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ACID-BASE BALANCE AND VENTILATION DURING STERNAL AND LATERAL RECUMBENCY IN FIELD IMMOBILIZED BLACK RHINOCEROS (*DICEROS BICORNIS*) RECEIVING OXYGEN INSUFFLATION: A PRELIMINARY REPORT

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ABSTRACT: Posture, ventilation, and acid-base balance using auricular venous blood values (pH, lactate, base excess [BE], HCO_3^-, PO_2, SO_2, and PCO_2), oxygen saturation of hemoglobin (SpO_2), and end-tidal carbon dioxide ($P_{ET}CO_2$) were compared between sternal (STE) and lateral (LAT) recumbency in free-ranging black rhinoceros *(Diceros bicornis bicornis)* receiving oxygen insufflation. Data are reported as median, minimum, and maximum (median [minimum, maximum]). Thirty-six desert-adapted black rhinoceros (20 male, 16 female; age 8 [1.5, 33] yr) were immobilized in Namibia in March and April of 2008, from a helicopter, by remote intramuscular injection with etorphine HCl, azaperone, and hyaluronidase. Time from darting to recumbency was 6.0 (3, 15.5) min. Data were organized into two sampling periods: sample period 1 (P1, collected within 0–20 min postdarting; 13 [6.5, 19] min) and sample period 2 (P2, collected between 20–40 min postdarting; 32 [22.3, 39] min). All animals were acidemic (pH 7.24 [7.07, 7.32]) and hypoxemic (PO_2 51 [38, 95.2]; SO_2 78 [64, 96] mmHg) after capture. Lactate at P1 was 7.2 (3.2, 16.8) mmol/l and decreased ($P=0.01$) to 4.6 (1.2, 10.9) mmol/l at P2. At P2, lactate was less ($P=0.06$) in LAT 3.5 (1.2, 8.6) mmol/l than in STE posture 7.4 (3.1, 10.9) mmol/l. In P2, PO_2, SO_2, and SpO_2 were higher ($P=0.02$, 0.10, and 0.01, respectively) in STE than in LAT. End-tidal carbon dioxide in LAT was 38 (26, 47) mmHg and increased ($P<0.001$) rapidly to 48 (37, 55) mmHg when animals were moved into STE; no corresponding change in PCO_2 was observed. These preliminary findings suggest that STE posture in recumbent black rhinoceros reduces dead-space ventilation and improves oxygenation. Lateral posture was associated with lower blood lactate, quicker lactate recovery, or both. It is possible that the posture of recumbent rhinoceros after capture affects lactate accumulation and clearance, or both, and procedures should consider positioning in order to enhance perfusion.

Key words: Anesthesia, capnography, dead space, lactate, posture, rhinoceros.

INTRODUCTION

The black rhinoceros *(Diceros bicornis)* is critically endangered, and interventions to ensure its conservation in Africa depend on safe chemical restraint. Because rhinoceros capture protocols are usually based on potent μ-agonist opioids, respiratory depression with hypoventilation, hypoxia, hypercapnea, hypertension, and acidemia are common (Heard et al., 1992; Hattingh et al., 1994; Bush et al., 2004, 2005; Portas, 2004). Postcapture mortality is a particular concern when immobilizing endangered species, and postanesthetic myopathy is a risk in black rhinoceros

FIGURE 1. An adult, free-ranging black rhinoceros manifesting postcapture myopathy and recumbency from which the animal did not recover. Although not a subject of our study, this animal was captured in Namibia in 2005 using standard doses of etorphine, azaperone, and hyaluronidase.

(Radcliffe and Morkel, 2007). Myopathy in the rhinoceros is characterized by a dog-sitting posture and can result from excessive exertion at capture, inadequate dosage or partial injection, incomplete antagonism of the opioid, and straining to rise from recumbency (especially upon reversal in a crate; Fig. 1). To attenuate the stress of capture in free-ranging rhinoceros, it is usual to dart them with relatively high doses of etorphine combined with hyaluronidase to minimize the time between darting and recumbency (Morkel, 1989; Kock et al., 1990; Kock, 1992). One disadvantage of high-dose etorphine protocols is the resulting cardiopulmonary side effects, which can be complicated by exertion-related perturbations.

In other large quadrupeds, both the pulmonary and cardiovascular systems are affected by posture under anesthesia (Thurmon et al., 1996; Wenger et al., 2007). In anesthetized horses, alveolar ventilation, oxygenation, and systemic perfusion are greater in sternal than in lateral recumbency (Gleed and Dobson, 1988). In contrast, the cardiopulmonary system of anesthetized elephants may be disadvantaged in sternal recumbency (Harthoorn, 1973). The optimal position for rhinoceros under anesthesia after capture has not been determined. The objective of this study was to compare respiratory and acid-base parameters between two postures, sternal (STE) and lateral (LAT) recumbency, and with time after darting.

MATERIALS AND METHODS

Study sites and subjects

The protocol was approved by the Cornell University Institutional Animal Care and Use Committee (Protocol 2006-0170) and the Namibian Ministry of Environment and Tourism. Study sites were located in eastern Etosha National Park (19°0′0″S, 16°0′0″E) and on several private conservancies or custodial lands in north-central Namibia. As part of routine capture and translocation operations from 27 March through 10 April 2008, we immobilized 36 desert-adapted black rhinoceros (20 male, 16 female; age 8 (1.5, 33) yr (median [minimum, maximum]) from a helicopter by remote intramuscular injection with etorphine HCl 4.5 (2.0, 5.5) mg, azaperone (80.0 mg), and hyaluronidase (2,500 IU) using a stainless steel Joubert dart and a 6-cm barbed needle (Joubert Capture Equipment, Jacobsdal, Free State, South Africa). As soon as practical after a rhinoceros was recumbent, we administered intranasal insufflation with 5–15 l/min^{-1} oxygen. We also sprayed rhinoceros with water during recumbency. We administered intravenous mixed agonist-antagonist drugs (nalbuphine, nalorphine, or butorphanol) in 17 rhinoceros to partially reverse the effects of etorphine. Rhinoceros posture was dictated by recumbency: 25 rhinoceros fell into LAT and were subsequently moved at 23.5 (7.5, 38) min into STE posture. Seven rhinoceros fell into STE and were subsequently moved at 7.3 (6, 18) min into LAT posture. Four subjects changed posture on more than one occasion.

Measurements

Upon recumbency, we measured rectal temperature by using a digital thermometer (Rite Aid Corp., Harrisburg, Pennsylvania, USA) and muscle temperature by inserting a thermistor (Electro-therm Model TC100A, Cooper-Atkins Corp., Middlefield, Connecticut, USA) into the needle tract of the dart site. We collected blood for gas and acid-base evaluation (pH, PCO_2, PO_2, BE, HCO_3^-, SO_2, and lactate) from the auricular vein within 10 min of recumbency, and prior to recovery, where possible. We measured blood gas partial pressures and acid-base parameters using an i-STAT® handheld clinical analyzer (Abbott Laboratories, Abbott Park, Illinois, USA),

and corrected to rectal temperature. We measured $P_{ET}CO_2$ and SpO_2 using a combined capnograph and pulse oximeter (Oridion® Microcap® Plus, Oridion Capnography Inc., Needham, Massachusetts, USA; Nellcor® Oximax® N-85™, Nellcor Puritan Bennett LLC, Pleasanton, California, USA). We collected SpO_2 data using a reflectance sensor (Nellcor® OxiMax® Max-Fast®) held on the mucous membrane inside the nares. We collected $P_{ET}CO_2$ data by side-stream sampling from inside the nasal passage. We recorded $P_{ET}CO_2$ and SpO_2 measurements once per minute. To avoid transportation-related stress on female rhinoceros, we examined them for pregnancy at the capture site using a portable transrectal ultrasound monitor (Aloka 500V, Aloka America, Wallingford, Connecticut, USA; Radcliffe et al., 2001).

Data analysis

Post hoc, we organized data into two sampling periods based on the time blood samples were collected after darting. Sample period 1 (P1) corresponds to a blood sample collected during the first 20 min after remote drug delivery (0–20 min postdarting), and sample period 2 (P2) corresponds to a blood sample collected during the second 20 min after drug delivery (20–40 min postdarting). To be included in the study, a rhinoceros had to be in one posture for at least 7 min before blood collection and sampled within the P1 and P2 periods.

Supplemental agonist-antagonist drugs are a potential confounder for the outcomes of primary interest ($P_{ET}CO_2$ and PCO_2). Therefore, we stratified the $P_{ET}CO_2$ and PCO_2 data for rhinoceros that received such drugs and those that did not, and used the Wilcoxon signed rank test to test the significance of differences between postures within each cohort. Data were stratified as follows: for rhinoceros moving from LAT to STE posture, 15 of 25 rhinoceros received mixed agonist-antagonist drugs, and 10 of 25 did not receive drugs. These stratified data had the same direction, magnitude, and type-1 error risks; therefore, we also analyzed all rhinoceros as pooled data to increase study power.

We analyzed data using descriptive and inferential methods. Continuous data were described by medians, minimum, and maximum values and presented in box plots. For data reported in Table 1, we used unpaired analysis with the Wilcoxon rank sum test to compare postures and times because the data had nonnormal distributions (Rosner, 1986). When we made comparisons within rhinoceros and between postures (e.g. $P_{ET}CO_2$ and PCO_2), we used paired analysis with the Wilcoxon signed rank test. We used simple linear regression to investigate the linear effect of lactate changes over time. We set the type-1 error rate at 10% (i.e., $P<0.1$). We analyzed the data using commercially available software (SAS Institute Inc., Cary, North Carolina, USA; KaleidaGraph, Synergy Software, Reading, Pennsylvania, USA).

This study was complicated by factors that reflected the realities of conducting research in the field. For example, we measured venous blood gases for convenience, and these may not relate to arterial values. Additionally, all rhinoceros received nasal oxygen insufflation. A subset of animals received supplemental pharmacologic agents (i.e., nalbuphine, nalorphine, or butorphanol) that may have had significant respiratory effects; data were stratified and analyzed separately where possible.

RESULTS

Time from darting to STE or LAT recumbency was 6.0 (3.0, 15.5) min. The environmental temperature was 28.2 C (19.4, 33.1). Muscle temperature in P1 was 38.6 C (37.2, 39.5); this was greater ($P<0.001$) than the corresponding rectal temperature 37.7 C (36.8, 39.1). Rectal temperatures were within, or exceeded, the normal range for standing, unrestrained white rhinoceros (*Ceratotherium simum*, 36.6 C, 37.2 C; Citino and Bush, 2007), but were consistent with free-ranging black rhinoceros at capture, 38.7 C (36.5, 41.2; Kock et al., 1990).

At P1, all rhinoceros were acidemic, pH 7.24 (7.07, 7.30), with lower base excess and bicarbonate when compared with normal reference values (arterial pH 7.35, 7.43; BE 1.9, 5.9; HCO_3^- 27.3, 32.2; Citino and Bush, 2007). There were no differences over time, or with posture, for these variables (Table 1).

Lactate concentration in P1 was 7.2 (3.2, 16.8) mmol/l and did not differ with posture; however, median lactate declined ~32% ($P=0.01$) from P1 to P2 (Fig. 2A). At P2, median lactate concentration was less (~53%, $P=0.06$) in LAT than in STE recumbency (Fig. 2B). When lactate con-

TABLE 1. Median (minimum, maximum) acid-base, venous blood gas, and ventilation values for free-ranging black rhinoceros after immobilization with etorphine HCl, 4.5 (2.0, 5.5) mg, azaperone (80.0 mg), and hyaluronidase (2,500 IU) in eastern Etosha National Park (19°0′0″S, 16°0′0″E) 27 March–10 April 2008.[a]

Time after darting (min)	Posture in recumbency	pH	Lactate (mmol/l)	Bicarbonate (mEq/l)	BE (mEq/l)	PO_2 (mmHg)	SO_2 (%)	S_pO_2 (%)	PCO_2 (mmHg)	BR (per min)
1 to 20	Lateral	7.23	6.8	19.9	−7.5	51	76	85	47	8
(Period 1)	(n=16)	(7.07, 7.30)	(3.2, 16.8)	(10.0, 26.5)	(−20.0, 0.0)	(43, 95)	(67, 94)	(73, 92)	(27, 57)	(5, 16)
	Sternal	7.24	9.0	16.1	−10.5	60	83	93	38	11
	(n=6)	(7.07, 7.29)	(4.0, 16.0)	(10.7, 28.0)	(−19.0, 1.0)	(43, 72)	(70,92)	(90, 97)	(32, 59)	(5, 14)
	Pooled	7.24	7.2	18.9	−8.0	56	78	85	46	9
	(n=22)	(7.07, 7.30)	(3.2, 16.8)[b]	(10.0, 28.0)	(−20, 1.0)	(43, 95)	(67, 94)	(73, 97)	(27, 59)	(5, 16)
20 to 40	Lateral	7.25	3.5	18.2	−8.5	44	71	85	40	8
(Period 2)	(n=8)	(7.19, 7.32)	(1.2, 8.6)[c]	(11.5, 25.2)	(−16.0, −2.0)	(38, 90)[d]	(64, 96)[e]	(83, 89)[f]	(27, 59)	(5, 10)
	Sternal	7.21	7.4	19.3	−8.0	57	84	88	44	9
	(n=6)	(7.19, 7.32)	(3.1, 10.9)[c]	(12.7, 23.4)	(−15.0, −3.0)	(48, 95)[d]	(74, 96)[e]	(86, 92)[f]	(33, 59)	(4, 12)
	Pooled	7.24	4.6	18.2	−8.5	48	78	86	42	9
	(n=14)	(7.19, 7.32)	(1.2, 10.9)[b]	(11.5, 25.2)	(−16.0, −2.0)	(38, 95)	(64, 96)	(83, 92)	(27, 59)	(4, 12)

[a] BE = base excess; BR = breathing rate.

[b,c,d,e,f] Significant difference in values: [b] P=0.01, [c] P=0.06, [d] P=0.02, [e] P=0.1, [f] P=0.01; values without a superscript were not statistically different.

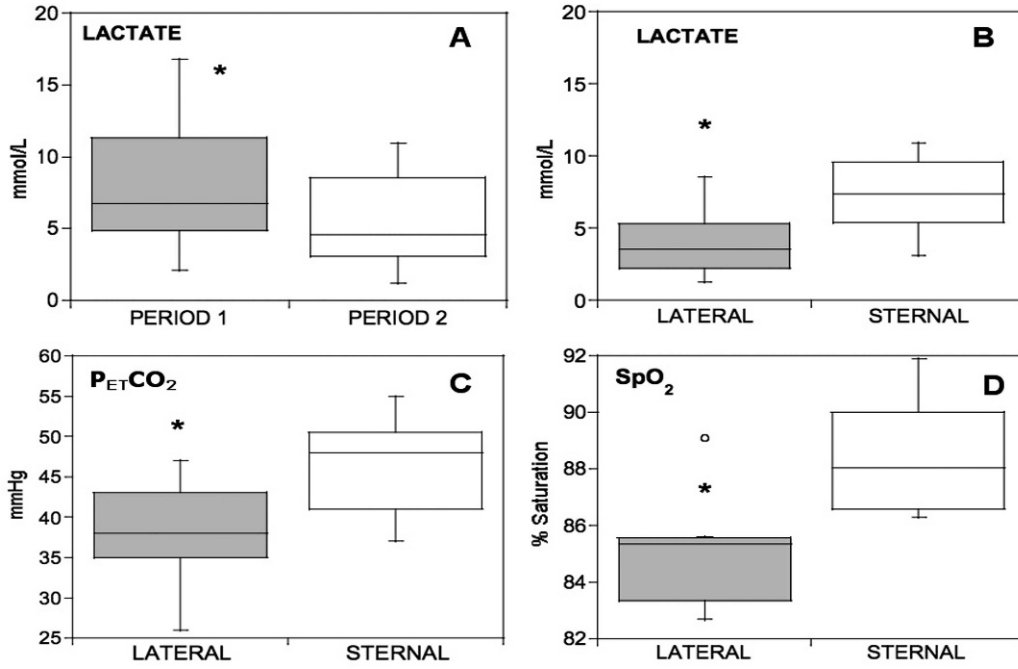

FIGURE 2. Median (minimum and maximum) venous blood values for free-ranging black rhinoceros immobilized with etorphine HCl 4.5, (2.0, 5.5) mg, azaperone (80.0 mg), and hyaluronidase (2,500 IU) in eastern Etosha National Park (19°0′0″S, 16°0′0″E), 27 March–10 April 2008: (A) Drop in lactate over time from sampling period 1 to period 2 ($n=14$); period 1 corresponds to a blood sample collected during the first 20 min after remote drug delivery (0–20 min postdarting) and sample period 2 corresponds to a blood sample collected during the second 20 min after drug delivery (20–40 min postdarting); (B) Lower blood lactate in lateral than in sternal posture at period 2 ($n=14$); (C) Higher $P_{ET}CO_2$ in sternal than in lateral posture ($n=25$); (D) Higher SpO_2 in sternal than in lateral posture at period 2 ($n=14$). Asterisk (A, B, C, & D) indicates $P=0.01$, 0.06, <0.001, and 0.01, respectively.

centration was regressed against time after darting, lactate declined in LAT ($P=0.06$), but not in STE ($P=0.94$) posture (Fig. 3).

Breathing rate (9 [4, 16] breaths/min) was lower than normal reference values (16, 23 breaths/min; Citino and Bush, 2007), but within the range reported for black rhinoceros at capture, 10.5 (4, 35; Kock et al., 1990). There was no difference ($P=0.30$) in breathing rate between LAT and STE postures, or between P1 and P2 sampling periods ($P=0.34$). Most rhinoceros were hypoxemic with a venous PO_2 of 51 (38, 95.2) mmHg and venous SO_2 of 78 (64, 96) mmHg, which is below normal arterial values (PO_2 90.2, 108.6; SO_2 96.6, 98.0; Citino and Bush, 2007). Oxygen saturation of hemoglobin was 85% (73, 97) at P1 and 86% (83, 92) at P2. There were no differences over time for PO_2, SO_2, and SpO_2; however, these were higher in STE than in LAT posture ($P=0.02$, 0.10, and 0.01, respectively) during P2 (Table 1 and Fig. 2D).

Median $P_{ET}CO_2$, 42 (26, 55) mmHg, was within normal reference values ($P_{ET}CO_2$ 41.7, 48.0 mmHg; Citino and Bush, 2007); however, the minimum and maximum values in our study exceeded the normal range. Partial pressure of carbon dioxide (42.5 [26.7, 59.0] mmHg) was below normal reference values (PCO_2 44.4, 53.7 mmHg; Citino and Bush, 2007). End-tidal carbon dioxide, but not PCO_2, was higher ($P<0.001$, $P=0.92$, respectively) in STE than in LAT posture (Figs. 2C, 4).

Stratified data for $P_{ET}CO_2$ and PCO_2 in

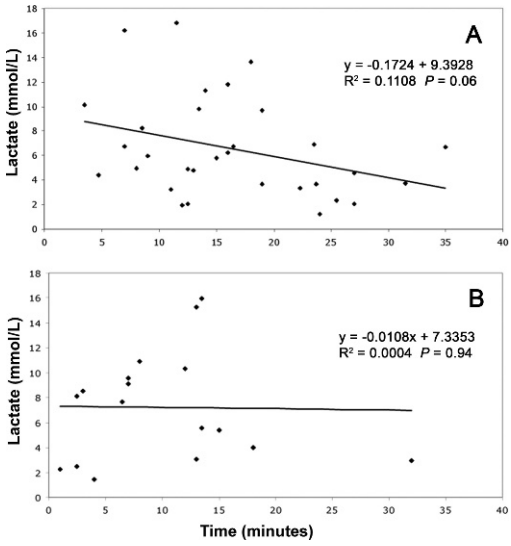

FIGURE 3. Linear regression analysis indicating the observed change in lactate concentration through time in (A) lateral compared to (B) sternal posture in immobilized black rhinoceros ($P=0.06$ in lateral, $n=24$; $P=0.94$ in sternal, $n=15$). Rhinoceros were immobilized with etorphine HCl 4.5, (2.0, 5.5) mg, azaperone (80.0 mg), and hyaluronidase (2,500 IU) in eastern Etosha National Park (19°0′0″S, 16°0′0″E) 27 March–10 April 2008.

those animals receiving mixed agonist-antagonist drugs were first analyzed separately from those that did not receive drugs. In animals moving from LAT to STE and receiving supplemental drugs ($n=15$), median $P_{ET}CO_2$ in LAT was 38 (26, 47) mmHg and increased ($P<0.01$) to 47 (37, 55) mmHg in STE. In animals not receiving drugs ($n=10$), median $P_{ET}CO_2$ in LAT was 38.75 (32, 46.5) mmHg and increased ($P<0.01$) to 48.5 (37.5, 50.5) mmHg in STE. In the group receiving supplemental drugs and having paired blood samples ($n=8$), PCO_2 in LAT was 39.8 (30.4, 57) mmHg and did not change ($P=0.31$) with the move into STE posture, 38.5 (18.7, 59.1) mmHg. In animals not receiving drugs and having paired samples ($n=4$), PCO_2 in LAT was 32.5 (26, 56.4) mmHg and likewise did not change ($P=0.25$) with the move into STE posture, 44.8 (31.4, 45.8) mmHg.

Pooled $P_{ET}CO_2$ and PCO_2 data for animals moved from LAT to STE recumbency ($n=25$) were comparable to the

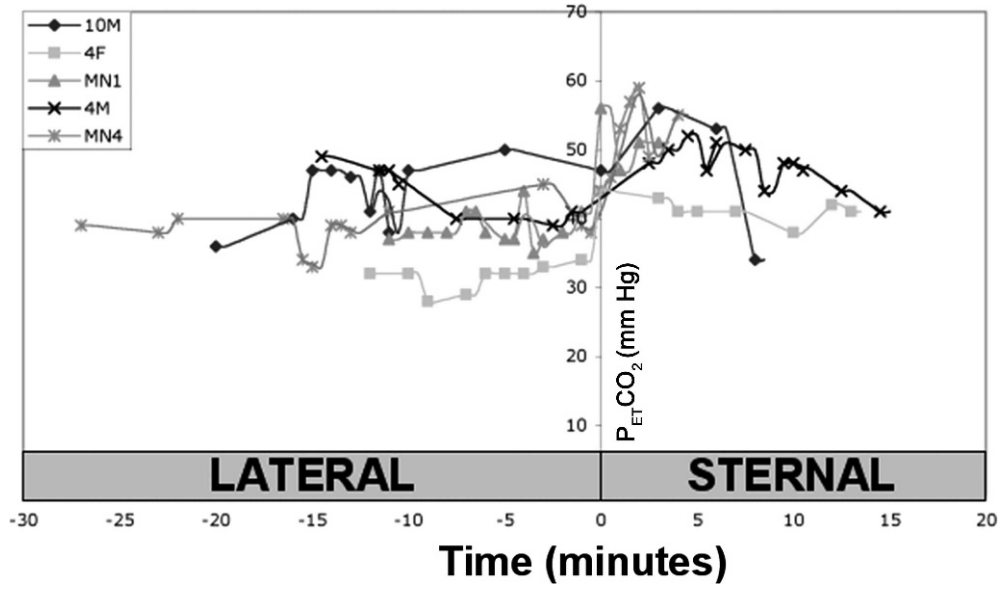

FIGURE 4. Sequential $P_{ET}CO_2$ values (mmHg) in a subset of black rhinoceros before and after movement from lateral to sternal posture (only five of 25 subjects shown for clarity). Time 0 is the time at which the rhinoceros were moved from lateral to sternal recumbency. Rhinoceros were immobilized with etorphine HCl, 4.5 (2.0, 5.5) mg, azaperone (80.0 mg), and hyaluronidase (2,500 IU) in eastern Etosha National Park (19°0′0″S, 16°0′0″E) 27 March–10 April 2008.

stratified results. The median $P_{ET}CO_2$ in LAT was 38 (26, 47) mmHg and increased ($P<0.01$) to 48 (37, 55) mmHg in STE. In rhinoceros moved from LAT to STE and having paired samples ($n=12$), PCO_2 in LAT was 37.3 (26, 57) mmHg and did not change ($P=0.97$) with the move into STE posture, 42.5 (18.7, 59.1) mmHg.

The two highest blood lactate values (16.2 and 16.8 mmol/l) were recorded in pregnant animals with gestation lengths of 35 days and 8 mo, respectively. Another pregnant female experienced one of the longest times from darting to recumbency (15.5 min) and was found dead 1 wk after capture, presumably from complications of late pregnancy (no ultrasound exam; a full-term fetus was discovered at necropsy). This animal also had high blood lactate at P1 (lactate 9.8 mmol/l), which was still elevated (8.15 mmol/l) 25.5 min later.

DISCUSSION

Free-ranging rhinoceros are susceptible to acidosis and muscle damage from exertion during the capture process (Kock et al., 1995; Bush et al., 2004; Wenger et al., 2007). Although prevention of acidosis through careful capture planning is desirable, some level of acidosis due to exertion is probably unavoidable, given the nature of field capture using helicopters under free-ranging conditions (Kock et al., 1990; Kock, 1992). Our data corroborate previous reports that demonstrate acidemia and high blood lactate under similar conditions, with the latter declining with time after darting (Fahlman et al., 2004; Wenger et al., 2007). Our data suggest that, in addition to time, posture is an important determinant of the rate of lactate decline in recumbent black rhinoceros. Because lactate is a marker of anaerobic metabolism in muscle, declining plasma lactate concentration could suggest that the cellular environment in muscle tissue is improving; this may be important for preserving muscle function in the rhinoceros during recovery from anesthesia (Robergs, 2001). More-rapidly declining lactate suggests an advantageous relationship between lactate production and clearance in LAT. This could be related to an improved perfusion of muscle in this posture that causes a reduction in lactate production, or improved perfusion of the liver where lactate is metabolized, or both, or some other factors.

Large quadrupeds tend to be hypoxemic while recumbent under anesthesia because of an increase in venous admixture in the pulmonary circulation (Thurmon et al., 1996). Self regulation of hypoxemia in STE, as seen in this study, was similar to reports for horses and free-ranging white rhinoceros, but in contrast to reports for elephants, where STE exacerbates hypoxemia (Harthoorn, 1973; Gleed and Dobson, 1988; Wenger et al., 2007). Likewise, significant decreases in PaO_2 were observed in unsedated cattle maintained in LAT and dorsal recumbency (although STE was not evaluated; Wagner et al., 1990).

Ventilation of under-perfused alveoli constitutes alveolar dead-space ventilation and leads to dilution of expired carbon dioxide and, hence, reduced $P_{ET}CO_2$ (Lumb, 2005). Rapid increase in $P_{ET}CO_2$ after changing from LAT to STE (Fig. 4) is compatible with a decrease in alveolar dead space and suggests dead space was greater in LAT posture. Conditions that cause greater alveolar dead space include decreased pulmonary artery pressure and reduced cardiac output. It is possible that blood flow to the rhinoceros lung in LAT is sufficiently impaired to increase alveolar dead-space ventilation, and that this is reversed with the change to STE. The same trend (higher $P_{ET}CO_2$, but not PCO_2, in STE compared to LAT) was observed regardless of starting posture, with $P_{ET}CO_2$ starting high in STE and declining rapidly with a move to LAT. The $P_{ET}CO_2$ difference was usually evident within one or two breaths after postural

change. Both posture and anesthesia drugs influence the spatial distribution of ventilation and perfusion in the lungs of people and quadrupeds and, hence, influence dead-space ventilation (Pansard et al., 1992; Grenier et al., 1999; Chang et al., 2002).

Compared with standing, unrestrained white rhinoceros, capture of black rhinoceros resulted in acidosis, high lactate, low breathing rate, hypoxia, and variable PCO_2 and $P_{ET}CO_2$ values. Besides $P_{ET}CO_2$, posture did not affect any of the factors tested within 20 min after darting. However, LAT, in comparison to STE posture, played a role in the improvement of lactate between 20 and 40 min after darting. An improvement in PO_2, SO_2, and SpO_2 was observed in STE (in comparison to LAT posture) during the same period. Repositioning may be an option for strategically improving these parameters.

Although critical thresholds for rectal temperature have not been reported in rhinoceros after capture, muscle temperature in our study exceeded rectal temperature ($n=13$) and may indicate hyperthermia from heat generated by muscle during capture-related exertion. If black rhinoceros skin is as vascular as the skin of white rhinoceros (Cave and Allbrook, 1958), topical application of water would facilitate conductive and evaporative cooling after stressful captures.

Pregnancy is a risk factor during field anesthesia, and losses (both fetal and maternal) have been observed following capture procedures of rhinoceros in late gestation. In our study, we recorded the two highest blood lactate values in pregnant females, one early in gestation and another in midterm gestation (16.2 and 16.8 mmol/l), but neither female's pregnancy was interrupted. One pregnant female with a nearly full-term fetus died 1 wk after capture (her drug induction took 15.5 min and her lactate levels were persistently high). Circumstances dictated we transport this female regardless of pregnancy status. Therefore, we conducted no rectal ultrasound examination after capture and we were unaware of the pregnancy until necropsy. It is likely that advanced pregnancy affects perfusion due to hormonal perturbation and compression of blood vessels and diaphragm during recumbency, and might lead to other negative side effects. Therefore, ultrasonogaphic pregnancy diagnosis before translocation is helpful for identifying females during late gestation so that efforts can be taken to minimize stress. Further studies of anesthetic capture of female rhinoceros should include investigation of methods that may be safely applied to females during advanced pregnancy.

The standard field practice of administering partial agonist-antagonist agents to rhinoceros in efforts to ensure animal safety affected our ability to draw definite conclusions. Therefore, we caution overinterpretation of these preliminary results, and further studies are planned to better characterize our observations.

In summary, our data suggest sternal recumbency was advantageous for the pulmonary system in anesthetized rhinoceros because blood oxygen saturation was greater than in lateral recumbency. In addition, there is evidence that black rhinoceros may have less alveolar dead space when positioned sternally. However, lateral posture may be preferable to sternal for recovery from lactatemia. A definitive preference for one position over the other will depend on physiologic measures collected at the time, and such a preference awaits studies that include observations of perfusion pressure and oxygen delivery to dependent (compressed) muscle, global oxygen delivery, and outcome analysis of large groups, with more-rigorously controlled conditions.

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