Correlation between some arterial and venous blood gas parameters in healthy newborn Martina Franca donkey foals from birth to 96 hours of age

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ABSTRACT

In neonatology, blood gas analysis is a useful tool in the evaluation of the health of newborns and plays a key role in early detection of critically ill subjects. Because blood gas analysis parameters have not previously been studied in any depth in donkey foals, this study was performed on 16 healthy Martina Franca donkey foals born after an uncomplicated delivery. Arterial and venous blood samples were collected at 5 minutes and at 12, 24, 72, and 96 hours of age. Blood gas analysis was performed by a portable analyzer, measuring arterial and venous total carbon dioxide, carbon dioxide partial pressure (pCO₂), oxygen partial pressure (pO₂), oxygen saturation (sO₂), bicarbonate, base excess (BE), pH, and lactate (LT). Lower blood pH values, pO₂ and sO₂, and a higher level of lactate were found at birth in comparison with subsequent sampling times. This moderate acidotic profile disappeared at 12 hours, when all the parameters became constant until the end of the study period. As expected, significant differences between arterial and venous blood gas parameters related to the oxygenation, such as pO₂ and sO₂, and partially carbon dioxide partial pressure were found, whereas total carbon dioxide, pH, BE, and LT were comparable in arterial and venous blood samples. For these latter parameters, the highly significant correlation between arterial and venous findings suggests that venous samples could be an acceptable alternative to the arterial sample for blood gas analysis in newborn donkey foals, when the oxygenation status of the patient is not the first goal of patient analysis.

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1. Introduction

In mammals, during the perinatal period, the cardiopulmonary system undergoes the most dramatic changes, which affect the ability of the newborn to survive [1]. A short perinatal asphyxia is known to occur in newborns, even under normal conditions, as the result of myometrial contractions and transient imbalance of gas exchange [2]. However, perinatal asphyxia must be quickly and efficiently counteracted by the progressively efficient respiration [3]. The evaluation of blood gas analysis immediately after birth could therefore be useful in detecting the neonates needing special monitoring in the first weeks of life [4]. As reported for human babies, blood gas analysis is important for early evaluation of the health of a newborn [5], providing valuable diagnostic and prognostic information, essential to patient assessment and management. Blood gas analysis aims primarily to measure blood oxygen and carbon dioxide quantity, and pH. To be specific, the analysis provides data regarding blood pH, oxygen (pO₂) and carbon dioxide
(pCO2) partial pressures, total carbon dioxide (tCO2), oxygen saturation (sO2) but often also lactate, bicarbonate (HCO3), and base excess (BE). Blood gas analysis can be performed on arterial (ABG) or venous blood (VBG), the former being considered the elective, traditional method, albeit characterized by some limitations, especially when adapted to animals. Although arterial blood sampling is considered a low-risk procedure, bleeding, arterial injury, and infection are recognized as possible side-effects also in humans. In horse foals, performing blood sampling from the brachial, great metatarsal, or palmar arteries requires lateral recumbence restraint [6], easily performed in sick animals but not in healthy, viable neonates. Alternative to ABG, VBG can be a safer procedure, easier to perform, and very convenient especially during animal hospitalization, when many patients have a central venous catheter from which venous blood samples can be quickly and easily retrieved.

Blood gas analysis can be performed by laboratories or by portable analyzers, the latter being much more useful for use under veterinary practice in the field. As reported by Castagnetti et al. [7], the accuracy of some handheld analyzers has been verified for use in equine medicine. Among them is the i-STAT (Abbott Laboratories, Abbott Park, IL, USA), the accuracy of which has previously been demonstrated [8,9].

A quick assessment of neonatal viability is essential to provide the proper care or intensive resuscitation at birth in newborns of every species, to improve the chance of offspring survival. In donkeys, many breeds are recognized by the Food and Agriculture Organization as endangered populations, meaning that the neonatal survival is even more crucial. The Martina Franca donkey breed has been recognized as endangered because of the small number of approved-for-breeding jackasses (48) and jennies (515) [10]. Although one study provides data about the hematology, biochemistry, and an analysis of VBGs in the first 24 hours of life of donkey foals [11], to the author’s knowledge, no data are available about the suitability of using venous blood instead of arterial blood for gas analysis in donkey foals in the first 96 hours of age.

Therefore, the aims of the present study were to define VBG and ABG analysis parameters in healthy newborn donkey foals in the first 96 hours of age and to verify the agreement between arterial and venous values of blood gas and acid-base parameters.

2. Material and methods

2.1. Animals

The study was conducted during the 2015 breeding season on donkeys housed at the Veterinary Teaching Farm of the University of Teramo. The clinical study was approved by the Interuniversity Ethics Committee for Animal Experimentation (CEISA, Protocol number #45/2013/CEISA/COM).

According to the criteria for normal, spontaneous parturition and the requisites for healthy, mature, and viable donkey foals [11], 16 Martina Franca donkey foals were enrolled in the present study. Two weeks before the expected date of delivery, every jenny aged between 4 and 12 years and 310 to 390 kg was moved to box equipped with two closed-circuit television cameras for video surveillance of birth.

Within 5 minutes after birth, foals were clinically evaluated for maturity and congenital defects, weighed, and submitted to APGAR score index measurement [12]. In this study, the APGAR score was calculated on appearance (pink mucous membranes—score 1; pale pink mucous membrane—score 1; and gray/blue—score 0), the pulse (>60 bpm and regular rhythm—score 2; irregular rhythm or <60 bpm—score 1; and absent rhythm—score 0), grimace (avoidance of stimulation—score 2; grimace/weak—score 1; and absent response—score 0), activity (sternal/active—score 2; hypotonic—score 1; and atonic—score 0), and respiration (regular—score 2; irregular—score 1; and absent—score 0).

2.2. Blood sampling and gas analysis

All the 16 donkey foals underwent arterial and venous blood sampling according to the following schedule: 5 minutes (T1), 12 hours (T2), 24 hours (T3), 48 hours (T4), and 96 hours (T5) after birth. The sampling schedule was adjusted to reduce the number of blood collections in the animals. Arterial blood samples were collected from the great metatarsal artery on foals in lateral recumbency by using a 1-mL heparinized syringe. Venous samples were collected soon after the arterial sample from the jugular vein; foals were restrained in sternal recumbence for the first sample and in standing position for the subsequent samplings. All samples were collected by the same vet, in accordance with the good veterinary practice, and did not cause evident pain to the animal.

Immediately after collection, blood samples were loaded on a CG4+ cartridge (Abbott Laboratories, Chicago, USA) and analyzed using a portable blood gas analyzer (i-STAT System, Abbott Laboratories, Abbott Park, IL, USA) as previously reported [13]. The following parameters were analyzed: total CO2 (tCO2, mmol/L), partial pressure CO2 (pCO2, mm Hg), partial pressure O2 (pO2, mm Hg), oxygen saturation (sO2, %), HCO3 (mmol/L), base excess (BE, mmol/L), pH, and lactate (LT, mmol/L).

2.3. Statistical analysis

Data are presented as mean ± standard deviation (SD). Differences for each parameter between different sampling times were tested by univariate ANOVA followed by a Scheffé posthoc test, where appropriate. Correlations between arterial and venous parameters were tested using Pearson’s correlation coefficient. Significance was set at P < 0.05. The agreement between arterial and venous blood and acid-base parameters was also evaluated using the Bland–Altman plot, as previously described [14,15].

Statistical analyses were performed using SPSS 15.0 (SPSS Inc. Chicago, IL, USA), the Bland–Altman plot was performed using Medcalc 12 (Medcalc software bvba, Ostend, Belgium).
3. Results

The 16 donkey foals, nine males and seven females, were born after normal pregnancy lasting 366.2 ± 12 days (range, 345–392 days). The mean birth weight of the foal was 33.7 ± 3.26 kg (range, 31–37 kg), and the mean APGAR score recorded was 9.4 ± 0.4 (range, 8–10). All the newborns followed a normal clinical course during the 96 hours of study and also up to the first 2 weeks of age.

Arterial and venous tCO2, pCO2, pO2, sO2, HCO3, BE, pH, and LT at the scheduled sampling times were summarized in Table 1. Overall, the statistical analysis showed the significant effect of the foal in all parameters (P < 0.05), and therefore remarkable interindividual variation. Total carbon dioxide and pCO2 did not show significant differences over the sampling times in both arterial and venous samples. Bicarbonate, BE, and pH showed significant increases (P < 0.05) between birth and 12 hours of age in both arterial and venous samples, without further differences until the end of the study at 96 hours after birth. Furthermore, LT decreased significantly (P < 0.05) in both arterial and venous samples from birth to 12 hours of age, but a significant further decrease at 48 hours of age was found only in arterial samples, whereas venous LT remained statistically unchanged until the end of the study. Partial O2 and sO2 increased significantly (P < 0.05) from birth to 12 hours of age without any further change in arterial samples, whereas no significant differences were found for the venous samples throughout the sampling times.

When the comparison between the arterial and venous values for each parameter was assessed, no significant differences were found at any sampling time for tCO2, pCO2, BE, and LT, whereas venous pO2 and sO2 were significantly lower (P < 0.05) than their arterial counterparts. The Pearson correlation test showed a positive strong (R > 0.75, P < 0.01) correlation between arterial and venous tCO2, bicarbonate, BE, pH, and LT, whereas a weak (R = 0.58, P < 0.05) correlation was found for pCO2. No significant correlation was found for arterial and venous pO2 and sO2 (Table 2).

The BE was very variable among individuals at birth, with individual variability decreasing by 12 hours after birth. Agreement between parameters measured in arterial and venous samples was positive for most of the parameters (Table 2), with narrow 95% limits of agreement (Fig. 1).

4. Discussion

The survival of offspring is a necessary prerequisite for population survival, and offspring survival is even more important where programs aiming to improve the endangered populations are concerned. Because the first minutes after birth are the most challenging time for the newborn survival and because cardiorespiratory changes play the most important role in the process of neonatal adaptation, the present study aimed to improve knowledge about blood gas analysis immediately after birth in healthy Martina Franca donkey foals. The aim was to provide useful information for better management of both normal, mature and viable neonates and also to enable the quick detection of newborns requiring special assistance. To the authors’ knowledge, at present, only data provided by a study

Table 1
Mean (±standard deviation [SD]) of blood gas analysis in arterial and venous samples at different sampling time in the 16 newborn Martina Franca donkey foals.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time (h)</th>
<th>0</th>
<th>12</th>
<th>24</th>
<th>48</th>
<th>96</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>tCO2 (mmol/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>25.3 ± 2.3a</td>
<td>27.2 ± 1.7b</td>
<td>27.7 ± 1.3b</td>
<td>27.7 ± 1.4b</td>
<td>26.4 ± 1.6ab</td>
<td>27.6 ± 2.2ab</td>
</tr>
<tr>
<td>Venous</td>
<td>25.4 ± 2.2a</td>
<td>27.5 ± 2.1ab</td>
<td>28.1 ± 1.6b</td>
<td>28.9 ± 1.7ab</td>
<td>27.6 ± 2.2ab</td>
<td></td>
</tr>
<tr>
<td>pCO2 (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>7.394 ± 0.039a</td>
<td>7.453 ± 0.029b</td>
<td>7.446 ± 0.021b</td>
<td>7.452 ± 0.023b</td>
<td>7.445 ± 0.026b</td>
<td>7.437 ± 0.015b</td>
</tr>
<tr>
<td>Venous</td>
<td>7.387 ± 0.038a</td>
<td>7.450 ± 0.023b</td>
<td>7.450 ± 0.020b</td>
<td>7.445 ± 0.026b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pO2 (mm Hg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>3.78 ± 1.16a</td>
<td>2.43 ± 0.58b</td>
<td>2.14 ± 0.61bc</td>
<td>1.58 ± 0.28c</td>
<td>1.79 ± 0.33bc</td>
<td></td>
</tr>
<tr>
<td>Venous</td>
<td>3.86 ± 1.15a</td>
<td>2.19 ± 0.46bc</td>
<td>2.10 ± 0.45b</td>
<td>1.43 ± 0.35b</td>
<td>1.58 ± 0.33b</td>
<td></td>
</tr>
</tbody>
</table>

In the same row, values with different letter in superscript differ significantly (P < 0.05).

Abbreviations: tCO2, total carbon dioxide; pCO2, carbon dioxide partial pressure; pO2, oxygen partial pressure; sO2, oxygen saturation.
limited to the first 24 hours of age on VBG analysis are available. For this reason, this study aimed to provide a more complete blood gas data set regarding healthy donkey newborns, from 16 normal, mature, viable, and correctly weighted Martina Franca donkey foals, born at term through supervised spontaneous vaginal foaling. Data regarding the jennies’ pregnancy length, birth weight of foals, and Apgar score and foal maturity corresponded with those reported for the same donkey breed [12,16]. In a previous study, some data regarding VBG analysis in donkey foals limited to the first 24 hours of age showed that some changes occurred from birth or at 12 hours of age, in comparison to the last sampling, performed at 24 hours of age [11]. For this reason, in the present study, the period of observation was extended to 96 hours after birth.

Arterial blood gas analysis represents the gold standard for the evaluation of the acid-base and respiratory status in newborn foals [17] and humans [5,18–20]. However, this procedure is not free from complications such as arterial injuries, thrombosis with distal ischemia, hematoma, aneurysm, and more rarely, reflex sympathetic dystrophy [21,22]. In the present study, therefore, both VBG and ABG analysis were compared to verify the suitability of venous blood sampling for gas analysis in newborn donkeys.

In term of age-related changes, the results of the present study showed that the most remarkable changes occur during the first 12 hours after birth, for most of the studied parameters, except for arterial LT, which continues to reduce at 48 hours of age. Mean tCO2 and pCO2 did not change significantly in the first 96 hours after birth. These results highlight that the most important blood gas changes occur during the very first neonatal period in donkey foals, as well as in horse, as previously demonstrated [8,23].

In the present study, the mean pH at birth (7.39 in both arterial and venous samples) was very similar to the venous pH previously reported in donkey foals [11] and similar to the arterial pH values previously reported in horse foals [17,24]. A significant increase from birth to 12 hours of age was found for pH, identical in venous and in arterial

Table 2
Mean values of the parameters for correlation and agreement between arterial and venous sample in Martina Franca donkey foals.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Arterial mean value</th>
<th>Venous mean value</th>
<th>Correlation (Pearson value)</th>
<th>Mean difference</th>
<th>Limits of agreement (CI 95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>tCO2 (mmol/L)</td>
<td>28.1</td>
<td>28.7</td>
<td>0.755*</td>
<td>-0.6</td>
<td>2.5 – 3.8</td>
</tr>
<tr>
<td>pCO2 (mm Hg)</td>
<td>39.4</td>
<td>42.2</td>
<td>0.584*</td>
<td>-1.5</td>
<td>3.8 – 6.9</td>
</tr>
<tr>
<td>pO2 (mm Hg)</td>
<td>68.7</td>
<td>37.3</td>
<td>0.071</td>
<td>31.6</td>
<td>57.1 – 6.1</td>
</tr>
<tr>
<td>sO2 (%)</td>
<td>93.1</td>
<td>69.7</td>
<td>0.189</td>
<td>23.1</td>
<td>36.5 – 9.6</td>
</tr>
<tr>
<td>Bicarbonate (mmol/L)</td>
<td>26.9</td>
<td>27.7</td>
<td>0.830*</td>
<td>-0.8</td>
<td>1.4 – 3.1</td>
</tr>
<tr>
<td>Base excess (mmol/L)</td>
<td>2.5</td>
<td>3.1</td>
<td>0.847*</td>
<td>-0.5</td>
<td>1.4 – 2.5</td>
</tr>
<tr>
<td>pH</td>
<td>7.44</td>
<td>7.42</td>
<td>0.783*</td>
<td>0.05</td>
<td>0.05 – 0.04</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>2.4</td>
<td>2.4</td>
<td>0.968*</td>
<td>0.1</td>
<td>0.63 – 0.43</td>
</tr>
</tbody>
</table>

Correlations pointed with asterisk are significant (P < 0.01).
Abbreviations: tCO2, total carbon dioxide; pCO2, carbon dioxide partial pressure; pO2, oxygen partial pressure; sO2, oxygen saturation.

Fig. 1. Bias (Bland–Altman) plot showing agreement between arterial and venous pH values and 95% limits of agreement.
samples (from 7.39 to 7.45 and from 7.39 to 7.45, respectively). These results confirmed previous findings in donkey foals [11] but demonstrated a different trend in pH changes in donkey foals compared with horse foals, in which no significant pH changes were reported to occur during the first 48 hours of age in both horse foals born at sea level [17] and in foals born at 1500 meters above sea level [24]. Similarly, lower blood pH values at calving, with spontaneous recovery at 4 hours after delivery, were previously reported in calves [2]. This transient acidosis could be due to the process of parturition, which could affect the start of ventilation in newborns. In the present study, the lower blood pH seemed to be dependent on the LT being at a significantly higher level at birth than at 12 hours or later.

The lower pH recorded at birth could also be, at least partially responsible for the significant lower sO2 recorded in arterial blood samples at birth, in comparison to subsequent samples. It was reported that a reduction in pH could interfere with the hemoglobin ability to bind oxygen, with a subsequent shift on the right of the oxygen dissociation curve [25,26]. It is interesting to note that, in the present study, this condition appeared physiological because no donkey foal showed clinical signs of respiratory distress. On the other hand, this knowledge is interesting for the assessment of respiratory adaptation in the first few hours after birth and for the prompt recognition of risk of hypoxia in newborn donkeys.

The mean venous tCO2 at birth, at 12 and 24 hours after birth (27, 29, and 29 mmol/L, respectively), were similar to data previously reported in donkey foals (27, 27.6, and 29.7 mmol/L, respectively) [11].

The mean pCO2 at birth (42.2-mm Hg) was lower than 46.1-mm Hg reported at 10 minutes after birth in donkey foals [11] and even more lower than data reported for horse foals between birth and 10 minutes of age (47.7- to 54.1-mm Hg) [4,17,24]. The mean pCO2 values recorded at 12 and 24 hours of age (40.7- and 40.9-mm Hg, respectively) were higher in comparison to data reported (37.1- and 38.9-mm Hg, respectively) in newborn donkey foals [11], but very similar to values reported for horse foals (41.7- to 44.3-mm Hg and 41.5- to 45.5-mm Hg, respectively) [4,17,24]. The mean venous pCO2 did not change from birth to 96 hours of age, in contrast to what was previously reported by Veronesi et al, [11], which found a significant decrease in venous pCO2 from birth to 12 hours of age, similar to the decrease reported by several authors regarding horse foals [4,17,24].

The mean arterial pO2 at birth in donkey foals was similar (60-mm Hg) compared to arterial values for horse foals, whereas values at 12 hours (71-mm Hg) and at 24 hours of age (73-mm Hg) were only slightly lower than data recorded for horse foals (59- to 79-mm Hg and 67- to 85-mm Hg, respectively) (43- to 64-mm Hg) [4,17,24]. The mean venous pO2 at birth (37-mm Hg) was higher than the 32-mm Hg reported in donkey newborns, but then became almost identical at 12 and at 24 hours of age (40 and 39-mm Hg) [11]. The mean venous sO2 at birth (64%) was higher than the values reported in donkey foals (59%), whereas data recorded at 12 and 24 hours after birth (73% and 72%, respectively) were similar to results previously reported (78 and 76%, respectively) [11].

A significant increase in bicarbonate between the birth and 12 hours of age was found in both venous and arterial mean values (from 26.4 to 27.5 mmol/L, and from 25.3 to 27.2 mmol/L, respectively). This trend is slightly different from the findings of Veronesi et al, [11], which showed a significant increase of venous bicarbonate levels only at 24 hours (from 25.7 mmol/L at birth and 26.6 mmol/L at 12 hours to 27.4 mmol/L at 24 hours). In horse foals, similar bicarbonate mean arterial values at birth were reported (24.6–26.8 mmol/L) [4,7,24], but a decrease during the first 48 hours [24] or 1 week of age [8] was demonstrated.

Mean venous and arterial BE at birth were higher than venous data reported for donkey foals (1 and −0.1 vs. −0.44 mmol/L) [7] and also versus data reported at birth or at 15 minutes after birth in horse foals (ranging values from −0.1 to −0.8 mmol/L) [8]. Furthermore, the mean values recorded at 12 hours (3 mmol/L in both venous and arterial samples) and at 24 hours (3 mmol/L in both venous and arterial samples) were higher than the 2.2 mmol/L and 2.67 mmol/L reported for donkey foals and also higher than the −0.5 mmol/L and 0.3 mmol/L reported for horse foals at 12 and 24 hours respectively.

The mean venous lactate values at birth (3.86 ± 1.15 mmol/L) were very similar to the mean values reported at birth for horse foals (3.8 ± 1.9 mmol/L) [7], slightly lower than values (4.9 ± 1.0 mmol/L) showed by Kitchen and Rossdale (1975) [23] in horse foals at birth and also a bit lower than data previously reported in donkey foals at birth (5.46 ± 1.36 mmol/L) [11]. Lactate blood concentration was not significantly different between arterial and venous samples, with values significantly higher (P < 0.05) at birth in comparison to all subsequent sampling times. On the other hand, arterial LT at 48 hours of age was significantly lower than levels recorded at birth and 12 hours of age. The significant decrease of venous LT from birth to 12 hours of age is in line with data previously reported in newborn horse foals by Kitchen and Rossdale (1975) [23], whereas Castagnetti et al, [7] found a significant decrease at 24 hours as compared with birth or 12 hours of age. In donkey foals, Veronesi et al, [11] demonstrated a significant decrease in venous lactate between birth and 12 hours of age and again at 24 hours of age.

The good level of agreement between arterial and venous tCO2, pH, bicarbonate, BE, and LT reported in the present study suggests that these parameters could be interchangeably measured in venous or arterial samples in donkey foal. These findings are in line with reports from human medicine [27–36] although most human studies were conducted on ill or critical patients, and not on newborns. A strong correlation between arterial and venous pH, bicarbonate, and BE was also found in newborn calves [2]. All these studies suggest that the venous sample could be an acceptable substitute for the ABG analysis for pH, bicarbonate, BE, and LT. Venous lactate was shown to be useful as a diagnostic and prognostic marker in critically ill neonatal foals [7].

As expected, only pO2 and sO2 did not correlate between arterial and venous samples, underlining that these parameters were significantly affected by the pulmonary activity and by the tissue consumption and suggesting that
reliable measurement of \( \text{pO}_2 \) and \( \text{sO}_2 \) for pulmonary gas exchange measurement should only be performed on arterial blood samples, as also previously suggested for newborn calves [2].

In conclusion, this study reported the blood gas analysis profile during the first 96 hours of age in newborn donkey foals. The significant changes occurring in the first 12 hours of age suggest that during the early neonatal period, the age of the donkey foal should be considered when blood gas analysis interpreting is necessary. The results indicate that in healthy and viable newborn Martina Franca donkey foals, that followed a normal neonatal course in the first 2 weeks of age, a mild, transient, self-recovering acidosis occurs without clinical impact during the first 12 hours of age. Furthermore, the high positive correlation between arterial and venous tCO2, pH, bicarbonate, BE, and LT reported for the first time in donkey foals highlights the usefulness of venous blood sampling for the evaluation and monitoring of these parameters also under field conditions.

References

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