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

Carluccio A[a], Contri A[a], Gloria A[a*], Veronesi MC[b], Sfirro MP[a], Parrillo S[a], Robbe D[a]

[a]Faculty of Veterinary Medicine, University of Teramo, Viale Crispi 212, 64100 Teramo, Italy.

[b]Department of Veterinary Science and Public Health, Università degli Studi di Milano, Via G. Celoria, 10, 21033 Milan, Italy.

*Corresponding author: Alessia Gloria, Faculty of Veterinary Medicine, University of Teramo, V.le Crispi 212, 64100 Teramo, Italy. Phone/fax: +39 0861 266995.

E-mail address: gloriaalessia@libero.it

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 (tCO_2), carbon dioxide partial pressure (pCO_2), oxygen partial pressure (pO_2), oxygen saturation (sO_2), bicarbonate (HCO_3), base excess (BE), pH, and lactate (LT). Lower blood pH values, pO_2 and sO_2, 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 pO_2 and sO_2, and partially pCO_2 were found, while tCO_2, 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.

Keywords: donkey; foal; blood gas analysis; arterial; venous

1. Introduction

In mammals, during the perinatal period, the cardiorespiratory system undergoes the most dramatic changes, which affects 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 is aims primarily to measure blood oxygen and carbon dioxide quantity, and pH. To be specific, the analysis provides data regarding blood pH, oxygen (pO_2) and carbon dioxide (pCO_2) partial pressures, total carbon dioxide (tCO_2), oxygen saturation (sO_2), but often also lactate, bicarbonate (HCO_3) and base excess. Blood gas analysis can be performed on arterial (ABG) or venous blood (VBG), the former being considered the elective, traditional method, albeit characterised by some limitations, especially when adapted to animals. Although arterial blood sampling is considered a low-risk procedure, bleeding, arterial injury, and infection are recognised 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. Alternatively 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

78 the i-STAT (Abbott Laboratories, Abbott Park, Il, USA), the accuracy of which has previously beed
79 demonstrated [8,9].
80 A quick assessment of neonatal viability is essential in order to provide the proper care or intensive
81 resuscitation at birth in newborns of every species, to improve the chance of offspring survival. In
82 donkeys, many breeds are recognized by the Food and Agriculture Organization (FAO) as
83 endangered populations, meaning that the neonatal survival is even more crucial. The Martina
84 Franca donkey breed has been recognized as endangered because of the small number of approved-
85 for-breeding jackasses (48) and jennies (515) [10]. Although one study provides data about the
86 hematology, biochemistry, and an analysis of venous blood gases in the first 24 hours of life of
87 donkey foals [11], to the author's knowledge, no data are available about the suitability of using
88 venous blood instead of arterial blood for gas analysis in donkey foals in the first 96 hours of age.
89
90 Therefore, the aims of the present study were to define venous and arterial blood gas analysis
91 parameters in healthy newborn donkey foals in the first 96 hours of age, and to verify the agreement
92 between arterial and venous values of blood gas and acid-base parameters.
93
94 **2. Material and Methods**
95 **2.1 Animals**
96 The study was conducted during the 2015 breeding season on donkeys housed at the Veterinary
97 Teaching Farm of the University of Teramo. The clinical study was approved by the Interuniversity
98 Ethics Committee for Animal Experimentation (CEISA, Protocol number #45/2013/CEISA/COM).
99 According to the criteria for normal, spontaneous parturition, and the requisites for healthy, mature
100 and viable donkey foals [11], sixteen Martina Franca donkey foals were enrolled in the present
101 study. Two weeks before the expected date of delivery, every jenny between 4 to 12 years old and
102 310 to 390 kg was moved to box equipped with two closed-circuit television (CCTV) cameras for
103 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 2; pale pink mucous membrane – score 1; gray/blue – score 0), the pulse (>60 bpm and regular rhythm – score 2; irregular rhythm or <60 bpm – score 1; absent rhythm - score 0), grimace (avoidance of stimulation – score 2; grimace/weak – score 1; absent response – score 0), activity (sternal/active – score 2; hypotonic – score 1; atonic – score 0), and respiration (regular – score 2; irregular – score 1; 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 recumbence 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 caused 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 analysed: total CO_2 (tCO_2, mmol/L), partial pressure CO_2 (pCO_2, mmHg), partial pressure O_2 (pO_2, mmHg), oxygen saturation (sO_2, %), HCO_3 (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 Scheffè post-hoc 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, 9 males and 7 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 two weeks of age.

Arterial and venous tCO_2, pCO_2, pO_2, sO_2, HCO_3, 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 inter-individual variation. Total carbon dioxide and pCO_2 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, while venous LT remained statistically unchanged until the end of the study. Partial O_2 and sO_2 increased significantly ($P < 0.05$) from birth to 12 hours of age without any further change in arterial samples, while 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 tCO_2, pCO_2, BE, LT, while venous pO_2 and sO_2 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 tCO_2, bicarbonate, BE, pH and LT, while a weak ($R = 0.58$, $P < 0.05$) correlation was found for pCO_2. No significant correlation were found for arterial and venous pO_2 and sO_2. (Table 2).

The base excess (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 (Figure 1).

4. Discussion

The survival of offspring is a necessary prerequisite for population survival, and offspring survival is even more important where programmes aiming to improve of endangered populations are concerned. Because the first minutes after birth are the most challenging 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 limited to the first 24 hours of age on venous blood gas 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 venous blood

gas 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 ischaemia, hematoma, aneurysm, and more rarely, reflex sympathetic dystrophy [21,22]. In the present study, therefore, both venous and arterial blood gas analysis were compared in order 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 tCO_2 and pCO_2 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 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 to 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 1,500 metres 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

208 the start of ventilation in newborns. In the present study, the lower blood pH seemed to be
209 dependent on the LT being at a significantly higher level at birth than at 12 hours or later.
210 The lower pH recorded at birth could also be, at least partially responsible for the significant lower
211 sO_2 recorded in arterial blood samples at birth, in comparison to subsequent samples. It was
212 reported that a reduction in pH could interfere with the hemoglobin ability to bind oxygen, with a
213 subsequent shift on the right of the oxygen dissociation curve [25,26]. It is interesting to note that,
214 in the present study, this condition appeared physiological, since no donkey foal showed clinical
215 signs of respiratory distress. On the other hand, this knowledge is interesting for the assessment of
216 respiratory adaptation in the first few hours after birth, and for the prompt recognition of risk of
217 hypoxia in newborn donkeys.
218 The mean venous tCO_2 at birth, at 12 and 24 hours after birth (27, 29, 29 mmol/l, respectively),
219 were similar to data previously reported in donkey foals (27, 27.6, 29.7 mmol/L, respectively) [11].
220 The mean pCO_2 at birth (42.2 mmHG) was lower than 46.1 mmHG reported at 10 min after birth in
221 donkey foals [11], and even more lower than data reported for horse foals between birth and 10 min
222 of age (47.7 to 54.1 mmHG) [4,17,24]. The mean pCO_2 values recorded at 12 and 24 hours of age
223 (40.7 and 40.9 mmHG, respectively) were higher in comparison to data reported (37.1 and 38.9
224 mmHG, respectively) in newborn donkey foals [11], but very similar to values reported for horse
225 foals (41.7 to 44.3 and 41.5 to 45.5 mmHG, respectively) [4,17,24]. The mean venous pCO_2 did not
226 change from birth to 96 hours of age, in contrast to what was previously reported by Veronesi et al,
227 (2014) [11], which found a significant decrease in venous pCO_2 from birth to 12 hours of age,
228 similar to the decrease reported by several authors regarding horse foals [4,17,24].
229 The mean arterial pO_2 at birth in donkey foals was similar (60 mmHg) compared to arterial values
230 for horse foals, while values at 12 hours (71 mmHg) and at 24 hours of age (73 mmHg) were only
231 slightly lower than data recorded for horse foals (59 to 79 and 67 to 85 mmHg, respectively) (43 to
232 64 mmHg) [4,17,24]. The mean venous pO_2 at birth (37 mmHg) was higher than the 32 mmHg
233 reported in donkey newborns, but then became almost identical at 12 and at 24 hours of age (40 and

234 39 mmHg) [11]. The mean venous sO_2 at birth (64%) was higher than the values reported in donkey
235 foals (59%), while data recorded at 12 and 24 hours after birth (73 and 72%, respectively), were
236 similar to results previously reported (78 and 76%, respectively) [11].
237 A significant increase in bicarbonate between the birth and 12 hours of age was found in both
238 venous and arterial mean values (from 26.4 to 27.5 mmol/L, and from 25.3 to 27.2 mmol/L,
239 respectively). This trend is slightly different from the findings of Veronesi et al, (2014) [11], which
240 showed a significant increase of venous bicarbonate levels only at 24 hours (from 25.7 mmol/L at
241 birth and 26.6 mmol/L at 12 hours to 27.4 mmol/L at 24 hours). In horse foals, similar bicarbonate
242 mean arterial values at birth were reported (24.6 to 26.8 mmol/L) [4,7,24], but a decrease during the
243 first 48 hours [24] or one week of age [8] was demonstrated.
244 Mean venous and arterial BE at birth were higher than venous data reported for donkey foals (1 and
245 -0.1 vs -0.44 mmol/L) [7], and also versus data reported at birth or at 15 min after birth in horse
246 foals (ranging values from -0.1 to -0.8 mmol/L) [8]. Furthermore, the mean values recorded at 12
247 hours (3 mmol/L in both venous and arterial samples) and at 24 hours (3 mmol/L in both venous
248 and arterial samples) were higher than the 2.2 mmol/L and 2.67 mmol/L reported for donkey foals
249 and also higher than the -0.5 mmol/L and 0.3 mmol/L reported for horse foals at 12 and 24 hours
250 respectively.
251 The mean venous lactate values at birth (3.86 ± 1.15 mmol/L) were very similar to the mean values
252 reported at birth for horse foals (3.8 ± 1.9 mmol/L) [7], slightly lower than values (4.9 ± 1.0
253 mmol/L) showed by Kitchen and Rossdale (1975) [23] in horse foals at birth, and also a bit lower
254 than data previously reported in donkey foals at birth (5.46 ± 1.36 mmol/L) [11]. Lactate blood
255 concentration was not significantly different between arterial and venous samples, with values
256 significantly higher ($P < 0.05$) at birth in comparison to all subsequent sampling times. On the other
257 hand, arterial LT at 48 hours of age was significantly lower than levels recorded at birth and 12
258 hours of age. The significant decrease of venous LT from birth to 12 hours of age is in line with
259 data previously reported in newborn horse foals by Kitchen and Rossdale (1975) [23], while

Castagnetti et al, (2010) [7] found a significant decrease at 24 hours as compared with birth or 12 hours of age. In donkey foals, Veronesi et al, (2014) demonstrated a significant decrease in venous lactate between birth and 12 hours of age and again at 24 hours of age [11].

The good level of agreement between arterial and venous tCO_2, 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], even though 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 arterial blood gas 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 pO_2 and sO_2 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 pO_2 and sO_2 for pulmonary gas exchange evaluation 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 two 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 tCO_2, 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

[1] Ousey J C. Endocrinological adaptation. In: McKinnon AO, Squires EL, Vaala WE, Varner DD, eds. Equine Reproduction, 2nd ed. Chichester: Wiley-Blackwell 2011; p. 69-83.

[2] Bleul U, Lejeune B, Schwantag S, Kahn W. Blood gas and acid-base analysis of arterial blood in 57 newborn calves. Veterinary Rec 2007;161:688-691.

[3] Knottenbelt DC, Holdstock N, Madigan JE. The foal at delivery. In: Equine neonatology: medicine and surgery. London: WB Saunders 2004; p. 65-74.

[4] Hodgson DR. Blood gas and acid-base changes in the neonatal fool. Vet Clin North Am Equine Prac 1987;3:617-29.

[5] Brouillette RT and Waxman DH. Evaluation of the newborn's blood gas status. Clinical Chemistry 1997;43:215-221.

[6] Rose RJ, Rossdale PD, Leadon DP. Blood gas and acid-base status in spontaneously delivered term-induced and induced premature foals. J Reprod Fertil 1982;32:521-528.

[7] Castagnetti C, Pirrone A, Mariella J, Mari G. Venous blood lactate evaluation in equine neonatal intensive care. Theriogenology 2010;73:343-57.

[8] Silverman SC, Birks EK. Evaluation of the i-STAT hand-held chemical analyser during treadmill and endurance exercise. Equine Vet J 2002;34:551-4.

[9] Saulez MN, Cebra CK, Dailey M. Comparative biochemical analyses of venous blood and peritoneal fluid from horses with colic using a portable analyses and an in-house analyser. Vet Rec 2005;157:217-23.

[10] Contri A, Robbe D, Gloria A, De Amicis I, Veronesi MC, Carluccio A. Effect of the season on some aspects of the estrous cycle in Martina Franca donkey. Theriogenology 2014;81:657-61.

[11] Veronesi MC, Gloria A, Panzani S, Sfirro MP, Carluccio A, Contri A. Blood analysis in newborn donkeys: hematology, biochemistry, and blood gases analysis. Theriogenology 2014;82:294-303.

[12] Panzani S, Carluccio A, Probo M, Faustini M, Kindahl H, Veronesi MC. Comparative study on 15-ketodihydro-PGF(2a) plasma concentrations in newborn horses, donkeys and calves. Reprod Domest Anim 2012;47:82–6.

[13] Peiró JR, Borges AS, Gonçalves RC, Mendes LC. Evaluation of a portable clinical analyzer for the determination of blood gas partial pressures, electrolyte concentrations, and hematocrit in venous blood samples collected from cattle, horses, and sheep. Am J Vet Res 2010;71:515-21.

[14] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.

[15] Bland JM, Altman DG. Comparing methods of measurement: why platting difference against standard method is misleading. Lancet 1995;346:1085-7.

337 [16] Carluccio A, Gloria A, Veronesi MC, De Amicis I, Noto F, Contri A. Factors affecting
338 pregnancy length and phases of parturition in Martina Franca jenny. Theriogenology 2015;84:650-
339 5.
340
341 [17] Stewart JH, Rose RJ, Barko AM. Respiratory studies in foals from birth to seven days old.
342 Equine Vet J 1984;16:323-8.
343
344 [18] Yildizdas D, Yapicioglu H, Yilmaz HL, Sertdemir Y. Correlation of simultaneously obtained
345 capillary, venous, and arterial blood gases of patients in a paediatric intensive care unit. Arch Dis
346 Child 2004;89:176-80.
347
348 [19] Treger R, Pirouz S, Kamangar N, Corry D. Agreement Between central venous and arterial
349 blood gas measurements in the intensive care unit. Clin J Am Soc Nephrol 2010;5:390-4.
350
351 [20] Byrne AL, Bennett M, Chatterji R, Symons R, Pace NL, Thomas PS. Peripheral venous and
352 arterial blood gas analysis in adults: are they comparable? A systematic review and meta-analysis.
353 Respirology 2014;19:168-75.
354
355 [21] Criscuolo C, Nepper G, Buchalter S. Reflex sympathetic dystrophy following arterial blood gas
356 sampling in the intensive care setting. Chest 1995;108:578-80.
357
358 [22] Barker WJ. Arterial puncture and cannulation. In: Roberts JR, Hedges JR, eds. Clinical
359 procedures in emergency medicine, 3rd ed. Philadelphia: WB Saunders 1998; p. 308-22.
360
361 [23] Kitchen H and Rossdale PD. Metabolic profiles of newborn foals. J Reprod Fertil Suppl
362 1975;23:705-7.

[24] Hackett ES, Traub-Dargatz JL, Knowles JE Jr, Tarr SF, Dargatz DA. Arterial blood gas parameters of normal foals born at 1500 metres elevation. Equine Vet J 2010;42:59-62.

[25] Refsum H, Opdahl H, Leraand S. Effect of extreme metabolic acidosis on the oxygen content of the blood. Crit Care Med 1997;25:1497-501.

[26] Opdahl H, Strømme TA, Jørgensen L, Bajelan L, Heier HE. The acidosis-induced right shift of the HbO_2 dissociation curve is maintained during erythrocyte storage. Scand J Clin Lab Invest 2011;71:314-21.

[27] Murdoch IA, Turner C, Dalton RN. Arterial or mixed venous lactate measurement in critically ill children. Is there a difference? Acta Paediatr 1994;83:412-13.

[28] Gallagher EJ, Rodriguez K, Touger M. Agreement between peripheral venous and arterial lactate levels. Ann Emerg Med 1997;29:479-83.

[29] Brandenburg MA, Dire DJ. Comparison of arterial and venous blood gas values in the initial emergency department evaluation of patients with diabetic ketoacidosis. Ann Emerg Med 1998;31:459-65

[30] Gokel Y, Paydas S, Koseoglu Z, Alparslan N, Seydaoglu G. Comparison of blood gas and acid-base measurements in arterial and venous blood samples in patients with uremic acidosis and diabetic ketoacidosis in the emergency room. Am J Nephrol 2000;20:319-23.

388 [31] Kelly AM, McAlpine R, Kyle E. Venous pH can safely replace arterial pH in the initial
389 evaluation of patients in the emergency department. Emerg Med J 2001;18:340-2
390
391 [32] Rang LC, Murray HE, Wells GA, MacGougan CK. Can peripheral blood gases replace arterial
392 blood gases in emergency department patients? Can J Emerg Med 2002;4:7-15.
393
394 [33] Ma OJ, Rush MD, Godfrey MM, Gaddis G. Arterial bood gas results rarely influence
395 emergency physician management of patients with suspected diabetic ketoacidosis. Acad Emerg
396 Med 2003;10:836-41.
397
398 [34] Kelly AM, McAlpine R, Kyle E. Agreement between bicarbonate measured on arterial and
399 venous blood gases. Emerg Med Australas 2004;16:407-9.
400
401 [35] Malinoski DJ, Todd SR, Slone S, Mullins RJ, Schreiber MA. Correlation of central venous and
402 arterial blood gas measurements in mechanically ventilated trauma patients. Arch Surg
403 2005;140:1122-5.
404
405 [34] Middleton P, Kelly A-M, Brown J, Robertson M. Agreement between arterial and central
406 venous values for pH, bicarbonate, base excess, and lactate. Emerg Med J 2006;23:622-4.
407

Figure 1. Bias (Bland Altman) plot showing agreement between arterial and venous pH values and 95% limits of agreement.

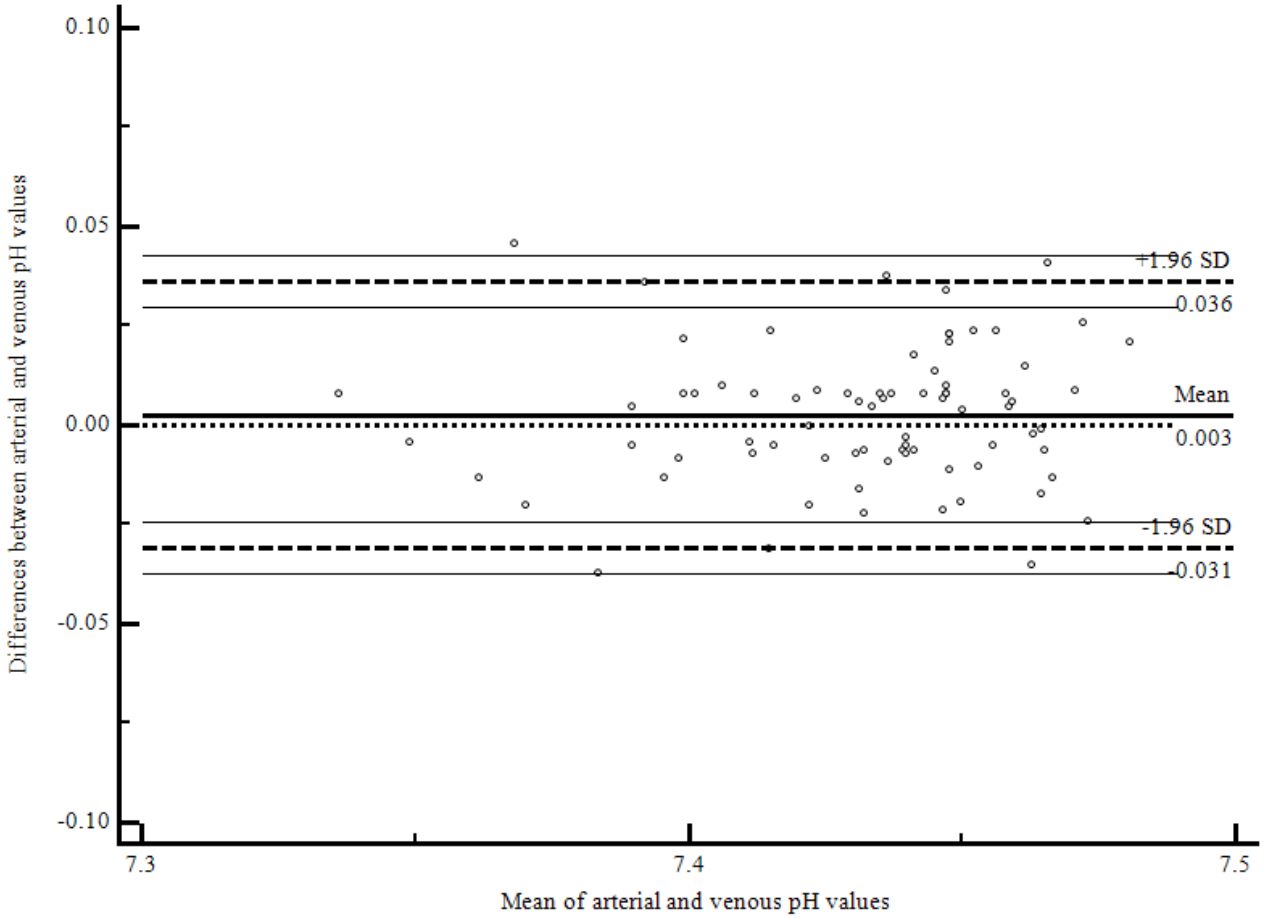

Table 1. Mean (±SD) of blood gas analysis in arterial and venous samples at different sampling time in the 16 newborn Martina Franca donkey foals.

		Time (h)				
		0	**12**	**24**	**48**	**96**
		Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**
tCO_2 (mmol/L)	**Arterial**	27±2	28±2	29±1	29±1	28±2
	Venous	27±3	29±2	29±2	30±2	28±3
pCO_2 (mmHg)	**Arterial**	41.4±3.9	39.6±3.5	40.3±2.2	39.6±2.5	39.5±2.8
	Venous	42.2±2.7	40.7±2.2	40.9±3.6	42.9±3.2	41.2±3.4
pO_2 (mmHg)	**Arterial**	60±16^{a}	71±9^{b}	73±9^{b}	70±7^{b}	71±5^{b}
	Venous	37±11	40±8	39±9	36±10	36±6
sO_2 (%)	**Arterial**	85±9^{a}	95±3^{b}	95±3^{b}	94±1^{b}	95±1^{b}
	Venous	64±6^{a}	73±6^{b}	72±7^{b}	71±6^{b}	70±9^{b}
Bicarbonate (mmol/L)	**Arterial**	25.3±2.3^{a}	27.2±1.7^{b}	27.7±1.3^{b}	27.7±1.4^{b}	26.4±1.6^{ab}
	Venous	26.4±2.2^{a}	27.5±2.1a^{b}	28.1±1.6^{b}	28.9±1.7^{b}	27.6±2.2^{ab}
Base excess (mmol/L)	**Arterial**	-0.1±2^{a}	3±1^{b}	3±1^{b}	3±1^{b}	2±1^{b}
	Venous	1±2^{a}	3±2^{b}	3±1^{b}	4±1^{b}	3±1^{b}
pH	**Arterial**	7.394±0.039^{a}	7.453±0.029^{b}	7.446±0.021^{b}	7.452±0.023^{b}	7.444±0.021^{b}
	Venous	7.387±0.038^{a}	7.450±0.023^{b}	7.450±0.020^{b}	7.445±0.026^{b}	7.437±0.015^{b}
Lactate (mmol/L)	**Arterial**	3.78±1.16^{a}	2.43±0.58^{b}	2.14±0.61^{bc}	1.58±0.28^{c}	1.79±0.33^{bc}
	Venous	3.86±1.15^{a}	2.19±0.46^{b}	2.10±0.45^{b}	1.43±0.35^{b}	1.58±0.33^{b}

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

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

	Arterial mean value	Venous mean value	Correlation (Pearson value)	Mean difference	Limits agreement (CI 95%)	
					Upper	Lower
tCO_2 (mmol/L)	28.1	28.7	0.755*	-0.6	2.5	-3.8
pCO_2 (mmHg)	39.4	42.2	0.584*	-1.5	3.8	-6.9
pO_2 (mmHg)	68.7	37.3	0.071	31.6	57.1	6.1
sO_2 (%)	93.1	69.7	0.189	23.1	36.5	9.6
Bicarbonate (mmol/L)	26.9	27.7	0.830*	-0.8	1.4	-3.1
Base Excess (mmol/L)	2.5	3.1	0.847*	-0.5	1.4	-2.5
pH	7.44	7.42	0.783*	0	0.05	-0.04
Lactate (mmol/L)	2.4	2.4	0.968*	0.1	0.63	-0.43

Correlations pointed with asterisk are significant ($P < 0.01$)