Relationship between Plasmatic Concentrations of K, Na and Ca, and ECG from Foals during Postnatal Phase

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ABSTRACT. The correlations between different electrocardiographic variables and plasma concentrations of K, Na and Ca ions were studied in foals of 1 to 14 days of age. The results obtained are only significant in neonate individuals of 1 day of age. Whilst the PQ segment and R wave duration showed a positive linear correlation ($p \leq 0.05$) with plasma concentrations of Na and Ca ions respectively, the amplitude of the T wave showed a negative linear correlation ($p \leq 0.05$) with the K ion. Moreover, the variability in duration of the QT and ST intervals can be explained by both Na ($p \leq 0.01$ and $p \leq 0.05$, respectively) and K ($p \leq 0.05$ and $p \leq 0.01$, respectively) plasma concentrations with which they show a positive linear correlation.—**KEY WORDS:** electrocardiogram, foal, horse, neonate, plasma electrolyte.

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The ECG has been considered as a sensitive indicator of changes in plasma concentrations of calcium and potassium ions and a poor indicator of abnormal concentrations of sodium and hydrogen ions [13]. Clinical studies have shown that decreases in serum potassium are followed by a depression of the ST segment and a flattening of T waves [7]. Paradoxically, the changes which appear in the foetus during hyperkalaemia resemble those previously described for hypokalaemia and are characterized by the lengthening of PR and QT interval, flattened and inverted T waves and depressed ST segments [12]. Likewise, it has been shown that calcium deficiency can lengthen the QT intervals, whilst an increase in levels of calcium ions and a decrease of potassium ions are associated with a flattening and inversion of the T wave [12].

In horses, a correlation has not been established between clinical hyperkalaemia and electrocardiographic changes because the maximum plasma concentration recorded was only 4.3 mmol/L. However, the

infusion of isotonic solutions of KCl causes changes in the ECG, 6.2 mmol/L pointed out as being the lowest level required to cause electrocardiographic changes [4]. On the contrary, in foals, limited data exists about the plasma levels of electrolytes during the neonatal life, or their influence on the ECG tracing.

In a previous study [14], slight variations in the ECG of foals during the neonatal period were detected. For that reason, in an attempt to find out if these variations were due to electrolytic imbalances, the plasma levels of potassium, sodium and calcium and their influence on the ECG during the first two weeks of life were determined, in order to obtain reference data for clinical practice.

MATERIALS AND METHODS

This study was carried out on 12 Spanish-bred foals during the first two weeks of neonatal life. Blood samples and electrocardiographic tracings were taken in the first 24 hours of life and were repeated at 7 days and 14 days.

The ECG's were recorded by a portable SAN-EI monochannel electrocardiograph, with a paper speed of 50 mm/sec and a sensitivity of 10 mm/mV. The unipolar V_{10} lead used was obtained by placing an alligator clip electrode on the dorsal spinal process of the seventh thoracic vertebrae as the exploring electrode. This lead was selected since it provides a more morphologically uniform tracing than that obtained with other leads (I and aVF leads), which permits us to analyze the electrolyte effects with greater confidence.

After obtaining electrocardiograms the following parameters were analysed: heart rate, amplitude of deflections, and the duration of waves and intervals.

The blood samples for the determination of plasma ions were collected by means of disposable sterile syringes, from the jugular vein of the foals, immediately after tracing was obtained so that they would not be affected by handling. The blood was placed in previously heparinized polyethylene tubes,

centrifuged before 2 hours in order to avoid the possible ionic interchange between plasma and erythrocytes, and the plasma decanted was frozen and kept until its analysis.

For determination of K, Na and Ca ions two different methods were used. The plasma concentrations of potassium and sodium were determined by flame photometry using a standard calibration with 140 mEq/L of sodium and 5 mEq/L of potassium. The calcium concentration was determined by spectrophotometry and the absorbance was measured at 580 nm.

The data obtained for electrocardiographic and plasmatic variables were separated into three groups corresponding to individual ages (1, 7 and 14 days). As a previous step in the statistical treatment of data the mean values and standard deviations for each variable were calculated. Next, the linear correlation coefficients between different pairs of variables were found in order to determine their dependence. Lastly, regression equations were

Table 1. Values (Means $\pm$ SD) obtained for different electrocardiographic variables during the first two weeks of postnatal life

	1 day	7 days	14 days
Heart rate (beats/min)	115.3 $\pm$ 8.4	116.8 $\pm$ 12.5	107.4 $\pm$ 13.9
<i>Duration (sec)</i>			
RR interval	0.521 $\pm$ 0.037	0.519 $\pm$ 0.065	0.565 $\pm$ 0.082
P wave	0.066 $\pm$ 0.013	0.064 $\pm$ 0.010	0.067 $\pm$ 0.018
Q wave	0.016 $\pm$ 0.003	0.017 $\pm$ 0.004	0.016 $\pm$ 0.003
R wave	0.051 $\pm$ 0.005	0.051 $\pm$ 0.005	0.051 $\pm$ 0.005
T wave	0.075 $\pm$ 0.011	0.069 $\pm$ 0.012	0.076 $\pm$ 0.016
PQ segment	0.063 $\pm$ 0.011	0.068 $\pm$ 0.012	0.066 $\pm$ 0.018
ST segment	0.124 $\pm$ 0.018	0.125 $\pm$ 0.014	0.133 $\pm$ 0.020
PQ interval	0.129 $\pm$ 0.017	0.132 $\pm$ 0.018	0.133 $\pm$ 0.029
ST interval	0.196 $\pm$ 0.011	0.194 $\pm$ 0.009	0.209 $\pm$ 0.022
QRS interval	0.066 $\pm$ 0.006	0.067 $\pm$ 0.005	0.067 $\pm$ 0.005
QT interval	0.266 $\pm$ 0.014	0.262 $\pm$ 0.011	0.276 $\pm$ 0.021
<i>Amplitude (mV)</i>			
P wave	0.116 $\pm$ 0.039	0.107 $\pm$ 0.032	0.102 $\pm$ 0.038
Q wave	0.104 $\pm$ 0.085	0.154 $\pm$ 0.108	0.137 $\pm$ 0.106
R wave	1.000 $\pm$ 0.269	0.820 $\pm$ 0.223	0.825 $\pm$ 0.186
T wave	0.127 $\pm$ 0.054	0.142 $\pm$ 0.078	0.131 $\pm$ 0.084

N=12.

obtained in those cases that showed a statistically significant r value [11].

RESULTS

The mean values and standard deviations for electrocardiographic and plasmatic variables are shown in Tables 1 and 2, and no statistically significant differences between age groups were observed. Only the plasma potassium level detected in 1 day old individuals was significantly lower ($p \leq 0.05$) than those recorded at 7 days old.

The analysis of correlation between the RR interval and the remaining electrocardiographic variables had previously been carried out. The obtaining of the non-significant results remove conjectures about the influence of the cardiac cycle duration (RR interval) on these variables.

The results of the correlation analyses between plasmatic and electrocardiographic variables showed significant r values only in 1 day old individuals (Table 3). Subsequently, when a pair of variables showed a

significant linear correlation, the regression equation was calculated between them.

Out of all the groups of variables analysed, only five of them (PQ segment, T wave amplitude, R wave duration, ST interval and QT interval) showed a dependence on the plasma levels of ions. The PQ segment which only showed a significant correlation with sodium ($r=0.646$) can be expressed as a

Fig. 1. Duration of PQ segment as a function of plasma concentration of Na ion, including regression equation.

Table 2. Plasma concentrations (Mean $\pm$ SD) of ions detected during the first two weeks of postnatal life

	1 day	7 days	14 days
SODIUM	126.21 $\pm$ 16.80	134.16 $\pm$ 2.82	132.83 $\pm$ 10.17
POTASSIUM	3.67 $\pm$ 0.68 ^{a)}	4.22 $\pm$ 0.43	4.09 $\pm$ 0.47
CALCIUM	5.38 $\pm$ 0.95	5.18 $\pm$ 0.86	5.41 $\pm$ 1.43

Concentration in mEq/L.; N=12; a) Significantly different ($p \leq 0.05$) from 7 days value.

Table 3. Correlation coefficients (r) between electrocardiographic variables and plasma concentrations of ions

Age (days)	POTASSIUM			SODIUM			CALCIUM		
	1	7	14	1	7	14	1	7	14
PQ segment	0.476	0.188	0.016	0.646 ^{a)}	-0.169	-0.038	0.183	-0.277	-0.016
ST interval	0.708 ^{b)}	-0.090	-0.324	0.641 ^{a)}	0.006	-0.025	0.074	-0.254	-0.066
QT interval	0.680 ^{a)}	-0.308	-0.382	0.759 ^{b)}	-0.135	-0.034	0.418	-0.026	0.016
R wave durat.	0.191	-0.396	0.097	0.418	-0.010	0.107	0.653 ^{a)}	-0.497	0.029
T wave amplit.	-0.582 ^{a)}	-0.342	-0.253	-0.507	-0.456	-0.483	0.021	-0.326	0.122

a) $p \leq 0.05$; b) $p \leq 0.01$; N=12.

Fig. 2. Amplitude of T wave as a function of plasma concentration of K ion, including regression equation.

Fig. 3. Duration of R wave as a function of plasma concentration of Ca ion, including regression equation.

Fig. 4. Duration of QT interval as a function of plasma concentration of K and Na ions, including regression equations.

Fig. 5. Duration of ST interval as a function of plasma concentration of K and Na ions, including regression equations.

function of its plasma concentration, by the equation: $PQ = 0.011 + 4.128 \times 10^{-4} (Na^+)$ (Fig. 1). Furthermore, the T wave ampli-

tude is related to the potassium ion and the relationship between them is expressed by means of the equation: $T \text{ wave} = 0.298 - 0.046 (K^+)$ (Fig. 2). On the

contrary, the R wave duration is expressed as a function of the plasma concentration of the calcium ion by the equation: $R\text{ wave} = 0.033 + 0.003 (\text{Ca}^{2+})$ (Fig. 3).

The two remaining variables, ST and QT intervals, show a linear correlation with plasma levels of both sodium and potassium. The equations of regression for the four pair of variables are shown in Figs. 4 and 5.

DISCUSSION

During the postnatal age changes were observed in the electrocardiographic tracing obtained in lead I [14] that were not related to the plasma ion levels. Nevertheless, by using lead V_{10} , correlations between different electrocardiographic variables and the plasma levels of potassium, sodium and calcium ions were detected.

With regard to the plasma ions analysed, it was observed that the calcium concentration does not undergo any significant variation during two weeks of study (Table 2) coinciding with data given by other authors [1]. Similar results are obtained with the sodium ion, although the mean concentration obtained from 1 day old individuals was slightly lower than those recorded at 7 and 14 days (Table 2).

In the case of potassium ion, the mean concentration obtained in each of the three age groups is very near to the data given by diverse authors for foals and adult horses [1, 2, 8]; however, the mean plasma concentration obtained for this ion during the first day is significantly lower than that recorded at 7 days postpartum.

The correlation analysis carried out between plasmatic and electrocardiographic variables only gave statistically significant results during the first postnatal day, which suggests a greater cardiac sensitivity to slight variations in electrolyte plasma levels of newborn foals. This sensitivity decreases

throughout the study period.

During the first neonatal day, the results showed that the time taken by the excitation to spread through the atrioventricular node, bundle of His and its branches (PQ segment), may be significantly affected by slight variations in plasma levels of Na ion. Consequently, a slight decrease of this ion, within a normal range, may cause an acceleration in the conduction of the excitation. It is hard to establish the cause of this correlation in newborn individuals because the research carried out in man and adult animals shows the Na ion to be a poor indicator of electrocardiographic alterations [13].

The electrical ventricular systole duration (QT interval) also showed a positive linear correlation with plasma concentrations of Na and K ions. However, these ions seemed to affect the ventricular recuperation (ST interval) more significantly than the activation process (R wave duration).

The cardiac activation is represented by R wave whose inscription in V_{10} lead coincides with the excitation of the basilar third of the interventricular septum [6]. The R wave duration is only affected by plasma concentration of Ca ion, both showing a positive linear correlation. This agrees with Surawicz's data [13] who postulated that hypercalcemia increases and hypocalcemia decreases the duration of ventricular activation.

During the ventricular recuperation in foals a T wave is inscribed whose amplitude is smaller than that observed in adult horses [5]. The variability in amplitude of this wave during the first day of postnatal life appears to be bound to the plasma concentration of K ion, contrary to what was indicated by Epstein [3] who failed to correlate clinical hyperkalaemia with electrocardiographic changes in the horse because the maximum plasma concentration recorded was only 4.3 mmol/L. On the other hand, our results are

opposite to those described for hyperkalaemia in adults [3, 13] that is characterized by peaked and tall T waves, because within a normal range for K ion, the higher plasma levels of this ion in newborn foals are associated with T waves of a smaller amplitude.

The results obtained for ST interval showed differences between experimental results and clinical observations. It has been postulated [13] that a decreased extracellular concentration of K ion causes the prolongation of the action potential by the lengthening of phase 3, which could result in a delay in the repolarization time of the myocardial cell and, consequently, in an increase of the ST interval duration. In newborn foals, however, a decrease in plasma levels of K ion is related with an acceleration of the ventricular recuperation, with the consequent shortening of the ST interval.

It is difficult to establish an explanation for the different behaviour of the electrocardiographic tracings of newborn, 7 day and 14 day foals, with relation to the small variations in plasma levels of electrolytes, since they could be the result of different electrophysiological manifestations of the myocardium of newborn and adult animals [9], or a consequence of the interaction with other metabolic factors related to the hypoxia in partum [10].

Nevertheless, as a summary of the results shown in this survey we wish to point out that the changes experienced in newborn foals by some of the electrocardiographic variables in relation to the plasma ion levels manifest the greater sensitivity of the myocardium during the perinatal period, and that a response similar to that of the adult horse is already reached at the age of one week.

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要 約

出生初期における子馬の ECG と血漿 K, Na, 及び Ca 濃度との相関性：Escabias, M.I.・Santisteban, R.,・Rubio, M.D.・Tovar, P. (スペインコルドバ大学生理部門生物学講座)——1～14日齢の小馬を用いて、血漿中の K, Na 及び Ca イオン濃度と ECG 変動との相関性を調べた所、1日齢の新生子にのみ有意な相関性が認められた。PQ 部分と R 波の幅は血漿の Na 及び Ca イオン濃度との間に各々正の相関が認められた。T 波の振幅は、血漿 K イオン濃度との間に負の相関を示した。更に、QT 及び ST 間隔の変動は、血漿の Na と K 濃度との間に各々正の相関を示すことから説明しうる。