pronounced in the 3rd group.

3. The AA in the last part of the QRS complex (70—90 or 100 ms from the QRS onset) decreased or had no changes in all groups.

In the subject with three AA maxima in the 0 gravity period as compared with the 1 gravity period AA decreased at 15 and 60—75 ms from the QRS onset and increased at 25—35 and 90—95 ms from the QRS onset. In the 2 gravity period AA increased at 25 and 55—65 ms from the QRS onset. At the end of the flight this subject displayed an A-V-junctional rhythm with low heart rate, which led to syncope. The changes of AA in this subject just before the syncope are shown in Figure 3.

Discussion

As mentioned above, when constructing instantaneous decartograms, we use the maximum QRS vector as a scale. So, the instantaneous decartograms reflect internal relationships between different parts of the QRS complex. Therefore, when discussing the changes of AA, it is necessary to pay attention to the factors that influence different parts of the QRS complex differently. One of such factors is the so-called Brody effect.

The term "Brody effect" is used for the description of the following phenomenon. The increase of electric conductance of the medium in the heart chambers leads to an increase of radial (with respect to the myocardium surface) components of the heart bioelectric generators and to a decrease of its tangential components (4, 5, 6). It is known that during the initial part of the QRS period the activation fronts in the heart are spreading predominantly in the radial direction, and during the middle part of the QRS period in the tangential direction.

The electric conductivity of the blood may be influenced by various factors (electrolyte balance, hematocrite, etc.). Except for short periods of time the volume of intracavital blood plays the principal role: the greater its volume, the greater the conductance.

So it may be said that an increase of the intracavital blood volume leads to the increase of AA in the initial parts of the QRS complex and to a decrease of AA in the middle part of the QRS complex, insofar as AA is defined by the intensity of the myocardial bioelectric generators. The decrease of the intracavital blood volume has the opposite effects.

Obviously, the changes of AA in the initial and middle parts of the QRS complex in the 1st and 2nd groups may be explained

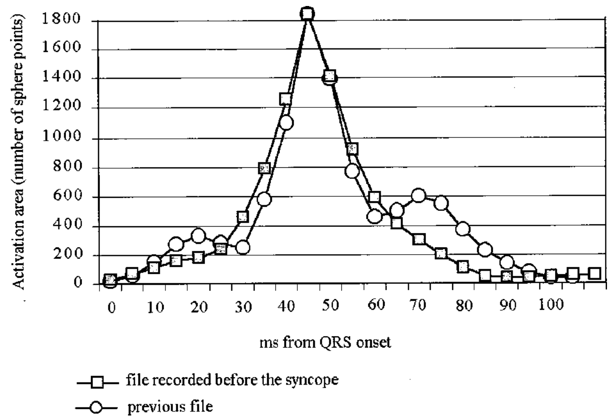

Fig. 3. Changes of the activation area in the subject with syncope during the flight.

by the Brody effect. However, it can not explain differences between these groups and the 3rd group.

During the 0 gravity period in the 3rd group changes of AA of the QRS initial part are opposite to those in the 1st and 2nd groups (an increase in the 1st and 2nd groups and a decrease in the 3rd group). The changes of AA of the QRS middle part are similar in all groups (a decrease as compared with 1 g period), but they are more pronounced in the 3rd group.

One of the factors causing the decrease of the electric potentials on the body surface is the increase of the electric conductance of the body tissues, for example, because of an increase of the blood volume in the vascular bed of the lungs. This factor may influence all parts of the QRS complex, including the maximum QRS vector, in a similar way. Thus, this factor is unlikely to cause the changes of AA. However, its influence should not be completely excluded because of the asymmetric configuration of the lungs.

Another factor causing the decrease of electric potentials on the body surface is the increase of the electric conductivity of the myocardium. It depends on the volume of blood in the myocardial vascular bed. Whether this has different influences on different parts of the QRS complex is unclear. Possibly this factor produces effects which interact with the Brody effect. In this case, the increase of the intramyocardial blood volume would lead to a decrease of the heart bioelectric generators. Consequently, the increase of the intramyocardial blood volume would cause a decrease of the AA of the initial as well as the middle QRS parts. The intramyocardial blood volume, in turn, depends on the intramyocardial pressure. So if we assume this hypothesis, the 3rd group would be characterised by lower intramyocardial pressure during the initial part of QRS (end-diastolic period) and the middle and last parts of the QRS complex (isovolumetric contraction period), as compared to the 1st and 2nd groups.

The changes of AA during the last part of the QRS complex may be the result of mutual neutralization of the depolarization fronts related with the changes of the QRS duration.

References

1. Capderou A, Bailliart O, Vaida P et al. VCG changes under the conditions of changing gravitation. IV international scientific and practical conference "Piloted space flights", 21-22 March, 2000, Star City, Moscow region, Russian Federation, Abstract volume: 295—297 (in Russian).

2. Atkov OYu, Vaida P, Cholley B et al. Noninvasive examination of cardiovascular system during parabolic flights. 13th "Humans in space" symposium, 20-26 May, 2000, Santorini, Greece, Abstract volume: 34.

3. Titomir LI, Ruttkay-Nedecky I, Bacharova L. Comprehensive analysis of the electrocardiogram in orthogonal leads. Electrocardiographic Introscopy of the heart. Moscow: Nauka, 2001 (in Russian).

4. Lepeshkin E. Physiological influences on transfer factors between heart current and body-surface potential. In: C.V.Nelson, D.B.Geselowitz, eds. The Theoretical Basis of Electrocardioligy. Oxford: Clarendon Press, 1976: 135—161.

5. Bernadič, M., Hulín, I.: The effect of body position on the location of the electrical center of ventricular depolarisation in healthy male adolescents. S. 135—137. In: Antalóczy, Z., Préda, I. (Eds.): Electrocardiology 81. Akadémiai Kiadó, Budapest 1982, 675 s.

6. Bernadič, M., Hulín, I.: Vektorkardiografický obraz vývinových zmien u detí pri statickej záťaži. Folia Fac. Med. Univ. Comenianae Bratisl., 21, 1983, č. 2, s. 9—148.

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