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Title

How to Perform Umbilical Cord Arterial and Venous Blood Sampling in Neonatal Foals

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26 **Abstract:**

27 Umbilical cord arterial and venous blood gas analysis is a commonly performed
28 procedure in human neonatal medicine to help ascertain a newborn infant's
29 oxygenation and acid-base status prior to birth. Defined protocols for performing
30 the procedure have been described in the medical literature. The aim of this
31 report was to describe in detail the procedure for collecting paired blood samples
32 from the umbilical artery and vein in newborn foals so that stall-side blood gas
33 analysis could be carried out. Thirty-five Thoroughbred foals >320 days
34 gestation from mares at one stud farm were sampled. Paired umbilical arterial
35 and venous whole-blood samples were obtained in n=30 foals, umbilical artery
36 only samples obtained in n=3 and umbilical vein only samples obtained in n=2
37 foals. There were no adverse events or clinical outcomes associated with the
38 sampling protocol described. The authors found that umbilical cord blood
39 collection for blood gas analysis was a practical clinical technique that
40 potentially could be used as a stall-side method for assessing the *in utero*
41 oxygenation and acid-base status of newborn foals.

42

43 **Keywords:**

44 Foal, Hypoxia, Perinatal Asphyxia Syndrome, Blood Gas Analysis, Umbilical
45 Cord

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51 **1. Introduction**

52 The combination of Apgar scoring [1,2] and umbilical cord blood gas analysis is
53 routinely used by human neonatologists to assess the likelihood that a hypoxic
54 event effecting the human infant occurred *in utero*, either acutely during
55 parturition or more chronically during the pregnancy [3,4,5]. Umbilical cord
56 blood gas analysis is thought to be a particularly useful diagnostic technique, as
57 it provides the most accurate insight into the neonate's acid-base status prior to
58 birth [5]. These assessments help identify at-risk babies without delay, allowing
59 for early medical intervention [6,7,8]. Mortality rates as well as adverse clinical
60 sequelae both in the short and long-term, particularly in relation to
61 neurodevelopmental disease, appear to be reduced with such early intervention
62 [9,10,11]. Similar to the hypoxic syndromes seen in human neonates, perinatal
63 asphyxia syndrome (PAS) in neonatal foals is likely caused by hypoxic-
64 ischaemic damage that occurred during pregnancy or parturition [12,13].
65 Although numerous risk factors have been identified for PAS, currently there are
66 no confirmed biochemical parameters that can be used to inform on the risk of
67 this disease being present [12].
68
69 Our research group recently published a study in which reference intervals (RI)
70 were determined for umbilical cord arterial and venous blood gas samples from
71 healthy Thoroughbred foals [14]. The aim had been to evaluate the practicality
72 of umbilical cord blood sampling from foals in a field-based setting and to
73 determine RI values from normal, healthy foals. It was hypothesised that if RIs
74 could be determined and the technique found to be feasible in a field-based
75 setting, this assessment modality could then be used to evaluate for differences

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76 between normal foals and foals at risk of PAS. During the study, the umbilical
77 cord blood collection technique developed by the authors was found to be simple
78 and minimally disruptive with consistent and accurate umbilical cord blood
79 sampling. Furthermore, RIs were definitively identified for the group of healthy
80 foals sampled in the study [14]. Because use of this technique in foals has not
81 been reported since the publication by Rose et al. (1982) [15], the purpose of the
82 present paper was to describe the protocol developed by the authors in greater
83 detail. The authors believe that stall-side umbilical blood gas analysis may
84 become a useful method for assessing *in utero* oxygenation and acid-base status
85 in the equine neonate.
86
87 **2. Materials and Methods**
88 The study was approved by the University College Dublin Animal Research
89 Ethics committee, with informed written owner consent for all procedures. The
90 methodology and results from the study for which the following technique is
91 described can be found in further detail in the publication by Jeawon et al.
92 (2018) [14].
93
94 Thirty-five full-term gestation (>320 days old) foals were sampled in the study.
95 All mares were from the same stud farm, and managed under similar
96 circumstances. The mares foaled under constant supervision, which involved at
97 least 2 trained staff members attending every parturition. One author (SSJ)
98 attended all parturitions and took all umbilical cord blood samples. Whilst the
99 mare was in second stage labour, preparations were made to ensure efficient and
100 successful sampling and analysis (Figure 1). Two 1 ml pre-heparinised

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101 disposable blood gas syringes (RAPIDLyte, Cruinn medical Ltd, Dublin,
102 Ireland) were prepared; one with a 23g x 1" (blue) needle and one with a 21g x
103 1" (green) needle. The colour coding system was to allow ease of identification
104 of samples since the syringes were identical, with the green needle hub equating
105 to the arterial sample and the blue needle hub equating to the venous sample.
106 Foal identification details were entered into the blood gas analyser (Vetscan i-
107 Stat® 1, Abaxis UK Ltd, York, United Kingdom) as stage 2 parturition
108 commenced in order to expedite sample measurement. Sterile gloves
109 (GAMMEX® moisturising latex, Ansell Healthcare Europe, Brussels, Belgium)
110 were then put on in anticipation of umbilical cord blood sampling. Whilst not a
111 sterile procedure, the authors deemed it appropriate to maximise cleanliness
112 when handling the umbilical cord to help minimise risk of ascending umbilical
113 infection.
114
115 Once the foal was safely delivered, the time of foaling was noted. As soon as the
116 foal was expelled, the umbilical structures were identified via visual and manual
117 palpation (Figure 2). An incontinency pad (Laboratorios INDAS, Madrid, Spain)
118 was placed underneath the umbilical cord to keep it clean and aid visualisation
119 of the structures. The umbilical cord was not clamped for sampling, with the
120 arterial sample always obtained first from the largest umbilical artery (Figure 3).
121 The timing of each sample collection in relation to foetal expulsion was
122 recorded. Sampling was best achieved by positioning oneself beside the foal's
123 lumbar spine region, then leaning over the foal to hold the umbilical cord in the
124 non-dominant hand and using the dominant hand for sampling (Figure 3). Ease
125 of umbilical structure identification was aided by the fact that a) the vein was

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126 consistently the largest vessel and b) the largest artery usually had a palpable
127 pulse in it (Figure 2).
128
129 All umbilical cord blood samples were taken as close to the foal's body wall as
130 possible, approximately one hand's breath away from the body wall (Figure 3).
131 Using the 21g needle, a 1 ml umbilical arterial blood sample was collected into
132 the pre-heparinised blood gas syringe, followed by a 1 ml umbilical venous
133 blood sample obtained into a second pre-heparinised blood gas syringe using the
134 23g needle. Due to the small gauge needles being used to sample both vessels,
135 there was negligible bleeding from the puncture sites noted. Each foal then had
136 an Apgar score assigned and a rectal temperature taken to temperature-correct
137 the samples for blood gas analyses, which were performed without delay.
138
139 The portable Vetscan i-Stat® 1 machine was used to analyse all samples using
140 the CG4+ cartridge (Abaxis UK Ltd, York, United Kingdom). This analyser has
141 previously shown to produce reliable, accurate and repeatable results as
142 compared to laboratory-grade machines for the measurement of equine blood
143 gas samples [16–20]. The parameters analysed included pH, PCO_2, PO_2, HCO_3,
144 TCO_2, SO_2%, base excess/deficit and lactate. All samples were analysed in
145 duplicate, with the arterial sample always measured first followed by the venous
146 sample. Both the machine and cartridges were kept at room temperature to
147 ensure the sensors would be calibrated at all times. As per the manufacturer's
148 guidelines, the well of the cartridge was filled to the line with the blood from the
149 pre-heparinised syringe. The well portal was closed and inserted into the
150 Vetscan i-Stat® 1 gas analyser. Each sample took 120 seconds to run.

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151

152 All foals had complete clinical examinations performed on days 1, 2, 3, 7, 14, 21
153 and 28 post-partum. This involved all vital parameters being assessed as well as
154 a systematic clinical evaluation of all body systems. Clinical notes were
155 documented on each animal after each examination. All foals also had a blood
156 sample taken between 10–14 hours after parturition for measurement of serum
157 IgG concentration.

158

159 **3. Results and Discussion**

160 Paired umbilical arterial and venous whole-blood samples were obtained in *n*=30
161 foals, umbilical artery samples alone obtained in *n*=3 foals and umbilical vein
162 samples alone obtained in *n*=2 foals. The average time from birth to the first
163 umbilical cord sample acquisition was 1.2±0.8 minutes, and the average time from
164 sampling to analysis was 5.0±2.3 minutes.

165

166 The location and timing of the umbilical cord blood samples were the same for all
167 foals in the present study with the protocol based on human publications supporting
168 the importance of considering these parameters [21,22]. A consistent increase in the
169 arterial pH and PCO_2 values and a decrease in the PO_2 values have been
170 demonstrated to occur in human neonates as blood moves from the area of placental
171 attachment of the umbilical cord distally to the foetal attachment of the cord [21]. It
172 is thus recommended that the umbilical cord blood sampling occur at a site as close
173 to the foetus as possible, as was done in the present study. Researchers have
174 identified that 60 minutes after birth umbilical cord blood gas measurements in
175 human neonates will have altered from their original state with PCO_2 and PO_2

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176 significantly decreasing and increasing, respectively, as compared to 5-minute post-
177 birth samples [22]. A 30-minute sampling window has thus been proposed as optimal
178 [23]. The sampling timings for both acquisition and analysis in this study were all
179 within this optimal time-frame.

180

181 The results obtained allowed RIs to be determined for umbilical arterial and
182 venous blood pH, PO_2, PCO_2, SO_2, HCO_3^-, base-excess, TCO_2 and lactate [14].
183 Umbilical arterial blood samples had lower pH (P<0.0001), PO_2 (P=0.002) and
184 SO_2 (P<0.0001) and higher PCO_2 (P<0.0001) and lactate (P<0.0001) than
185 venous samples [14]. These consistently measured differences between the
186 paired vessels along with the anatomical landmarks used to identify the different
187 vessels supports the authors' conclusions that arterial and venous samples had
188 been correctly and consistently obtained. The importance of obtaining paired
189 arterial and venous blood samples for analysis is emphasised in the human
190 medical literature, as the difference between the vessels' measured values can
191 indicate whether there was an acute or chronic insult [5]. A large arterio-venous
192 base-deficit difference has been demonstrated to indicate a more acute event,
193 whilst a small arterio-venous base-deficit difference has been shown to indicate
194 a more chronic problem; this is explained by the fact that it will take a
195 significantly longer time for the venous sample to reflect changes due to the
196 influence of the maternal circulation [5,24].

197

198 Umbilical arterial blood gas parameters for equine neonates were originally reported
199 by Rossdale (1968) [25]. Rose et al. (1982) then published additional results from this
200 work, reporting on 8 premature-induced and full-term-induced foals [15] with

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201 umbilical arterial pH values identified to be similar to those reported by Jeawon et al.
202 (2018) [14]. However, the umbilical arterial PO_2 values were higher and the PCO_2 and
203 base-excess values lower for the foals from the study by Rose et al. (1982) as
204 compared to the values reported by Jeawon et al. (2018) [14,15]. A likely reason for
205 these differences is variations in experimental design between the two studies. The
206 study reported by Rose et al. (1982) involved a much smaller sample population of
207 foals, all of which were born after an induced parturition using fluprostenol [15].
208 Furthermore, there were differences in the timing of sampling as well as differences in
209 blood gas analysers used. Rose et al. (1982) also used a catheter to obtain umbilical
210 arterial samples from an unknown umbilical cord location and did not acquire paired
211 umbilical venous samples [15], all in contrast to the work of Jeawon et al. (2018) [14].
212
213 An understanding of normal foetal circulation is key to being able to understand
214 the theory behind umbilical cord blood sampling. Furthermore, anatomical
215 knowledge of the umbilical cord structures is vital for correctly performing the
216 sampling technique as described in the present study. McGeady et al. (2017)
217 [26] comprehensively outlined the intricacies of the foetal circulatory system in
218 some of the common domestic species (Figure 4). During embryonic
219 development the left and right umbilical veins initially convey blood from the
220 allantoic cavity, through the septum transversum and into the sinus venosus. As
221 the embryonic liver continues to grow, the veins become subdivided into cranial,
222 middle and caudal segments. The cranial segments atrophy with the middle
223 segments becoming incorporated into the hepatic vasculature to contribute to
224 hepatic sinusoid formation. The left and right umbilical veins later fuse, whereby

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225 the caudal segment of the right vein atrophies and the caudal segment of the left
226 vein enlarges accordingly (Figure 5).
227
228 In most domestic species within the foetal circulation, oxygenated blood from the
229 umbilical vein bypasses the liver via the *ductus venosus*; however, the full-term
230 equine foetus does not have a *ductus venosus* with the umbilical venous blood passing
231 through the foetal liver before emptying into the right atrium via the caudal *vena cava*
232 [27,28]. Pressure and oxygenation gradients redirect most blood in the right atrium
233 through the open *foramen ovale* into the left atrium, where it mixes with some blood
234 coming from the non-functional foetal lungs via the pulmonary veins, before leaving
235 the heart and entering the systemic circulation. Deoxygenated blood ultimately returns
236 from the aorta to the placenta via the paired umbilical arteries (Figure 6). Since the
237 umbilical vein carries oxygenated blood to the foetus and the two umbilical arteries
238 carry deoxygenated blood away from the foetus, the umbilical arterial blood solely
239 reflects the foetal acid-base and oxygenation status; in comparison, the umbilical
240 venous blood reflects the foetal acid-base and oxygenation status that has been
241 influenced by the maternal acid-base status [5,29].
242
243 The umbilical cord blood sampling technique detailed in this study became more
244 refined as the sampling progressed, with the author taking the samples becoming
245 increasingly more efficient at accurately identifying the individual vessels.
246 Failure to obtain a paired arterial and venous sample in a foal was either due to
247 the mare standing prematurely and rupturing the umbilical cord before the
248 venous sample could be taken or due to the mare lying awkwardly against the
249 wall as she foaled, preventing adequate access to the umbilical artery. Having

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250 the mare's hindquarters well away from the wall allowed better access to the
251 umbilicus once the foal had been delivered, making the sampling procedure
252 easier to perform. The author found it easy to obtain the required amount of
253 blood from each vessel for analysis.
254
255 The importance of calm, professional foaling practices was emphasised during
256 the sampling process. Experienced staff helped to keep the mare calm and
257 minimally stressed after the foal was born, ensuring the mare did not stand
258 prematurely, inadvertently breaking the umbilical cord. Whilst it is normal
259 practice in human obstetrics for the umbilical cord to be clamped after birth, the
260 authors decided against this approach prior to sampling for two reasons. Firstly,
261 it was noticed that the application of clamps to the cord was more time
262 consuming than just taking the samples directly, given the often-awkward
263 positioning of the umbilical cord between the mare's hind quarters/back legs and
264 the foal itself. Secondly, as the amount of blood passed from the placenta to the
265 foal through the umbilical cord in the minutes after birth may be as high as 30%
266 of the total blood volume [26] the authors did not want to hinder this from
267 occurring. Whilst the authors are not aware of any specific studies in the
268 veterinary literature, the benefits of increased blood volume from placental
269 transfer on neonatal health has been reported widely in for humans with the
270 primary positive benefits related to increased total blood volume and reduced
271 incidence of neonatal anaemia and iron deficiency [30,31]. Furthermore, delayed
272 cord clamping in human neonates (performed approximately 2 minutes after
273 birth) has not been shown to significantly change the blood gas findings when

274 compared with clamping at 10 seconds after birth [32]. This supports the
275 sampling protocol described in the present study.
276
277 Complete clinical examinations performed by one of two authors (SSJ or NPG) over
278 the first month for each of the foals in the present study revealed no adverse events
279 or clinical consequences of the umbilical cord blood sampling for any of the foals.
280 Clinical exams were within normal limits at all time-points, with all foals exhibiting
281 normal immediate post-foaling behaviour including the ability to stand, nurse and
282 pass meconium and urine. All foals had a serum IgG of >800mg/dl, with none of the
283 foals developing umbilical haemorrhage in the immediate post-parturient period nor
284 omphalophlebitis over the follow-up time-frame.
285
286 **4: Conclusion**
287 The described protocol for obtaining umbilical cord blood samples from foals in
288 a field-setting was shown to be an effective and simple technique, with minimal
289 disruption to the foaling environment. Umbilical cord blood sampling of
290 neonatal foals is a practical technique that can be employed in the field.
291
292 **Acknowledgements:**
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294 collaborating on this project, in particular Gretta Clarke, Meaghan Hegarty and
295 Gillian Murray who greatly facilitated ease of sample collection. The authors
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297 for publication.
298
ACCEPTED MANUSCRIPT

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299 **References:**

300 [1] Apgar, V. A proposal for a new method of evaluation of the newborn infant.
301 Curr Res Anesth Analg 1953;32(4):260–267.
302 [2] Casey BM, McIntire DD, Leveno KJ. The continuing value of the Apgar score for
303 the assessment of newborn infants. N Engl J Med 2001;344:467–471.
304 [3] Dudenhausen JW, Luhr C, Dimer JS. Umbilical cord blood gases in healthy term
305 newborn infants. Int J Gynecol Obstet 1997;57:251–258.
306 [4] Armstrong L, Stenson BJ. Use of umbilical cord blood gas analysis in the
307 assessment of the newborn. Arch Dis Child Fetal Neonatal Ed. 2007;92(6):F430-
308 F434.
309 [5] Blickstein I, Green T. Umbilical cord blood gas. Clin Perinatol 2007;34:451–459.
310 [6] Azzopardi D, Brocklehurst P, Halliday H, Levene M, Thoresen M, Whitelaw A.
311 The TOBY study. Whole body hypothermia for the treatment of perinatal asphyxial
312 encephalopathy: a randomised controlled trial. BMC Pediatrics 2008;8(1):17.
313 [7] Hobson A, Baines J, Weiss, MD. Beyond hypothermia: alternative therapies for
314 hypoxic-ischemic encephalopathy. Open Pharmacol J. 2013;7:26–40.
315 [8] Dingle J, Tooley J, Liu X, Schull-Brown E, Elstad M, Chakkarapani E, Sabir H,
316 Thoresen M. Xenon ventilation during therapeutic hypothermia in neonatal
317 encephalopathy: a feasibility study. Pediatrics 2014;133(5):809–818.
318 [9] van Schie PE, Schijns J, Becher JG, Barkho F, van Weissenbruch MM,
319 Vermeulen RJ. Long-term motor and behavioral outcome after perinatal hypoxic-
320 ischemic encephalopathy. Eur J Paediatr Neurol 2015;19(3):354–359.
321 [10] Pappas A, Korzeniewski SJ. Long-term cognitive outcome of birth asphyxia and
322 the contribution of identified perinatal asphyxia to cerebral palsy. Clin Perinatol
323 2016;43(3):559–572.

ACCEPTED MANUSCRIPT

324 [11] Adhikari S, Rao KS. Neurodevelopmental outcome of term infants with perinatal
325 asphyxia with hypoxic ischemic encephalopathy stage II. Brain Dev. 2017;39(2):107–
326 111.
327 [12] Galvin N, Collins D. Perinatal asphyxia syndrome in the foal: review and case
328 report. Ir Vet J 2004;57(12): 707–714.
329 [13] Gold, JR. Perinatal asphyxia syndrome. Equine Vet Educ. 2015;29(3):158–164.
330 [14] Jeawon SS, Katz LM, Galvin NP, Fogarty UM, Duggan VE. Determination of
331 reference intervals for umbilical cord blood gas analysis in healthy thoroughbred
332 foals. Theriogenology 2018;118:1–6.
333 [15] Rose RJ, Rossdale PD, Leadon DP. Blood gas and acid-base status in
334 spontaneously delivered, term-induced and induced premature foals. J Reprod Fertil
335 Suppl 1982;32:521─528.
336 [16] Grosenbaugh DA, Gadawski JE, Muir WW. Evaluation of a portable clinical
337 analyser in a veterinary hospital setting. J Am Vet Med Assoc 1998;213:691─694.
338 [17] Looney AL, Ludders J, Erb HN, Gleed R, Moon P. Use of a handheld device for
339 analysis of blood electrolyte concentrations and blood gas partial pressures in dogs
340 and horses. J Am Vet Med Assoc 1998;213:526─530.
341 [18] Silverman SC, Birks EK. Evaluation of i-STAT hand-held chemical analyser
342 during treadmill and endurance exercise. Equine Vet J Suppl 2002;34:551─554.
343 [19] Saulez MN, Cebra CK, Dailey M. Comparative biochemical analyses of venous
344 blood and peritoneal fluid from horses with colic using a portable analyser and an in-
345 house analyser. Vet Rec 2005;157:217─223.
346 [20] Bardell D, West E, Senior JM. Evaluation of a new handheld point-of-care blood
347 gas analyser using 100 equine blood samples. Vet Anaesth Analg 2017;44:77─85.
348 [21] Perlman S, Goldman RD, Maatuk H, Ron E, Shinwell E, Blickstein I. Is the

ACCEPTED MANUSCRIPT

349 sampling site along the umbilical artery significant? Gynecol Obstet Invest
350 2002;54:172─175.
351 [22] Valenzuela P, Guijarro R. The effects of time on pH and gas values in the blood
352 contained in the umbilical cord. Acta Obstet Gynecol Scand 2006;85:1307─1309.
353 [23] Lynn A, Beeby P. Cord and placenta arterial blood gas analysis: the accuracy of
354 delayed sampling. Arch Dis Child Fetal Neonatal Ed 2007;92:F281─F285.
355 [24] Ross MG, Gala R. Use of umbilical artery base excess: algorithm for the timing
356 of hypoxic injury. Am J Obstet Gynecol 2002;187(1):1─9.[20]
357 [25] Rossdale P. Blood Gas Tensions and pH Values in the Normal Thoroughbred
358 Foal at Birth and in the following 42h. Biol Neonat 1968; 13: 18-25
359 [26] McGeady TA, Quinn PJ, Fitzpatrick ES, Ryan MT, Kilroy D, Lonergan P 2017.
360 Cardiovascular System. In: *Veterinary Embryology*. 2nd edn. West Sussex: John Wiley
361 and Sons; 138–139.
362 [27] Comline RS, Silver M. A comparative study of blood as tensions, oxygen affinity
363 and red cell 2,3 DPG concentrations in foetal and maternal blood in the mare, cow
364 and sow. J Physiol 1974;242:805–826.
365 [28] Tchirikov M, Schröder, Hecher K. Ductus venous shunting in the venous
366 circulation: regulatory mechanisms, diagnostic methods and medical importance.
367 Ultrasound Obstet Gynecol 2006;27:452–461.
368 [29] Belai Y, Goodwin TM, Durand M, Greenspoon JS, Paul RH, Walther FJ.
369 Umbilical arteriovenous PO_2 and PCO_2 differences and neonatal morbidity in term
370 infants with severe acidosis. Am J Obstet Gynecol 1998;178(Pt. 1):13─19.
371 [30] Van Rheenen P, Brabin BJ. Late Umbilical cord-clamping as an intervention for
372 reducing iron deficiency anaemia in term infants in developing and industrialised
373 countries: a systematic review. Ann Trop Paediatr 2004;24:3–16.

ACCEPTED MANUSCRIPT

374 [31] Hutton EK, Hassan ES. Late vs Early Clamping of the Umbilical Cord in Full
375 term Neonates. JAMA 2007;297(11):1163–1278.
376 [32] De Paco C, Florido J, Garrido MC, Prados S, Navarette L. Umbilical cord blood
377 acid-base and gas analysis after early versus delayed cord clamping in neonates at
378 term. Arch Gynecol Obstet 2011;283:1011─1014.

379

380 Figure Legends

381

382 Figure 1: Image of the sampling equipment used (clockwise from top left): Vetscan
383 iStat® 1 machine, CG4+ sampling cartridge, incontinency pad, colour-coded blood
384 gas syringes, sterile gloves.

385

386 Figure 2: Image of the umbilical cord structures prior to sampling. a = umbilical vein;
387 b = smaller umbilical artery; c = larger umbilical artery.

388

389 Figure 3: Image of the umbilical cord blood sampling procedure being performed. a =
390 umbilical vein; b = smaller umbilical artery; c = larger umbilical artery.

391

392 Figure 4: Diagram of equine foetal circulation. Arrows indicate direction of blood
393 flow.

394

395 Figure 5: Close-up of the gross image of the fusion of the left and right umbilical
396 veins (*). a = left umbilical vein; b= right umbilical vein.

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398 Figure 6: Schematic of the umbilical cord vessels running between the placenta and

399 foal. Arrows indicate the direction of blood flow.

400

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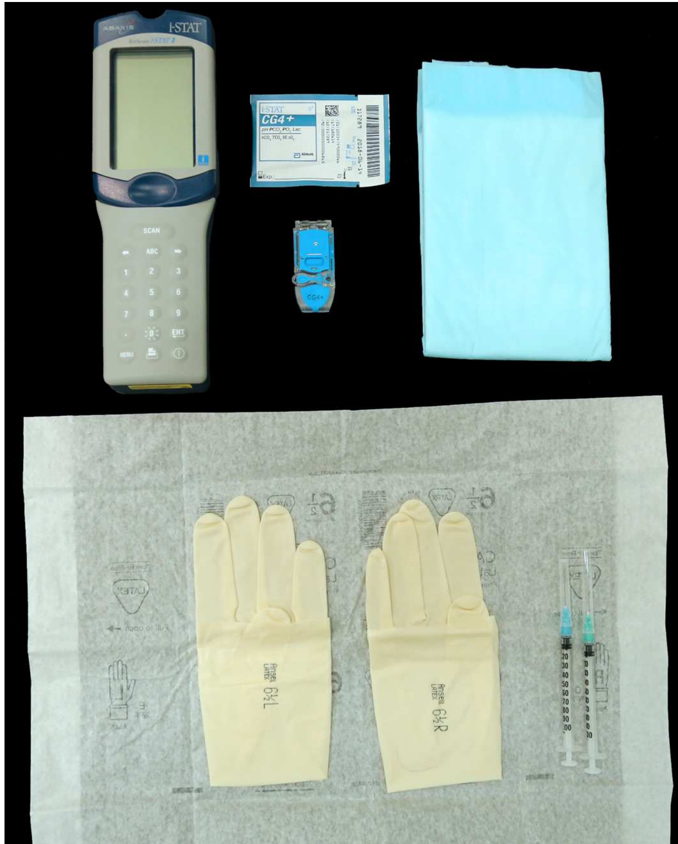

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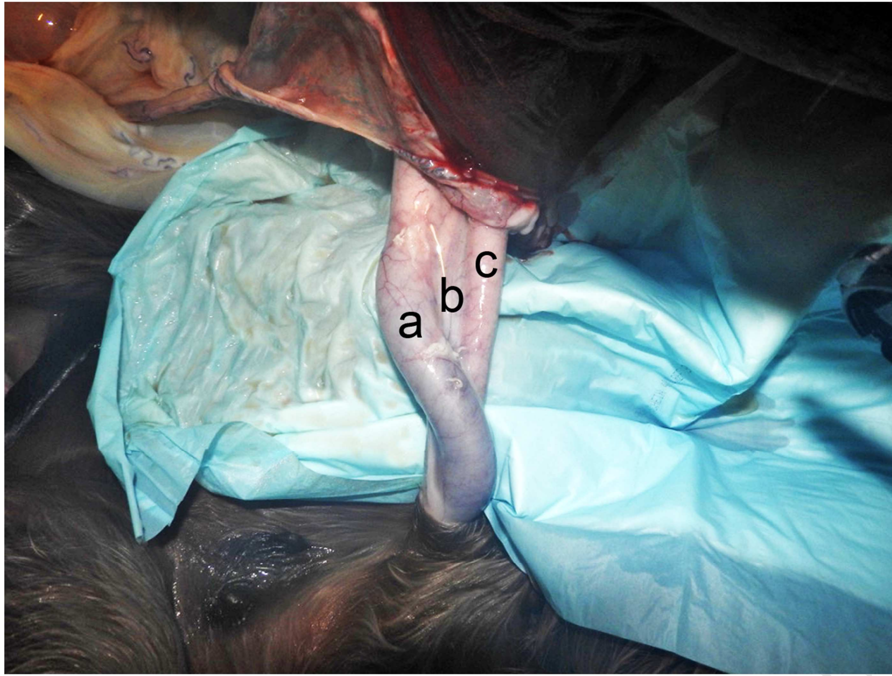

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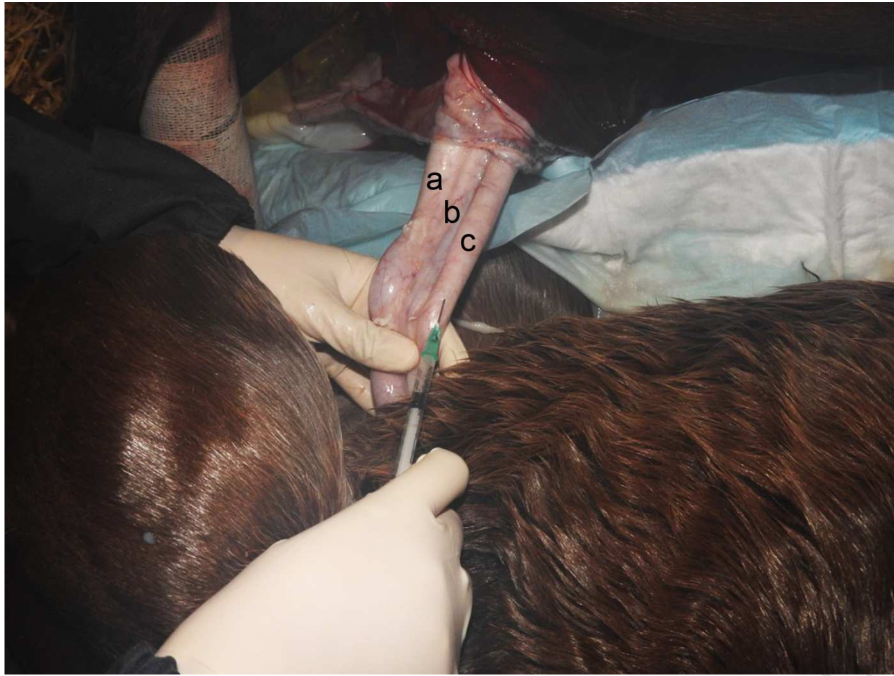

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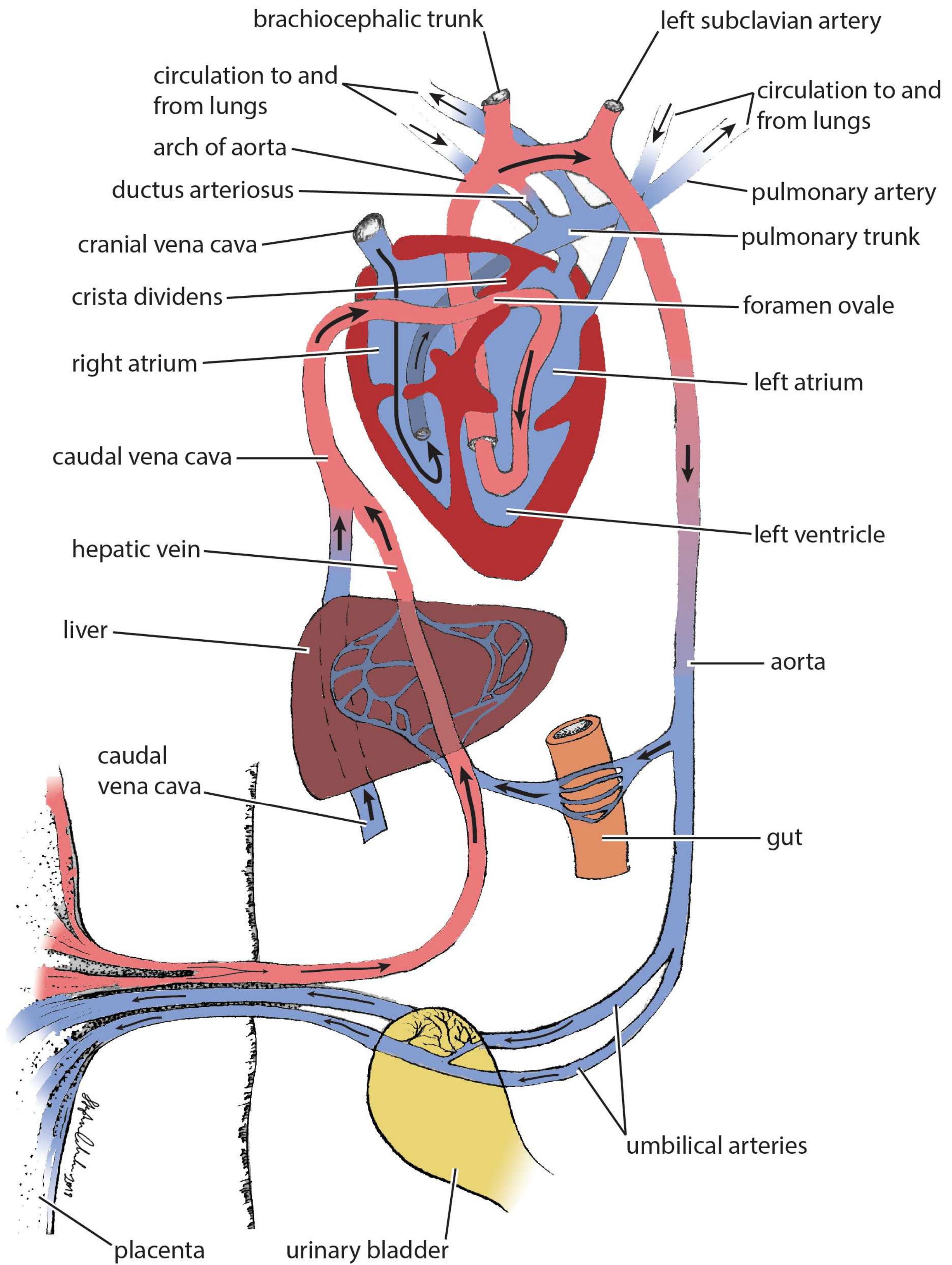
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left subclavian artery
circulation to and from lungs
circulation to and from lungs
arch of aorta
ductus arteriosus
pulmonary artery
pulmonary trunk
cranial vena cava
crista dividens
foramen ovale
right atrium
left atrium
caudal vena cava
left ventricle
hepatic vein
liver
aorta
caudal vena cava
gut
umbilical arteries
placenta
urinary bladder

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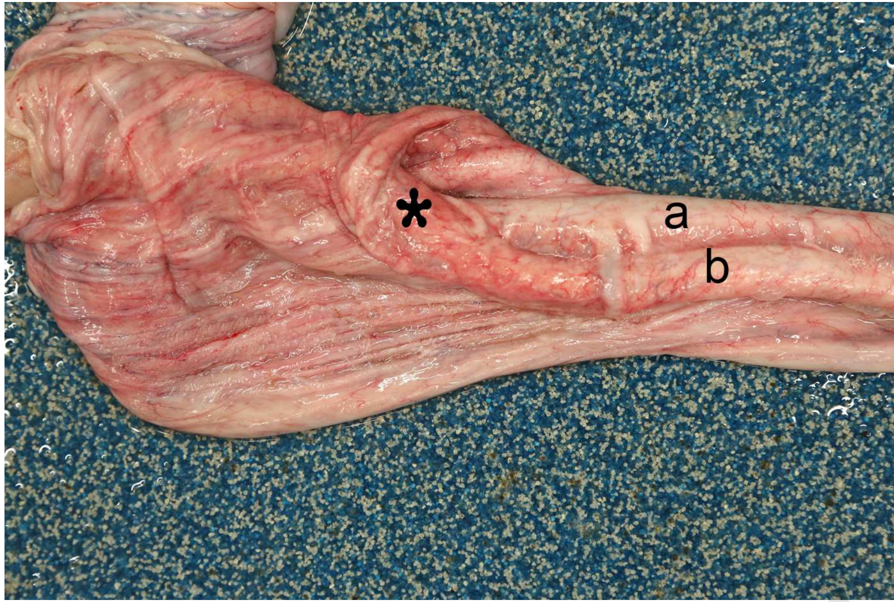

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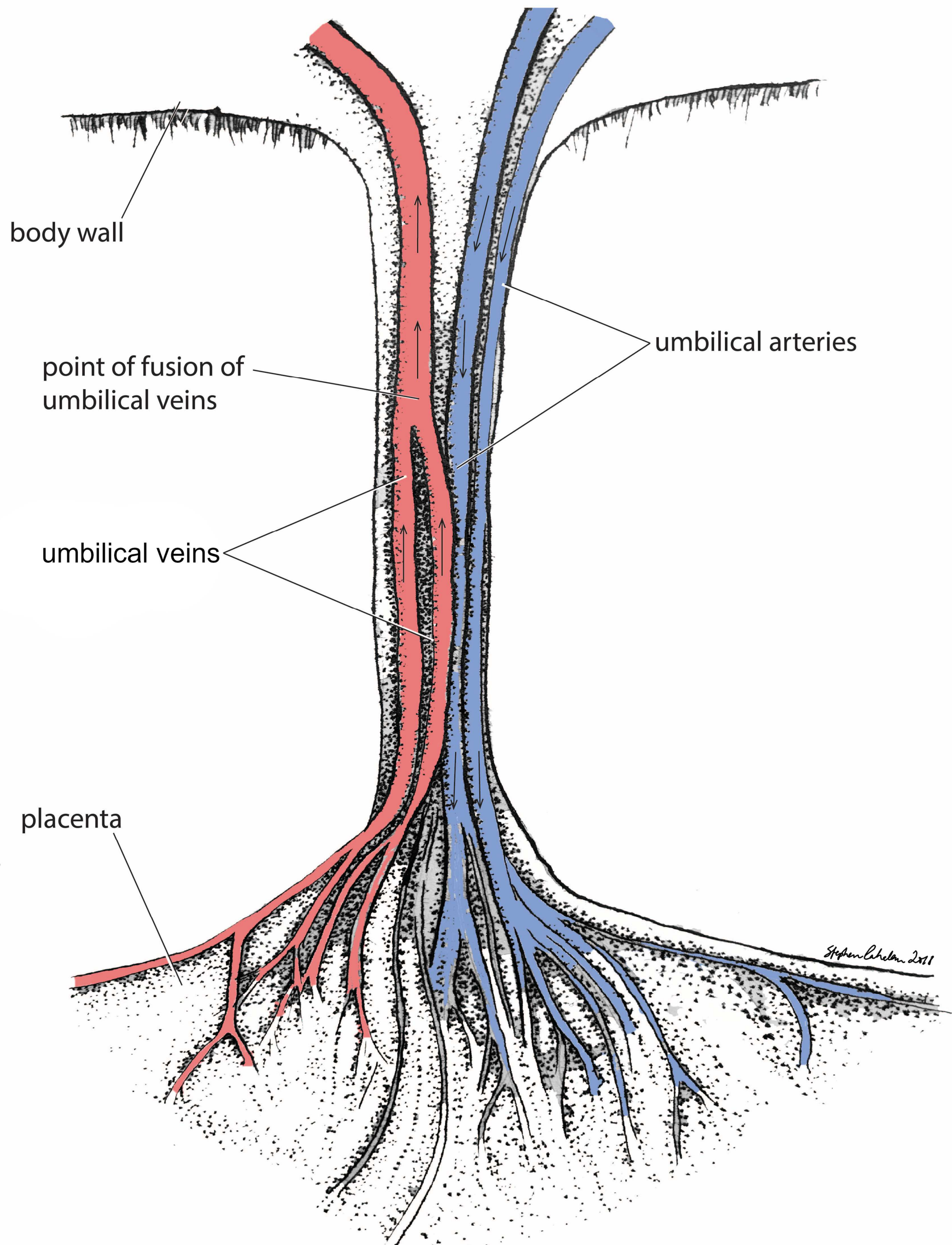
body wall
umbilical arteries
point of fusion of
umbilical veins
umbilical veins
placenta
Stephen Whelan 2018

ACCEPTED MANUSCRIPT

Ethical Statement

University College Dublin's Animal Research and Ethics Committee approved this study. Owner consent was also granted.

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Conflict of Interest Statement

The authors declare no conflict of interest associated with this paper.

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