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Title: Hematological and blood biochemical characteristics of newborn heavy draft foals after dystocia

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Abstract

The negative impact of equine dystocia on hematological and serum biochemical profile of neonatal foals remains unknown, particularly in heavy draft horses that show high incidence of dystocia. This study aimed to reveal the hematological and serum biochemical profile of the foals born in normal delivery and examine the effect of dystocia on blood properties in heavy draft newborn foals. In the normal birth group (n = 23), stage II labor was <30 min, with spontaneous or assisted delivery with mild traction by one or two people. In the dystocia group (n = 13), stage II labor was ≥30 min, with strong traction by more than three people or mechanical tools with or without correcting fetal displacement. Blood samples were collected from the jugular vein at 0, 1, and 12 hr and 1 and 2 days after foaling. Red blood cells, hemoglobin concentration, and packed cell volume remained significantly lower in the dystocia group than in the normal birth group. The white blood cell count was significantly higher in dystocia foals (1 day: $P < .05$). Dystocia foals had significantly higher cortisol (1 hr: $P < .05$), urea nitrogen (1 hr: $P < .05$), and creatine kinase activities (1 hr: $P < .01$, 12 hr: $P < .05$). This study revealed that dystocia foals were more likely to be affected by anemia, physical stress, and muscle damage than normal birth foals.

Key Words: dystocia, foal, anemia, stress, muscle damage

1. Introduction

Dystocia is a difficult labor that can result in neonatal death without assistance by humans [1]. The incidence rate of dystocia has been found to be 4%–10% in horses, and dystocia occurs more frequently in heavy draft horses than in light breed horses [2]. Most dystocia cases are caused by fetal displacement [3]. Parturition is divided into three stages: the first stage of parturition is associated with cervical dilation and uterine contractions, the second stage includes the time from the rupture of the chorioallantoic membrane to the end of fetal delivery, and the third stage is associated with discharge of the placental and fetal membranes [4]. The progression of equine parturition occurs more rapidly than that in other farm animals. Stage II lasts for only 20–30 min in mares [5]. A recent study reported that prolonged labor (Stage II ≥ 30 min) is associated with a higher risk of stillbirth [6]. In other studies, the morbidity and mortality in dystocia foals have been found to be higher than those in normal birth foals [7–8]. The cortisol concentration in saliva [9] and blood [10] has been reported to be higher in dystocia calves, leading to metabolic changes such as increased blood glucose (Glu) and cholesterol levels [10]. The negative impact of equine dystocia on hematological and serum biochemical profile of neonatal foals remains unknown, particularly in heavy draft horses that show high incidence of dystocia. Understanding the effects of dystocia on neonatal foals would contribute to the development of nursing and treatment procedures. This study aimed to reveal the hematological and serum biochemical profile of foals born via normal delivery and examine the effect of dystocia on blood properties in heavy draft newborn foals.

2. Materials & Methods

2.1 Animals

Heavy draft foals (Percherons and crossbreeds between Percheron, Belgian, and Breton heavy draft horses) born from January 2013 to January 2015 at three stud farms (Tokachi, Hokkaido, Japan) were included in the study. Prepartum dams showing signs of foaling were monitored. Foaling events such as rupture of the chorioallantoic membrane, appearance of the fetal sac, and delivery of foals were recorded. Cases were excluded from the study if there was foaling in the absence of witnesses, abortion, premature birth, or cesarean section.

62

63 *2.2 Definition of normal birth and dystocia*

64 In our study, dystocia was defined as prolonged labor with strong fetal traction with or without fetal
65 displacement. If stage II was ≥30 min and the labor did not progress, traction was applied to the fetus. In the
66 normal birth group (n = 23), stage II labor was <30 min, with spontaneous or assisted delivery with mild
67 traction by one or two people. In the dystocia group (n = 13), stage II labor was ≥30 min, with strong traction
68 by more than three people or mechanical equipment with or without correcting fetal displacement.

69

70 *2.3 Physical examination and blood sampling*

71 Physical examination and blood sampling were conducted at 0 hr (within 5 min after birth), 1 hr (before
72 suckling colostrum), 12 hr, and 1 (24-48 hr) and 2 days (48-72 hr) after birth. The foal's vitality was
73 assessed immediately after birth using advanced APGAR score (seven items, each 2-point scale, a total of 0-
74 14 points) [11]. Rectal temperature, heart rate, respiratory rate and appearance of visible mucous membrane
75 were recorded. Peripheral blood was collected into 7 ml vacuum tubes (Venoject II VP-P070K, Terumo
76 Corp., Tokyo, Japan) and 5 ml vacuum tubes containing ethylenediaminetetraacetic acid (EDTA) (Venoject
77 II VP-NA050K, Terumo Corp.) by jugular venipuncture using 21 gauge × 1½ inch needles (MN-2138MS,
78 Terumo Corp.). All blood samples were stored on ice until transfer to the laboratory and processed within 3
79 hr. The samples containing EDTA were used for complete blood counts. Tubes without EDTA were
80 centrifuged for 12 min at 3,000 rpm after incubation (37°C, 90 min). Serum was withdrawn and frozen at −
81 30°C for serum amyloid A (SAA), cortisol, and other biochemical analyses at a later date.

82

83 *2.4 Hematological and serum biochemical analysis*

84 The numbers of white blood cells (WBCs) and red blood cells (RBCs), hemoglobin (Hb) concentration,
85 packed cell volume (PCV), mean cell volume (MCV), mean cell Hb (MCH), mean cell Hb concentration
86 (MCHC), and platelet count were determined using an automated hematology analyzer (Celltac alpha
87 MEK-6358, Nihon Kohden Corp., Tokyo, Japan). In each sample, the levels of Glu, free fatty acid (FFA),
88 total cholesterol, triglyceride (TG), total protein, albumin, urea nitrogen (UN), creatinine (Cre), aspartate

aminotransferase, gamma-glutamyltransferase, alkaline phosphatase, creatine kinase (CK), lactate dehydrogenase, iron, calcium, inorganic phosphate, magnesium, sodium, potassium, and chlorine were measured using an automated clinical chemistry analyzer (TBA-120FR, Toshiba Medical Systems Corp., Otawara, Japan). The SAA level was measured using commercially available enzyme-linked immunosorbent assay (ELISA) kits (Tridelta Phase Range Kit, Tridelta Development Ltd., Kildare, Ireland) according to the manufacturer's instructions. The serum cortisol level was assessed by chemiluminescence enzyme immunoassay in a commercial clinical laboratory (Obihiro clinical laboratory Inc., Obihiro, Japan).

2.5 Statistical analysis

The sequence of postnatal data was analyzed with repeated-measures analysis of variance (ANOVA). When significant differences or interactions between the two groups were observed, Student's or Welch's *t*-test were used to identify differences between the groups at each sampling period. Results with *P*-value $< .05$ were considered significant, and those with $P < .1$ were considered to have a tendency (marginal difference). These statistical analyses were conducted using Statcel3 (OMS Ltd, Saitama, Japan).

3. Results

There is a marginal difference ($P < .1$) in the APGAR score between the normal birth group (mean: 10.6, SD: 1.4, range: 8–13) and the dystocia group (mean: 9.4, SD: 2.3, range: 6–13). There were no significant differences in other physical examination findings between the two groups (Table 1). Significant differences or interactions between the two groups were observed for WBC and RBC counts; Hb concentration; PCV; and cortisol, UN, FFA, and CK levels by repeated-measures ANOVA. Significant differences were not observed for the other parameters (Tables 2 and 3). Significant differences between the two groups in each sampling period were examined using Student's or Welch's *t*-test, and the results are shown in Figures 1 and 2. The RBC count (0 hr: $P < .1$, 1 hr: $P < .05$, 12 hr: $P < .05$, 1 day: $P < .01$, 2 days: $P < .05$), Hb concentration (12 hr: $P < .1$, 1 day: $P < .05$, 2 days: $P < .05$), and PCV (12 hr: $P < .05$, 1 day: $P < .01$, 2 days: $P < .01$) remained at significantly lower levels in the dystocia group than in the normal birth group. Serum cortisol ($P < .05$), UN ($P < .05$), and CK ($P < .01$) levels at 1 hr; CK ($P < .05$) and FFA ($P < .1$) levels

at 12 hr; and the WBC count ($P < .05$) at 1 day were higher in dystocia foals than in foals in the normal birth group. Although, a foal in the dystocia group died after the first day of sampling (*n* for day 2 in the dystocia group = 12), the cause of death was unknown.

Table 1

Results of physical examinations of newborn heavy draft foals within 2 days after birth. Normal birth group (n = 23). Dystocia group (n = 13). Data are shown as mean (standard deviation). Statistical significance is denoted by ** ($P < .01$).

	Time after foaling					Repeated-measures ANOVA		
	0 hr	1 hr	12 hr	1 day	2 days	Time	Group	Interaction
Rectal temperature (°C)								
Normal	37.7 (0.7)	38.2 (0.5)	38.4 (0.3)	38.6 (0.2)	38.7 (0.2)	NS	NS	NS
Dystocia	38.0 (0.6)	38.1 (0.4)	38.5 (0.5)	38.7 (0.4)	38.8 (0.2)			
Heart rate (/min)								
Normal	86.0 (21.9)	98.8 (28.7)	105.4 (36.5)	92.0 (28.5)	98.4 (23.5)	**	NS	NS
Dystocia	78.7 (36.9)	116.1 (42.1)	118.0 (27.4)	99.4 (29.0)	98.0 (22.7)			
Respiratory rate (/min)								
Normal	75.2 (13.9)	56.0 (13.9)	67.1 (23.9)	67.7 (23.5)	67.2 (20.1)	**	NS	NS
Dystocia	72.1 (28.7)	50.2 (17.1)	58.2 (17.7)	62.8 (27.6)	53.3 (22.2)			

Table 2

Results of hematological analysis in newborn heavy draft foals within 2 days after birth. Normal birth group (n = 23). Dystocia group (n = 13). Data are shown as mean (standard deviation). Statistical significance is denoted by * ($P < .05$) or ** ($P < .01$).

	Time after foaling					Repeated-measures ANOVA		
	0 hr	1 hr	12 hr	1 day	2 days	Time	Group	Interaction
White blood cells ($10^2/\mu L$)								
Normal	74.0 (11.7)	64.2 (12.1)	82.1 (17.9)	57.5 (26.1)	60.9 (19.1)	NS	NS	*
Dystocia	72.8 (19.6)	60.9 (15.0)	89.2 (25.3)	79.4 (25.5)	69.8 (18.5)			
Red blood cells ($10^4/\mu L$)								
Normal	1129.7 (92.0)	1131.8 (87.8)	1093.6 (115.4)	1036.9 (108.9)	994.9 (107.2)	*	*	*
Dystocia	1071.2 (95.0)	1049.3 (89.5)	989.8 (105.1)	925.3 (84.2)	891.3 (102.4)			
Hemoglobin concentration (g/dL)								
Normal	14.9 (1.0)	15.3 (1.1)	14.5 (1.2)	13.8 (1.3)	13.4 (1.1)	NS	*	*
Dystocia	14.8 (0.9)	14.7 (1.0)	13.8 (1.3)	12.8 (1.1)	12.3 (1.2)			
Packed cell volume (%)								
Normal	49.5 (3.3)	49.7 (3.7)	47.3 (3.3)	44.6 (3.8)	42.3 (3.4)	*	**	NS
Dystocia	48.5 (3.1)	47.6 (3.0)	44.0 (3.9)	40.7 (3.1)	38.6 (4.0)			
Mean cell volume (fL)								
Normal	43.9 (2.5)	45.3 (8.1)	43.4 (2.5)	43.2 (2.6)	42.8 (3.4)	*	NS	NS
Dystocia	45.5 (2.7)	45.1 (2.6)	44.6 (2.7)	44.0 (2.7)	43.5 (2.9)			
Mean cell hemoglobin (pg)								
Normal	13.2 (0.9)	13.9 (2.4)	13.3 (0.9)	13.4 (1.0)	13.5 (1.2)	NS	NS	NS
Dystocia	13.9 (1.1)	14.1 (1.1)	13.9 (0.8)	13.9 (1.0)	13.8 (1.0)			
Mean cell hemoglobin concentration (g/dL)								
Normal	30.1 (1.3)	32.2 (6.4)	30.8 (1.4)	31.1 (1.2)	31.6 (1.3)	*	NS	*
Dystocia	30.5 (1.1)	31.2 (1.4)	29.1 (7.7)	31.5 (1.3)	31.8 (1.4)			
Platelet count ($10^4/\mu L$)								
Normal	35.1 (9.8)	36.9 (10.4)	32.1 (13.1)	29.2 (12.4)	31.6 (13.9)	NS	NS	NS
Dystocia	31.2 (6.6)	33.4 (5.2)	29.9 (6.6)	29.3 (4.8)	29.3 (6.2)			

Table 3

Results of serum biochemical analysis in newborn heavy draft foals within 2 days after birth. Normal birth group (n = 23). Dystocia group (n = 13). Data is shown as mean (standard deviation). Statistical significance is denoted by * ($P < .05$) or ** ($P < .01$).

	Time after foaling					Repeated-measures ANOVA		
	0 hr	1 hr	12 hr	1 day	2 days	Time	Group	Interaction
Cortisol (μg/dL)								
Normal	8.1 (0.8)	11.2 (2.1)	2.6 (1.5)	2.4 (2.2)	1.2 (0.5)	NS	NS	*
Dystocia	8.5 (2.2)	13.7 (4.5)	4.4 (3.8)	2.1 (0.7)	1.3 (0.5)			
Serum amyloid A (μg/ml)								
Normal	3.8 (12.0)	6.0 (22.7)	44.2 (57.7)	224.2 (215.1)	232.4 (585.6)	NS	NS	NS
Dystocia	1.0 (0.1)	1.0 (0.0)	67.0 (76.7)	216.4 (176.2)	200.9 (242.6)			
Glucose (mg/dL)								
Normal	72.0 (12.7)	61.0 (22.7)	136.9 (24.2)	130.3 (18.2)	134.1 (24.4)	*	NS	NS
Dystocia	86.5 (21.5)	74.7 (29.5)	122.0 (55.8)	127.6 (25.5)	134.5 (20.3)			
Free fattey acids (μEq/L)								
Normal	142.8 (28.1)	586.7 (173.3)	439.8 (168.8)	298.1 (106.8)	302.0 (117.5)	*	NS	**
Dystocia	154.3 (31.1)	584.6 (212.8)	667.8 (433.1)	451.5 (419.2)	293.3 (108.0)			
Total cholesterol (mg/dL)								
Normal	132.6 (28.0)	150.0 (37.3)	179.9 (51.8)	212.4 (57.9)	198.4 (59.3)	*	NS	NS
Dystocia	149.7 (42.7)	163.9 (49.1)	188.9 (50.9)	209.8 (60.4)	192.1 (33.6)			
Triglyceride (mg/dL)								
Normal	8.1 (2.8)	8.7 (15.8)	11.6 (5.7)	40.5 (23.0)	78.3 (41.3)	*	NS	NS
Dystocia	10.4 (3.9)	5.8 (2.8)	15.9 (11.0)	81.5 (146.2)	62.0 (27.8)			
Total protein (g/dL)								
Normal	4.0 (0.3)	4.2 (0.5)	5.3 (1.1)	5.5 (0.9)	5.4 (1.0)	*	NS	NS
Dystocia	4.1 (0.7)	4.1 (0.7)	5.0 (0.9)	5.1 (0.8)	5.1 (0.8)			
Albumin (g/dL)								
Normal	3.2 (0.2)	3.3 (0.4)	3.0 (0.4)	3.0 (0.3)	3.0 (0.3)	*	NS	NS
Dystocia	3.2 (0.6)	3.3 (0.6)	3.1 (0.5)	2.9 (0.4)	2.9 (0.4)			
Urea nitrogen (mg/dL)								
Normal	18.3 (5.3)	17.9 (5.4)	20.9 (4.6)	13.9 (2.9)	13.2 (4.8)	*	NS	**
Dystocia	18.1 (6.4)	18.5 (6.0)	24.3 (6.4)	21.2 (11.6)	14.4 (4.8)			
Creatinine (mg/dL)								
Normal	2.1 (0.5)	1.9 (0.5)	1.6 (0.5)	1.1 (0.3)	1.0 (0.2)	*	NS	NS
Dystocia	2.1 (0.5)	2.1 (0.5)	1.8 (0.6)	1.2 (0.4)	1.0 (0.1)			
Aspartate aminotransferase (IU/L)								
Normal	76.0 (26.7)	84.0 (26.4)	158.3 (54.0)	177.2 (35.9)	200.5 (91.3)	*	NS	NS
Dystocia	73.5 (15.1)	81.3 (20.7)	151.9 (34.7)	182.8 (47.2)	188.8 (35.5)			

Table 3

Results of serum biochemical analysis in newborn heavy draft foals within 2 days after birth. Normal birth group (n = 23). Dystocia group (n = 13). Data is shown as mean (standard deviation). Statistical significance is denoted by * ($P < .05$) or ** ($P < .01$).

	Time after foaling					Repeated-measures ANOVA		
	0 hr	1 hr	12 hr	1 day	2 days	Time	Group	Interaction
Gamma-glutamyltransferase (IU/L)								
Normal	22.8 (8.5)	25.3 (7.4)	38.1 (14.0)	33.2 (11.2)	44.1 (37.9)	*	NS	NS
Dystocia	20.6 (6.1)	21.6 (6.2)	35.9 (13.9)	31.8 (7.7)	33.7 (12.0)			
Alkaline phosphatase (IU/L)								
Normal	11311.0 (5158.8)	11902.6 (6048.0)	10351.6 (5590.1)	8994.6 (4430.4)	6477.7 (3161.1)	*	NS	NS
Dystocia	12582.7 (7574.4)	13212.5 (7884.0)	12300.0 (6899.9)	9990.0 (5308.8)	7470.0 (4279.7)			
Lactate dehydrogenase (IU/L)								
Normal	346.8 (83.5)	459.4 (111.2)	676.3 (157.2)	635.4 (105.3)	611.4 (156.1)	*	NS	NS
Dystocia	311.2 (66.6)	436.9 (79.3)	715.3 (214.9)	602.9 (95.7)	552.9 (118.7)			
Creatine kinase (IU/L)								
Normal	109.3 (58.1)	257.0 (129.7)	315.0 (249.4)	248.4 (218.6)	176.1 (126.3)	*	NS	**
Dystocia	119.9 (52.5)	386.5 (122.3)	510.2 (352.4)	319.8 (263.0)	152.2 (61.3)			
Calcium (mg/dL)								
Normal	13.0 (0.7)	11.7 (1.1)	11.8 (1.1)	11.4 (0.9)	11.9 (1.2)	*	NS	*
Dystocia	13.6 (2.1)	11.9 (1.7)	11.5 (1.5)	10.8 (1.0)	11.4 (1.4)			
Inorganic phosphate (mg/dL)								
Normal	4.9 (0.7)	4.0 (0.7)	4.2 (1.0)	5.0 (0.9)	5.7 (1.0)	*	NS	NS
Dystocia	5.4 (1.2)	4.1 (1.0)	4.4 (0.8)	4.7 (1.0)	5.2 (0.8)			
Magnesium (mg/dL)								
Normal	1.7 (0.1)	1.6 (0.2)	2.1 (0.4)	2.0 (0.3)	1.9 (0.2)	*	NS	NS
Dystocia	1.8 (0.3)	1.7 (0.3)	2.1 (0.4)	2.0 (0.3)	1.9 (0.3)			
Iron (μg/dL)								
Normal	469.4 (58.3)	463.2 (83.8)	338.0 (98.0)	192.3 (85.9)	108.0 (59.1)	*	NS	**
Dystocia	466.7 (81.1)	468.3 (84.1)	354.8 (69.7)	222.2 (83.8)	112.2 (52.9)			
Sodium (mEq/L)								
Normal	135.7 (29.2)	140.7 (7.3)	138.0 (8.3)	136.3 (6.9)	137.4 (9.0)	NS	NS	NS
Dystocia	137.0 (15.5)	137.3 (13.0)	134.7 (13.6)	134.0 (9.8)	133.5 (9.5)			
Potassium (mEq/L)								
Normal	4.8(1.1)	4.6 (0.4)	4.3 (0.4)	4.7 (0.3)	4.6 (0.4)	NS	NS	NS
Dystocia	4.9(0.5)	4.3 (0.5)	4.0 (0.5)	4.3 (0.5)	4.3 (0.3)			
Chlorine (mEq/L)								
Normal	95.1(20.3)	98.8 (5.0)	98.4 (5.7)	97.9 (5.1)	97.2 (5.9)	NS	NS	NS
Dystocia	95.5(10.3)	95.4 (8.5)	94.5 (9.2)	95.6 (6.6)	94.5 (6.6)			

4. Discussion

In the present study, we focused on heavy draft horses that have a higher incidence of dystocia and examined the hematological and serum biochemical features of foals born after dystocia. Statistically significant differences in some parameters were observed between the dystocia and normal birth group. Some parameters of both groups changed with time during the experimental period. Because we obtained the samples of 0 and 1 hr at night and the samples of 12 hr and 1 and 2 days during daytime in most cases, we should take the circadian rhythm into consideration when discussing the change in blood profile with time. Furthermore, we should also consider the influence by the dam because blood properties [12–13] and milk components [14–15] of the dam dramatically change in peripartum period.

The APGAR scoring system is a useful tool for grading the health status of foals immediately after birth [11]. A previous study found that APGAR score negatively correlates with plasma stress hormones such as ACTH and cortisol in healthy and ill foals [16]. There was only a marginal (not significant) difference in APGAR score and no significant difference in other physical findings between the groups in this study. This may be because most dystocia cases examined in this study were moderate, and the mortality rate of foals was very low (only one case). We should reconsider these results after more severe cases of dystocia are examined in future studies.

The RBC count, Hb level, and PCV were significantly lower in foals in the dystocia group than in those in the normal birth group. The cause of relative anemia in the dystocia group was suspected to be blood loss because there were no significant differences in MCV and MCHC between the two groups [17]. The cause of blood loss may have been continuous hemorrhage from the umbilical artery after premature rupture of the umbilical cord. However, we did not observe hemorrhage from the umbilicus during the study period. A recent study reported that lower red blood cell count is associated with increased risk of infectious diseases in the first 30 days in neonatal foals [18]. However, a relationship between low red blood cell counts and dystocia has not been revealed. Although we revealed that the RBC count was lower in dystocia foals, additional studies about the causes and outcomes of anemia are needed.

In general, infectious disease or physical stress causes increases in WBC counts in the peripheral blood [19–20]. The blood level of SAA, a major acute-phase protein, increases when there is inflammation caused

by an infectious disease. SAA is often measured in equine medical practice and quickly responds to infectious disease and inflammation [21–24]. Blood SAA levels rapidly increased within 1 day after birth in the normal birth group in the present study (Table 3). A similar result has been reported in a previous study [25]. There was no significant difference between normal birth foals and dystocia foals, suggesting that foaling difficulty would not affect blood SAA levels. Higher cortisol levels may have increased WBC counts of the dystocia group 1 day after birth. Neutrophilia is induced by the anti-inflammatory action of cortisol, but the migration of neutrophils to a specific site is suppressed [20]. More studies that investigate whether foaling stress during dystocia suppresses the immune reaction and is associated with susceptibility to infection are needed.

When animals are under stress, the secretion of corticotropin hormone from the neurohypophysis stimulates adrenocorticotropin (ACTH) release from the adenohypophysis. ACTH travels through the blood to the adrenal cortex to stimulate the production and release of cortisol [26]. Cortisol has anti-inflammatory effects and increases protein catabolism and decomposition of body fat [27]. Previous studies have reported that the cortisol concentration in the saliva [9] and blood [10] is higher in dystocia calves and causes metabolic changes and increases in Glu and cholesterol levels [10]. The cortisol concentration in normal neonatal foals is high immediately after birth and returns to the normal range by 24–48 hr after birth [28]. We observed similar changes in the present study, but the cortisol concentration in dystocia foals was higher than that in normal birth foals at 1 hr after birth. This suggests that dystocia foals are under more stressful conditions. Although, we assumed that strong traction at birth causes physical pain and stress, more investigation is needed to clarify the cause of high cortisol levels among dystocia foals. It has been reported that the cortisol concentration is associated with prognosis in sepsis foals [29]. We would like to examine the relationship between cortisol levels and prognosis in foals born after dystocia in future research.

The blood UN level is dependent on excretory function of the kidneys and protein catabolism [30]. Blood UN and Cre levels are widely used as indicators of kidney function. The blood Cre level did not differ significantly between the groups in the present study. We therefore assumed that the high UN level in dystocia foals was not the result of reduced kidney function but was caused by acceleration of protein catabolism by cortisol.

Blood FFA is produced by the degradation of TG mobilized from body fat and is used as an index of body fat mobilization [27]. The causes of higher FFA levels in dystocia foals may be mobilization of body fat by a negative energy balance or increased degradation of body fat by cortisol action. Hyperlipidemia is associated with excess circulating lipids that are mobilized in periods of negative energy balance and is diagnosed by serum TG levels [31]. Hyperlipidemia is a disease with high mortality and requires emergency treatment in equine medicine [32]. Although there was no significant difference in the mean values between the groups, a foal that died 1–2 days after birth had hyperlipidemia 1 day after birth (TG 565 mg/dL; normal range: 4–44 mg/dL) [33]. The possibility that hyperlipidemia causes neonatal death in dystocia foals should be examined in future research.

CK is present in heart and skeletal muscles and the brain [27]. It has been reported that the serum CK level increases when muscle fibers are damaged by vigorous exercise in horses [34]. Increased CK levels were revealed in both groups in the present study, which demonstrates that an elevation in the CK level is natural in neonatal foals. Possible causes of this elevated CK level in neonatal foals are pressure in the birth canal, muscle damage by falling when foals try to stand up after birth, and muscle damage by reactive oxygen [35]. Reactive oxygen, which is produced when cortisol is released [36], may be the cause of muscle damage.

The present study revealed that dystocia foals have relative anemia and more physical stress and muscle damage than normal birth foals. In future research, we plan to examine whether the administration of analgesic agents such as flunixin meglumine for physical stress and muscle damage and whole blood transfusion from dam to foal for anemia will reduce neonatal morbidity and mortality in dystocia foals.

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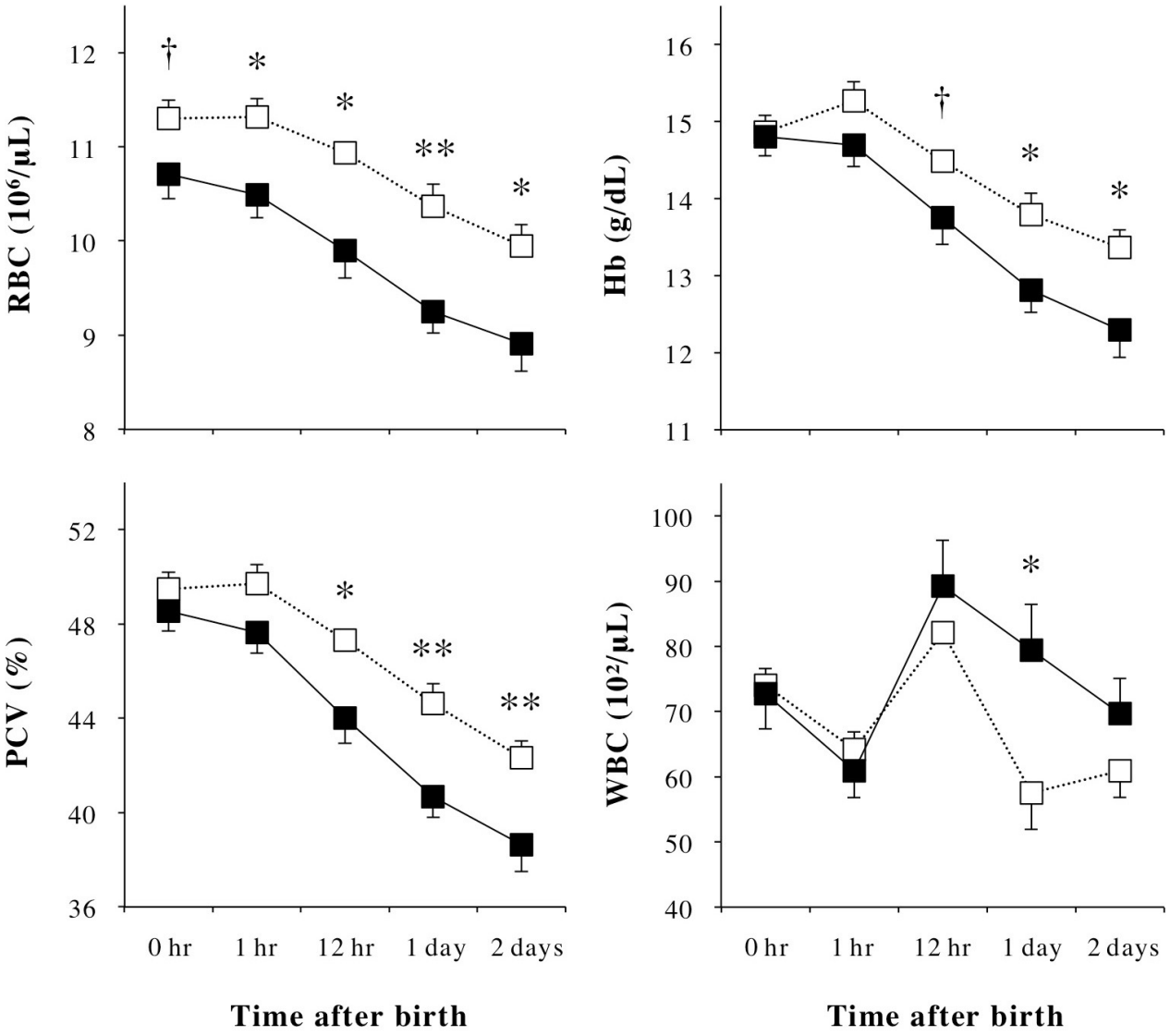
308

309 Figure 1

310



311

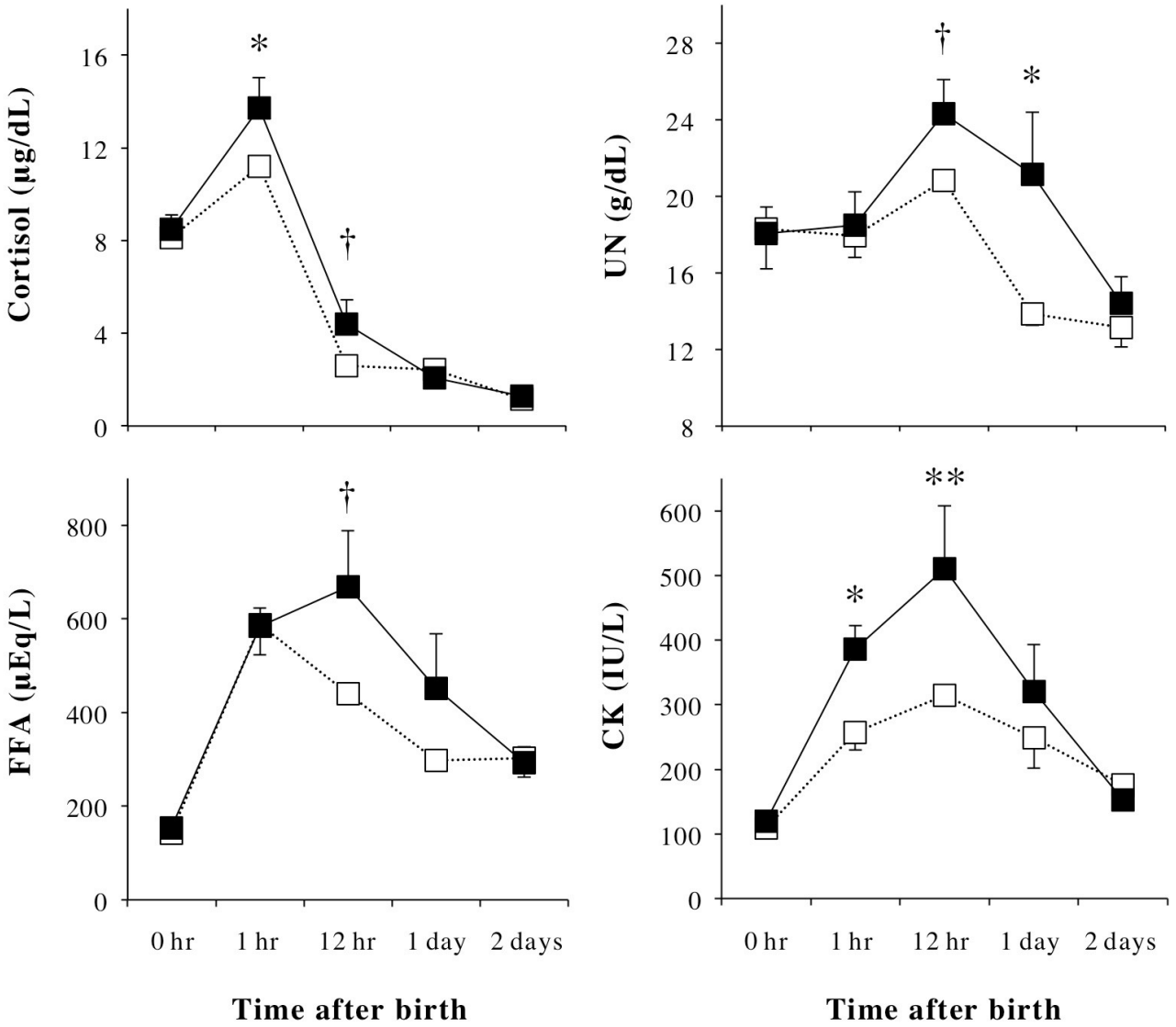
312

313 Fluctuations in red blood cell (RBC) and white blood cell (WBC) counts, hemoglobin (Hb) concentration,
314 and packed cell volume (PCV) in newborn heavy draft foals within 2 days after birth. □, normal birth group
315 (n = 23); ■, dystocia group (n = 13). Mean ± standard error is shown. Significant differences between
316 groups are denoted by * (P < .05) or ** (P < .01).

317

318 Figure 2

319



320

321

322 Fluctuations in serum cortisol, urea nitrogen (UN), free fatty acid (FFA), and creatine kinase (CK) levels

323 in newborn heavy draft foals within 2 days after birth. □, normal birth group (n = 23); ■, dystocia group

324 (n = 13). Mean ± standard error is shown. Significant differences between groups are denoted by * (P

325 < .05) or ** (P < .01).

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