Electrolyte, Blood Gas and Electrocardiographic Profile of Neonatal Foals in the First 48 Hours of Life

Raissa Karolliny Salgueiro Cruz, Angélica Alfonso, Maria Lucia Gomes Lourenço, Carla Maria Vela Ulilan, Mateus José Sudano, Eunice Oba, Carlos Roberto Padovani, Paulo Roberto Rodrigues Ramos & Simone Biagio Chiacchio

ABSTRACT

Background: The neonatal period is characterized as a physiological and metabolic adaptation phase, when organic systems need to face new challenges from extra uterine life. The knowledge in physiology, the evaluation of the newborn vigor and a fast intervention regarding to resuscitation, are essentials to decrease neonatal mortality. The aim of this study is to improve the understanding about clinical and laboratory evaluations of newborn foals through the determination of preventive or corrective methods, observe changes and describe the electrolytic blood gas and electrocardiographic profiles of Paint Horse foals in their first 48 h of life.

Material, Methods & Results: Twenty foals born in eutocia were evaluated at birth, 4, 8, 12, 16, 20, 24, 36 and 48 h thereafter. Clinical examinations (heart rate, respiratory rate and temperature), blood gas and electrocardiography were performed in all moments. No significant differences were observed in blood gas parameters during the analysis. Significant increases ($P < 0.001$) occurred in body temperature at birth, at 20 h and 36 h after foaling. The animals showed significant decreases in anion gap at birth, at 16 h and 24 h ($P < 0.01$); in sodium levels from birth to 20 h, and at 24 h ($P < 0.001$) and potassium levels between 4 h and 48 h after birth ($P < 0.05$); these concentrations were associated with variations in the electrocardiographic parameters. The electrocardiogram resulted in progressive decreases in QT interval, and in length and amplitude of T wave. There were negative correlations between QT interval and T wave amplitude at 16 h ($\rho = -0.56, P = 0.009$), the QT interval and cell volume at 24 h ($R = -0.48, P = 0.03$), the QT interval and hemoglobin level at 24 h ($R = -0.48, P = 0.03$), and the QT interval and temperature at 36 h ($R = -0.057, P = 0.007$). There were negative correlations for Potassium at birth ($R = -0.052, P = 0.01$) and at 20 h ($R = -0.49, P = 0.02$), and there was a positive correlation for anion gap at 20 h ($R = 0.52, P = 0.01$). There was a negative correlation between T wave amplitude and Sodium at 12 h after birth ($R = -0.47, P = 0.03$). Sinus rhythm was the main one, 85% of the animals presented this cardiac rhythm, followed by sinus tachycardia, presenting in 45% of the animals, and ventricular tachycardia in 15% of the animals. Premature ventricular contractions were observed in 10% of the foals.

Discussion: It was possible to set correlations between electrolytic levels and electrocardiographic parameters. The metabolic changes observed in this study can lead to variations in electrical heart activity, as the sinus arrhythmia and sinus tachycardia. The systemic metabolic changes can implicate, directly or indirectly, in changes at cardiovascular function, compromising the myocardial integrity. The main heart rhythm in our study was sinus rhythm, which is considered physiological for foals. However, there are few data about equine neonatology that report the importance of cardiac changes in the performance of the future athlete horse. The presence of sinus arrhythmia and sinus tachycardia in foals was described in previous studies, although these arrhythmias are common during the period of neonatal adaptation. These results are also associated with the neonatal adaptation, making it necessary to develop new studies to establish references values applicable to this period and to different breeds. The electrolyte values decreased over the first 48 h of life, suggesting that electrolyte homeostasis only occurs after 48 h of life.

Keywords: newborns, electrolytes, acid-base balance, horse, electrocardiogram.
INTRODUCTION

Respiratory disorders are the most frequent disorders found in human outpatient clinics and neonatal intensive care units and Neonatal Respiratory Distress Syndrome (NRDS) is the most common respiratory disorder [24]. In foals, respiratory disorders, including NRDS, occur frequently and are responsible for 3.6 to 5% of neonatal mortality [14]. Respiratory disorders have the following primary clinical signs: increases in respiratory rate and effort, hypoxemia, hypercapnia and respiratory acidosis [15]. By determining blood gas values, the degree of metabolic acidosis and neonatal breathing can be assessed. Such determinations are of great importance for the establishment of early therapeutic measures [8,18].

Blood gas parameters have been described in neonatal foals [10,21]; however, there is a lack of information on blood gas values for the samples obtained from the venous blood of healthy foals based on the various different breeds, environmental conditions and rearing systems.

There are numerous methods for monitoring the cardiovascular system, but the electrocardiogram is the best tool for diagnosing and classifying arrhythmias [23]. The occurrence of several types of arrhythmias in thoroughbred foals has been reported by Yamamoto et al. [26]; however, little is known of the frequency, duration and electrocardiographic characteristics of these arrhythmias in neonates.

The described parameters are useful for identifying foals at a greater risk of developing clinical signs and reducing neonatal mortality. Thus, the objective of this study was to describe the electrolyte, blood gas and electrocardiographic profiles of neonatal Paint Horse foals in the first 48 h of life.

MATERIALS AND METHODS

Animals

This study was conducted on a stud farm in Avaré, São Paulo State (SP), which has a subtropical climate and is at an elevation of 766 meters, a latitude of 23º05’55’’ and a longitude of 48º55’3’’[9]. All of the experimental procedures were performed after obtaining approval from the Animal Research Ethics Committee. Twenty Paint Horse foals produced by embryo transfer (ET) in crossbred recipients (n = 20, mean age between 5-12 years and mean weight of 450 kg) were evaluated. The newborns remained with their dams throughout the experimental period.

Blood analysis

Blood samples were collected by jugular venipuncture (3 mL of blood) using heparinized syringes. Collections were performed at birth and at 4, 8, 12, 16, 20, 24, 36 and 48 h after birth.

From the blood aliquots, the blood gas analyses were performed using a portable clinical analyzer i-Stat with specific cartridges (EG7; CHEM8) according to the manufacturer’s recommendations. The evaluated parameters were sodium (Na⁺; mEq/L), potassium (K⁺; mEq/L), chloride (Cl⁻; mM), ionized calcium (iCa; mM), anion gap (AnGap; mM), bicarbonate (HCO₃⁻; mM), pH, oxygen saturation (sO₂), total carbon dioxide (TCO₂; mM), partial pressure of carbon dioxide (PCO₂, mmHg), partial pressure of oxygen (PO₂, mmHg) and base excess/deficit (BEecf; mM). The values for pH, PO₂ and PCO₂ were corrected according to the rectal temperature of each animal, and the heart and respiratory rates were measured.

Electrocardiographic analysis

An electrocardiogram was performed on the six leads in the frontal plane (I, II, III, aVR, aVL, and aVF) with the ECG Acquisition Module PC-ECG, version 2.0F over 1 min with a speed of 50 mm/s and a sensitivity set to 1 cm = 1 mV. Recordings were performed for all of the animals for the nine periods; the recording location had rubber-coated floor plates to avoid interference in the electrocardiographic tracing, and the animals were not sedated, tranquilized or anesthetized. For each electrocardiographic recording, the duration (milliseconds) and amplitude (millivolts) of the P, R and T waves and the durations of the QRS complex and PR, QT and RR intervals were analyzed. In addition, any changes in heart rate and rhythm, ST segment and T wave polarity were also recorded.

Statistical analysis

An analysis of variance (ANOVA) was performed for the repeated measures model and was complemented with Bonferroni’s multiple comparison test. The nonparametric Friedman’s analysis was complemented by Dunn’s multiple comparison test. The normality of the data was verified by performing a Shapiro-Wilk test followed by Pearson’s or Spearman’s correlation tests using PROC GLM from Statistic Analysis Software (SAS version 9.1.3). The results were assessed at the 5% level of significance.
RESULTS

The results of BEecf (mmol/L), HCO_3\(^{-}\) (mmol/L), TCO_2\(^{-}\) (mmol/L), sO_2\(^{\%}\) (%), pH, PCO_2 (mmHg) and PO_2 (mmHg) are shown (Table 1); however, there were no significant differences among the different time periods (\(P > 0.05\)).

The heart and respiratory rate clinical parameters were not statistically significant. The body temperature values showed significant increases (\(P < 0.001\)) between birth (37.96 ± 0.84°C) and 20 h (38.50 ± 0.40°C) and 36 h (38.64 ± 0.42°C).

The blood Na\(^{+}\) levels decreased between birth and the first 16 h of life but were not significant. From birth (138.25 ± 2.75 mmol/L) to 20 h (135.25 ± 3.96 mmol/L) and 24 h (134.05 ± 3.64 mmol/L), a significant reduction of blood Na\(^{+}\) occurred (\(P < 0.001\)), and it increased again at 48 h (135.65 ± 2.30 mmol/L) [Table 2].

The K\(^{+}\) levels increased significantly (\(P < 0.05\)) between 4 h (3.41 ± 0.59 mmol/L) and 48 h (3.92 ± 0.46 mmol/L) after birth. The AnGap decreased between birth and 12, 16 and 48 h, but there were no significant differences. Nevertheless, there was a significant decrease in the AnGap between birth (16.65 ± 1.78 mmol/L) and 16 h (14.85 ± 1.95 mmol/L) and 24 h (14.40 ± 1.23 mmol/L) after birth (\(P < 0.01\)).

The Cl\(^{-}\) concentrations increased in the first 12 h of life and decreased between 12, 16, 20 and 24 h after birth; the iCa concentration also increased in the first 12 h, decreased after 24 h and increased again at 48 h. However, these variables were not significantly different.

The duration (milliseconds) and amplitude (milliseconds) of the waves and intervals in the electrocardiogram are shown (Table 3). The duration of the QT interval decreased significantly from 4 h (296.00 ± 23.62 ms) to 48 h after birth (270.55 ± 29.81 ms), with the lowest duration at 48 h (\(P < 0.05\)). There were negative correlations between the QT interval and the T wave amplitude at 16 h (\(\rho = -0.56, P = 0.009\)), the QT interval and cell volume at 24 h (\(R = -0.48, P = 0.03\)), the QT interval and hemoglobin level at 24 h (\(R = -0.48, P = 0.03\)), and the QT interval and temperature at 36 h (\(R = -0.057, P = 0.007\)).

The duration of the T wave did not differ from birth until 24 h; however, the difference between birth (104.40 ± 15.99 ms) and 36 h (84.30 ± 10.04 ms) was significant (\(P < 0.01\)). There were negative correlations for K\(^{+}\) at birth (\(R = -0.052, P = 0.01\)) and at 20 h (\(\rho = -0.49, P = 0.02\)), and there was a positive correlation for AnGap at 20 h (\(\rho = 0.52, P = 0.01\)).

The T wave amplitude showed a reduction in the mean and standard deviation at birth (-0.64 ± 0.26 mV), 24 h (-0.42 ± 0.30 mV) and 36 h (-0.39 ± 0 mV) (\(P < 0.01\)). There was a negative correlation between the amplitude of the T wave and Na\(^{+}\) at 12 h after birth (\(R = -0.47, P = 0.03\)).

The predominant cardiac rhythm at all periods was the sinus rhythm (85%; 17/20), with an average heart rate of 114 ± 17 bpm. Sinus tachycardia accounted for 45% (9/20) of the analyzed rhythms, with an average heart rate of 147.86 ± 8.2 bpm. Ventricular tachycardia occurred in 15% (3/20) of the animals, and ventricular premature contractions (VPC) occurred in 10% of the animals (2/20).

<table>
<thead>
<tr>
<th>Period</th>
<th>BE (mM)</th>
<th>HCO_3(^{-}) (mM)</th>
<th>TCO_2 (mM)</th>
<th>sO_2 (%)</th>
<th>pH</th>
<th>PCO_2 (mmHg)</th>
<th>PO_2 (mmHg)</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>5.50 ± 4.40</td>
<td>30.08 ± 3.69</td>
<td>31.35 ± 3.70</td>
<td>64.40 ± 13.06</td>
<td>7.39 ± 55.71</td>
<td>49.31 ± 5.86</td>
<td>36.95 ± 6.62</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>4 h</td>
<td>6.00 ± 3.07</td>
<td>30.26 ± 2.57</td>
<td>31.75 ± 2.65</td>
<td>70.60 ± 9.89</td>
<td>7.42 ± 42.67</td>
<td>47.00 ± 3.18</td>
<td>39.90 ± 6.79</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>8 h</td>
<td>6.35 ± 3.06</td>
<td>30.44 ± 2.67</td>
<td>31.70 ± 2.75</td>
<td>67.80 ± 8.58</td>
<td>7.42 ± 47.34</td>
<td>46.66 ± 4.47</td>
<td>37.75 ± 5.07</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>12 h</td>
<td>6.30 ± 3.68</td>
<td>30.63 ± 3.24</td>
<td>32.00 ± 3.37</td>
<td>65.85 ± 9.74</td>
<td>7.41 ± 37.49</td>
<td>47.39 ± 3.91</td>
<td>36.80 ± 6.93</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>16 h</td>
<td>6.50 ± 3.57</td>
<td>30.68 ± 3.21</td>
<td>32.00 ± 3.35</td>
<td>67.90 ± 10.09</td>
<td>7.42± 30.04</td>
<td>47.78 ± 3.93</td>
<td>38.75 ± 7.28</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>20 h</td>
<td>5.95 ± 3.41</td>
<td>30.27 ± 3.19</td>
<td>31.70 ± 3.31</td>
<td>67.85 ± 10.00</td>
<td>7.40± 25.70</td>
<td>48.41 ± 4.38</td>
<td>39.66 ± 7.27</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>24 h</td>
<td>6.15 ± 3.20</td>
<td>30.41 ± 2.83</td>
<td>31.90 ± 2.95</td>
<td>68.20 ± 9.52</td>
<td>7.41± 28.47</td>
<td>47.43 ± 3.48</td>
<td>39.25 ± 5.50</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>36 h</td>
<td>6.00 ± 2.12</td>
<td>30.18 ± 1.80</td>
<td>31.60 ± 1.87</td>
<td>67.65 ± 10.36</td>
<td>7.41± 27.49</td>
<td>47.74 ± 3.30</td>
<td>39.50 ± 6.94</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>48 h</td>
<td>6.45 ± 2.94</td>
<td>30.71 ± 2.58</td>
<td>32.10 ± 2.69</td>
<td>64.40 ± 8.03</td>
<td>7.41± 27.24</td>
<td>48.78 ± 3.69</td>
<td>36.70 ± 4.18</td>
<td>&gt;0.05</td>
</tr>
</tbody>
</table>


Table 2. Means and standard deviations of the electrolytes in foals at birth and at 4, 8, 12, 16, 20, 24, 36, and 48 h after birth.

<table>
<thead>
<tr>
<th>Period</th>
<th>Na (mM)</th>
<th>K (mM)</th>
<th>Cl (mM)</th>
<th>iCa (mM)</th>
<th>Anion Gap (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>138.25 ± 2.75&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.55 ± 0.55&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>99.50 ± 3.50</td>
<td>1.49 ± 0.07</td>
<td>16.65 ± 1.78&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>4 h</td>
<td>138.45 ± 2.90&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.41 ± 0.59&lt;sup&gt;a&lt;/sup&gt;</td>
<td>99.85 ± 3.63</td>
<td>1.52 ± 0.07</td>
<td>16.05 ± 1.70&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>8 h</td>
<td>138.00 ± 2.20&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.51 ± 0.63&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>99.90 ± 3.46</td>
<td>1.52 ± 0.06</td>
<td>15.30 ± 1.56&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>12 h</td>
<td>137.00 ± 3.00&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.48 ± 0.58&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>99.35 ± 4.29</td>
<td>1.52 ± 0.08</td>
<td>15.30 ± 1.97&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>16 h</td>
<td>135.70 ± 2.99&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>3.51 ± 0.51&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>98.55 ± 3.91</td>
<td>1.50 ± 0.06</td>
<td>14.85 ± 1.95&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>20 h</td>
<td>135.25 ± 3.96&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.76 ± 0.48&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>98.30 ± 4.56</td>
<td>1.49 ± 0.07</td>
<td>15.15 ± 1.93&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>24 h</td>
<td>134.05 ± 3.64&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.80 ± 0.53&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>98.15 ± 4.37</td>
<td>1.49 ± 0.06</td>
<td>14.40 ± 1.23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>36 h</td>
<td>135.20 ± 2.01&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.82 ± 0.52&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>98.80 ± 2.35</td>
<td>1.51 ± 0.08</td>
<td>14.70 ± 1.34&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>48 h</td>
<td>135.65 ± 2.30&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>3.92 ± 0.46&lt;sup&gt;b&lt;/sup&gt;</td>
<td>99.45 ± 2.37</td>
<td>1.54 ± 0.09</td>
<td>14.35 ± 2.27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P value:<sup>a,b</sup> Different superscript lowercase letters indicate significant differences among the evaluation periods (P < 0.05). Na: sodium; K: potassium; Cl: chloride; iCa: ionized calcium.

Table 3. Means and standard deviations of the electrocardiographic parameters in foals at birth and at 4, 8, 12, 16, 20, 24, 36, and 48 h after birth.

<table>
<thead>
<tr>
<th>Period</th>
<th>QT Interval (sec)</th>
<th>T Wave (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>284.20 ± 30.01&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.64 ± 0.26&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>4 h</td>
<td>296.00 ± 23.62&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.67 ± 0.26&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>8 h</td>
<td>291.65 ± 30.61&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.50 ± 0.37&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>12 h</td>
<td>290.30 ± 23.11&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.57 ± 0.20&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>16 h</td>
<td>282.70 ± 24.22&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.47 ± 0.25&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>20 h</td>
<td>275.60 ± 23.08&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.43 ± 0.41&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>24 h</td>
<td>275.00 ± 20.92&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-0.42 ± 0.30&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>36 h</td>
<td>274.80 ± 29.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.39 ± 0.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>48 h</td>
<td>270.55 ± 29.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.45 ± 0.41&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

P value:<sup>a,b</sup> Different superscript lowercase letters indicate significant differences among the evaluation periods (P < 0.05).

DISCUSSION

The PaO<sub>2</sub> values measured in this study were lower than those reported by other authors [10,25]; however, none of the animals in this study showed any symptoms of respiratory disorders, and this finding is considered common in equine neonates. Thus, the differences in PaO<sub>2</sub> values should be evaluated according to the age of the foal, the difficulty in obtaining the sample and the positioning of the animal [14,22,26]. The pH was greater than 7.35 for all periods, which was determined according to the methods of other researchers, who correlated pH values above this level with increased newborn foal survival [3]. The slight increase in the observed pH may have originated from the reduction of Cl<sup>-</sup> caused by the retention of HCO<sub>3</sub><sup>-</sup>, which is considered to be the second-most abundant negative ion in the body and function to restore the balance of negative charges. Thus, an excess of HCO<sub>3</sub><sup>-</sup> would occur, and compensatory hypochloremic metabolic alkalosis would be triggered [4], which would decrease the pH in the venous blood.

The levels of the AnGap, Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup> and iCa were lower than those described in the literature [1,12] and were reduced between the time periods. However, the differences between the values may be related to
the breed because most of the studies were performed in thoroughbred foals. Importantly, eutocia can also promote various levels of acid-base imbalance resulting from physiological uterine-placental ischemia during expulsive contractions. The mechanisms for the control of acid-base and electrolyte balances in newborns are peculiar in this age group because of significant differences in their metabolism and renal function compared with adults. The kidneys of newborn foals are not functionally active at birth; therefore, the renal excretion of ions is less efficient than in adults [13], which is a possible explanation for our results because the reductions did not clinically affect the health of the animal and are consistent with the period of neonatal adaptation and inefficiency of various organs and systems in the foal.

The reductions observed in the K$^+$ levels can be explained by the release of adrenaline during the stress of parturition and the increase of insulin levels, which promotes a greater influx of K$^+$ to muscle and liver cells [5]. When the acid-base imbalance is corrected after birth, the intracellular H$^+$ ions undergo translocation by K$^+$, which leads to a decrease of this ion in the blood, as observed in this study. The reduction in the duration of the T wave is correlated with a decrease in K$^+$ levels and may be associated with metabolic alkalosis because of the increased renal excretion of K$^+$ [17]. The changes in K$^+$ levels have important clinical consequences, including increasing the risk of complex ventricular arrhythmias [2]; they also and produce changes in the electrocardiographic tracing [4]. In hypokalemia, the electrocardiographic results include depression of the ST segments, shorter T wave duration and amplitude, prolonged QT intervals and variations in the ventricular and supraventricular arrhythmias [7,20]. Several of these changes were observed in this study.

The electrolyte concentrations could be easily correlated with the electrocardiographic variables. The observed electrolyte reductions facilitated a reduction of the duration and amplitude of the T wave and QT interval, thereby interfering in the formation of a cardiac electrical impulse. According to Holbrook et al. [11], systemic metabolic changes may directly or indirectly produce changes in the cardiovascular function and impair the myocardial integrity.

The predominant cardiac rhythm was the sinus rhythm, which is considered physiological for foals [16,19,26]. Sinus tachycardia and sinus arrhythmia in foals have been observed in previous studies [6,16], with many of these arrhythmias present during the neonatal adaptation period. The observed arrhythmias may be associated with the degree of hypoxemia; however, it was not possible to establish a statistical correlation. According to Yamamoto et al. [26], foals with severe arrhythmias present lower mean PaO$_2$ than foals with mild arrhythmias. However, many authors consider arrhythmias in foals to be benign or physiological and indicative of non-specific stress reactions [6,26,27]. The hypoxemia, hypercapnia, acidosis, high vagal tone and extent of the atrial muscle play important roles in neonatal arrhythmias [26,27]; however, these correlations are still limited.

It is likely that the electrolyte homeostasis in neonatal foals occurs only after 48 h of life because during this period, the foals have lower levels of An-Gap, Na$^+$, K$^+$, iCa and Cl$^-$. In addition, the animals are in hypochloremic metabolic alkalosis and have low levels of PaO$_2$ during the neonatal period, which is a compensatory response to the critical period of adaptation for the newborn. The electrocardiographic changes reflect this imbalance and are related to the decrease in K$^+$ and metabolic alkalosis in the first 12 h. Importantly, the changes observed in this study are consistent with the analyzed neonatal period and are considered physiological; thus, they do not affect the vitality of the newborn foal.

MANUFACTURERS
1Abbott Laboratories. Abbott Park, IL, USA.
2Tecnologia Eletrônica Brasileira Ltda. São Paulo, SP, Brazil.
3SAS Institute. Cary, NC, USA.

Funding. This research was supported by São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP), grant number 2012/24845-7.

Ethical approval. All procedures were performed after approval by the Ethics Committee on Animal Use the Faculty of Veterinary Medicine and Animal Science, São Paulo State University (Universidade Estadual Paulista “Júlio de Mesquita Filho”- Unesp), Botucatu-SP, under protocol 231/2012-CEUA.

Declaration of interest. The authors report no conflicts of interest. The authors alone are responsible for the content and writing of paper.
REFERENCES