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

P. vdB. Morkel,1 R. W. Radcliffe,2,4,9 M. Jago,3 P. du Preez,3 M. J. B. F. Flaminio,4 D. V. Nydam,4 A. Taft,5 D. Lain,6 M. M. Miller,7,8 and R. D. Gleed4

1 Frankfurt Zoological Society, 42 Kinnersley Street, Newton Park, 6045, South Africa
2 International Rhino Foundation, Rhino Conservation Medicine Program, 1 Armstrong Road, Lansing, New York 14882, USA
3 Namibia Ministry of Environment and Tourism, Private Bag 13306, Windhoek, Namibia
4 Cornell University, College of Veterinary Medicine, Tower Road, Ithaca, New York 14853, USA
5 Medical College of Georgia, Department of Respiratory Therapy, EC-4318, Augusta, Georgia 30912, USA
6 Oridion Capnography Inc., 160 Gould Street, Suite 205, Needham, Massachusetts 02494, USA
7 Disney’s Animal Kingdom, PO Box 10,000, Lake Buena Vista, Florida 32830, USA
8 Current address: Palm Beach Zoo, 1301 Summit Boulevard, West Palm Beach, Florida 33405, USA
9 Corresponding author (email: rwr32@cornell.edu)

ABSTRACT: Posture, ventilation, and acid-base balance using auricular venous blood values (pH, lactate, base excess [BE], HCO₃⁻, PO₂, SO₂, and PCO₂), oxygen saturation of hemoglobin (SpO₂), and end-tidal carbon dioxide (PETO₂) 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 (PO₂ 51 [38, 95.2]; SO₂ 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, PO₂, SO₂, and SpO₂ 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 PCO₂ 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 hypventilation, 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 rhinoceroses
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 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, PCO₂, PO₂, BE, HCO₃⁻, SO₂, 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 \( P_{\text{ET}} \text{CO}_2 \) and \( \text{SpO}_2 \) using a combined capnograph and pulse oximeter (Origion\textsuperscript{®} Microcap\textsuperscript{®} Plus, Orionid Capnography Inc., Needham, Massachusetts, USA; Nellcor\textsuperscript{®} Oximax\textsuperscript{®} N-ST\textsuperscript{TM}, Nellcor Puritan Bennett LLC, Pleasanton, California, USA). We collected \( \text{SpO}_2 \) data using a reflectance sensor (Nellcor\textsuperscript{®} Oximax\textsuperscript{®} Max-Fast\textsuperscript{®}) held on the mucous membrane inside the nares. We collected \( P_{\text{ET}} \text{CO}_2 \) data by side-stream sampling from inside the nasal passage. We recorded \( P_{\text{ET}} \text{CO}_2 \) and \( \text{SpO}_2 \) 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 (\( P_{\text{ET}} \text{CO}_2 \) and \( \text{PCO}_2 \)). Therefore, we stratified the \( P_{\text{ET}} \text{CO}_2 \) and \( \text{PCO}_2 \) 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, 1996). When we made comparisons within rhinoceros and between postures (e.g., \( P_{\text{ET}} \text{CO}_2 \) and \( \text{PCO}_2 \)), 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, 1990), but were consistent with free-ranging black rhinoceros at capture, 38.7°C (36.5, 41.2°C; 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; \( \text{HCO}_3^- \) 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 \( \sim 32\% \) \( (P=0.01) \) from P1 to P2 (Fig. 2A). At P2, median lactate concentration was less \( \sim 53\% \), \( P=0.06 \) 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.

<table>
<thead>
<tr>
<th>Time after darting (min)</th>
<th>Posture in recumbency</th>
<th>pH</th>
<th>Lactate (mmol/l)</th>
<th>Bicarbonate (mEq/l)</th>
<th>BE  (mEq/l)</th>
<th>PO₂ (mmHg)</th>
<th>SO₂ (%)</th>
<th>S₉O₂ (%)</th>
<th>PCO₂ (mmHg)</th>
<th>BR (per min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 20</td>
<td>Lateral</td>
<td>7.23</td>
<td>6.8</td>
<td>19.9</td>
<td>-7.5</td>
<td>51</td>
<td>76</td>
<td>85</td>
<td>47</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(n=16)</td>
<td></td>
<td>(7.07, 7.30)</td>
<td>(3.2, 16.8)</td>
<td>(10.0, 26.5)</td>
<td>(-20.0, -0.0)</td>
<td>(43, 95)</td>
<td>(67, 94)</td>
<td>(73, 92)</td>
<td>(27, 57) (5, 16)</td>
</tr>
<tr>
<td></td>
<td>Sternal</td>
<td>7.24</td>
<td>9.0</td>
<td>16.1</td>
<td>-10.5</td>
<td>60</td>
<td>83</td>
<td>93</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>(n=6)</td>
<td></td>
<td>(7.07, 7.29)</td>
<td>(4.0, 16.0)</td>
<td>(10.7, 28.0)</td>
<td>(-19.0, 1.0)</td>
<td>(43, 72)</td>
<td>(70, 92)</td>
<td>(90, 97)</td>
<td>(32, 59) (5, 14)</td>
</tr>
<tr>
<td></td>
<td>Pooled</td>
<td>7.24</td>
<td>7.2</td>
<td>18.9</td>
<td>-8.0</td>
<td>56</td>
<td>78</td>
<td>85</td>
<td>46</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(n=22)</td>
<td></td>
<td>(7.07, 7.30)</td>
<td>(3.2, 16.8)</td>
<td>(10.0, 28.0)</td>
<td>(-20.1, 1.0)</td>
<td>(43, 95)</td>
<td>(67, 94)</td>
<td>(73, 97)</td>
<td>(27, 59) (5, 16)</td>
</tr>
<tr>
<td>20 to 40</td>
<td>Lateral</td>
<td>7.25</td>
<td>3.5</td>
<td>18.2</td>
<td>-8.5</td>
<td>44</td>
<td>71</td>
<td>85</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(n=8)</td>
<td></td>
<td>(7.19, 7.32)</td>
<td>(1.2, 8.6)</td>
<td>(11.5, 25.2)</td>
<td>(-16.0, -2.0)</td>
<td>(38, 90)</td>
<td>(64, 96)</td>
<td>(83, 89)</td>
<td>(27, 59) (5, 10)</td>
</tr>
<tr>
<td></td>
<td>Sternal</td>
<td>7.21</td>
<td>7.4</td>
<td>19.3</td>
<td>-8.0</td>
<td>57</td>
<td>84</td>
<td>88</td>
<td>44</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(n=6)</td>
<td></td>
<td>(7.19, 7.32)</td>
<td>(3.1, 10.9)</td>
<td>(12.7, 23.4)</td>
<td>(-15.0, -3.0)</td>
<td>(48, 95)</td>
<td>(74, 96)</td>
<td>(86, 92)</td>
<td>(33, 59) (4, 12)</td>
</tr>
<tr>
<td></td>
<td>Pooled</td>
<td>7.24</td>
<td>4.6</td>
<td>18.2</td>
<td>-8.5</td>
<td>48</td>
<td>78</td>
<td>86</td>
<td>42</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(n=14)</td>
<td></td>
<td>(7.19, 7.32)</td>
<td>(1.2, 10.9)</td>
<td>(11.5, 25.2)</td>
<td>(-16.0, -2.0)</td>
<td>(38, 95)</td>
<td>(64, 96)</td>
<td>(83, 92)</td>
<td>(27, 59) (4, 12)</td>
</tr>
</tbody>
</table>

- BE = base excess; BR = breathing rate.
- 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.
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 PEtCO$_2$, 42 (26, 55) mmHg, was within normal reference values (PEtCO$_2$ 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 PEtCO$_2$ and PCO$_2$ in
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 \( P_{ETCO_2} \) 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 \( P_{ETCO_2} \) 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 \( (n=8) \), \( P_{CO_2} \) 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 \( (n=4) \), \( P_{CO_2} \) 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 \( P_{ETCO_2} \) and \( P_{CO_2} \) data for animals moved from LAT to STE recumbency \( (n=25) \) were comparable to the...
The median $P_{ET}\text{CO}_2$ in LAT was 38 (26, 47) mmHg and increased ($P<0.01$) to 48 (37, 55) mmHg in STE. In rhinoceroses moved from LAT to STE and having paired samples ($n=12$), $\text{PCO}_2$ 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 rhinoceroses 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 rhinoceroses. 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 rhinoceroses 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 hypoxic while recumbent under anesthesia because of an increase in venous admixture in the pulmonary circulation (Thurman et al., 1996). Self regulation of hypoxemia in STE, as seen in this study, was similar to reports for horses and free-ranging white rhinoceroses, 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 $\text{PaO}_2$ 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 $P_{ET}\text{CO}_2$ (Lumb, 2005). Rapid increase in $P_{ET}\text{CO}_2$ 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 rhinoceroses 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 $P_{ET}\text{CO}_2$, but not $\text{PCO}_2$, in STE compared to LAT) was observed regardless of starting posture, with $P_{ET}\text{CO}_2$ starting high in STE and declining rapidly with a move to LAT. The $P_{ET}\text{CO}_2$ 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 P\textsubscript{CO\textsubscript{2}} and P\textsubscript{ET\textsubscript{CO}}\textsubscript{2} values. Besides P\textsubscript{ET\textsubscript{CO}}\textsubscript{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\textsubscript{2}, SO\textsubscript{2}, and SpO\textsubscript{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, ultrasonographic 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.

ACKNOWLEDGMENTS

The authors thank the Namibian Ministry of Environment and Tourism and the International Rhino Foundation for their enthusiasm
during this collaboration. Financial support was provided by the US Fish and Wildlife Service Rhino and Tiger Conservation Fund, Grant 98210-7-G311, in partnership with the International Rhino Foundation, and Grant 98210-7-G123 in partnership with the Wilderness Wildlife Trust. We thank the Frankfurt Zoological Society for financial support of Pete Morkel. Sincere thanks to Disney’s Animal Kingdom for donation of an i-STAT® analyzer and for scientific collaboration in the field. Oridion Capnography Inc. and Nellcor® Puritan Bennett LLC provided kind donations of capnography-pulse oximetry equipment. Finally, a special thanks to John Lukas of the International Rhino Foundation and Gilman International Conservation, Annie and Bob Graham of the Tapeats Fund, Peter Hall of Hunter Hall Investment Management Limited, Kerry Crosbie of the Asian Rhino Project, and the Fossil Rim Wildlife Center for generous support of the Rhino Conservation Medicine Program.

LITERATURE CITED


Pansard, J. L., B. Cholley, C. Devilliers, F. Clercure, and P. Viars. 1992. Variation in arterial to end-tidal CO2 tension differences during anesthesia in the “kidney rest” lateral


Received for publication 7 June 2009.