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# EFFECT OF CAPTURE AND IMMOBILIZATION ON BOMA ADAPTATION IN FREE-RANGING WHITE RHINOCEROS (*CERATOTHERIUM SIMUM*) IN KRUGER NATIONAL PARK, SOUTH AFRICA

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ABSTRACT: Ninety-six white rhinoceros (*Ceratotherium simum*) were captured between February and October 2009–2011 in Kruger National Park, South Africa and placed in boma confinement before translocation. Of these, 19 rhinoceros did not adapt to the bomas and required early release ($n$=18) or died ($n$=1). The available immobilization data and physiologic parameters, including blood gas analyses, were compared between adapted and maladapted rhinoceros to determine whether predisposing causes could be identified. There were no statistical differences in age category, sex, or body weight at capture between adaptation cohorts. The recorded immobilization data, physiologic values, blood gas analytes, hematologic, or serum chemistry values were not statistically different between adapted and maladapted rhinoceros at capture, except maladapted rhinoceros had lower median serum aspartate aminotransferase, blood urea nitrogen, and phosphorus values; however, these statistically different values were not clinically important. Therefore, observable demographic or capture-related factors did not appear to predispose white rhinoceros to maladaptation to boma confinement. Further investigations into factors affecting adaptation should be performed to minimize the effect on rhinoceros health and welfare.

*Key words:* Boma adaptation, *Ceratotherium simum*, hematology, immobilization, serum biochemistry, white rhinoceros.

## INTRODUCTION

Hundreds of white rhinoceros (*Ceratotherium simum*) have been immobilized and translocated across Africa (Emslie et al. 2009). With ongoing threats of poaching, there is a growing need to confine free-ranging rhinoceros for treatment as well as to remove them from high-risk areas. However, there are also potential complications associated with capture and immobilization, which are compounded by transport and holding-facility (boma) confinement. Mortality for black rhinoceros (*Diceros bicornis*) translocations in South Africa, Zimbabwe, and Namibia, 2002–2006, was reported as 4.8% (Emslie et al. 2009). However, the occurrence of morbidity is probably higher, especially in white rhinoceros (Miller et al. 2016; Pohlin et al. 2020). The severe physiologic changes that occur in immobilized white rhinoceros have been well documented (Wenger et al. 2007; Miller et al. 2013; Buss et al. 2018), although long-term consequences and successful methods of addressing these problems have not been fully resolved.

Hypoxemia and hypercapnia are commonly associated with the potent opioids used for rhinoceros capture (Wenger et al. 2007; Buss et al., 2018). In addition, these drugs have been shown to cause muscle rigidity or tremors and tachycardia, which can increase oxygen consumption as well as thoracic rigidity that may decrease ventilatory potential (Schumacher 2008; Miller et al. 2013; de Lange et al. 2017). The resulting physiologic imbalances are acidosis and hypoxemia, which may result in cardiac arrhythmias, and muscle and nervous system dysfunction (Xue et al. 2008). Rhinoceros that are subjected to increased chase times and distances, prolonged hypoxemia, and tissue hypoperfusion during recumbency may have increased lactate, which has been used as a predictor of morbidity and mortality (Miller et al. 2013; Rosenstein et al. 2018). In addition, the appetite depressant effect of hypoxemia and influence on energy metabolism, as well as tranquilizers administered during initial confinement, might lead to a catabolic state (Rogers 1993; Bruder et al. 2005). Because rhinoceros that have undergone capture and immobilization may be catabolic, there is also a link between chronic metabolic acidosis and weight loss (Drochioiu 2008), which might contribute to potential boma maladaptation. Therefore, recently captured rhinoceros may be at increased risk of both acute and long-term complications during confinement (Fahlman et al. 2004; Wenger et al. 2007).

Maladaptation of free-ranging white rhinoceros to captivity is a significant threat to animal health and welfare. Maladaptation is the failure to adjust to a new environment and manifests as a rhinoceros that is not eating, defecating, or behaving normally (Rogers 1993; Kruger et al. 1999). Up to 20% of captured white rhinoceros are unable to adapt to confinement, require early release, and have complications leading to morbidity with possible mortality (Rogers 1993). In a previous study (Miller et al. 2016), a scoring system was developed to assess adaptation of recently captured white rhinoceros to captivity and provide a tool to wildlife managers and veterinarians. However, the underlying causes that predispose to maladaptation are unknown. Therefore, the aim of this study was to examine whether factors such as age, sex, body weight, health status (based on hematologic and serum biochemical results), or factors that occurred during chemical immobilization (such as physiologic changes in cardio-respiratory parameters due to exertion and drug effects) were associated with maladaptation.

## MATERIALS AND METHODS

### Animals and immobilizations

Between 2009 and 2011, 96 free-ranging white rhinoceros were captured in Kruger National Park (23°49′60″S, 31°30′0″E), South Africa. Rhinoceros were located visually and darted from a helicopter, immobilized, then loaded in a crate and moved by truck to adaptation bomas prior to translocation according to the South African National Parks (SANParks) Standard Operating Procedures for the Capture, Transportation and Maintenance in Holding Facilities of Wildlife (SANParks 2005; approved by SANParks Animal Use and Care Committee). Immobilizing drug combinations and administration techniques have been previously described (Miller et al. 2013, 2016). Briefly, drugs were administered in a 3-mL plastic dart using a compressed air rifle (DAN-INJECT International S.A., Skukuza, South Africa). Drug dosages were based on age categories and included etorphine (Novartis, Kempton Park, 1619 South Africa; dose range 2–4 mg intramuscularly [IM]), azaperone (Stressnil, Janssen Pharmaceutical Ltd., Halfway House, South Africa; dose range 20–40 mg IM), and hyaluronidase (Kyron Laboratories, Benrose, South Africa; dose 5,000 IU IM). Butorphanol (Kyron Laboratories) was administered either in the dart (dose range 40–130 mg IM) or intravenously (IV; dose range 10–80 mg) as previously described (Miller et al. 2013). Because it has been shown that administration of butorphanol in the dart leads to a greater proportion of rhinoceros becoming immobilized in a standing posture (Miller et al. 2013), the effect of initial posture (standing versus recumbent) during immobilization on boma adaptation was also compared. Each immobilized rhinoceros had capture-related information recorded including sex, estimated age, environmental temperature, time from darting to signs of ataxia, time to stopping or recumbency (i.e., time dart to immobilization), time from darting to administration of diprenorphine (i.e., time dart to reversal), distance travelled by rhinoceros from locating to darting, and distance travelled after darting to becoming immobilized. The time and distance traveled to the bomas were not recorded.

Physiologic monitoring was performed and values for heart rate, respiratory rate, and rectal temperature were recorded at 5-min intervals. Blood samples were collected approximately 10–20 min after immobilization, when animal was safe to approach, from a medial auricular artery for blood gas analyses using a heparinized syringe. In addition, blood was collected into ethylenediaminetetraacetic acid (EDTA) and serum vacutainers (BD Biosciences, Franklin Lakes, New

Jersey, USA) from the radial vein for hematologic and serum biochemistry panels.

Once sample collection was completed, rhinoceros were loaded into crates and weighed using a scale on a truck-mounted hydraulic crane, administered diprenorphine (Novartis Animal Health; dose range 6–12 mg IV) and zuclopenthixol acetate (Clopixol-Acuphase, H. Lundbeck Pty. Ltd., North Riding, South Africa; dose range 50–100 mg IM) as a long-acting tranquilizer and transported to rhinoceros holding bomas at a single site within Kruger National Park. Animals were housed individually except pairs of subadults that were captured together and considered compatible. Feeding and management routines followed established protocols (Miller et al. 2016). Animals were held in bomas for variable amounts of time prior to being translocated. When feasible, the rhinoceros were weighed in the crate when released from the bomas.

### Sample processing

Arterial blood samples were immediately analyzed in the field using a portable blood gas analyzer (iSTAT1 Handheld Clinical Analyzer, Heska Corporation, Loveland, Colorado, USA) and CG4+ cartridge (Heska Corporation) as previously described (Miller et al. 2013). White and red blood cell counts, platelet counts, and red blood cell parameters were analyzed using an automated hematology analyzer (Vet ABC, Scil Animal Care Company, Gurnee, Illinois, USA) available in the Veterinary Wildlife Services laboratories in Kruger National Park. Packed cell volumes (PCV) and total protein values were measured manually using a microhematocrit centrifuge and refractometer. Blood smears were prepared with a commercial eosin-methylene blue stain (Kyro-Quick stain, Kyron Laboratories) for manual differential counts. Serum chemistry panels were performed using the ABAXIS VetScan2 chemistry analyzer (ABAXIS, Inc., Union City, California, USA) and Large Animal chemistry rotor (ABAXIS), as previously described (Mathebula et al. 2012).

### Boma adaptation criteria

A scoring system was developed during this project to provide a standardized method for assessing boma adaptation in white rhinoceros (Miller et al. 2016). Scores were based on appetite, fecal consistency and volume, and behavior. Scoring was performed daily throughout the duration of boma confinement for each individual rhinoceros. Using this scoring system, a rhinoceros that was considered boma-adapted had a total median score $>15$. Maladapted individuals were identified by median scores of $\leq 15$ and/or a declining score within the first 8–16 d compared to adapted rhinoceros. Rhinoceros that were maladapted were transported to the areas in which they were captured and released, except for one animal that died.

### Data analyses

Descriptive statistics (mean, SD, median and range) were obtained for each variable under investigation (age, sex, body weight, health status, route of butorphanol administration, whether the rhinoceros was standing or recumbent when immobilized) as well as arterial blood gas and hematologic and serum biochemical values. Because there were some missing data, descriptive statistics were based on the number of study rhinoceros with data available, which is reflected by varying sample numbers in the tables. Results were stratified and compared between adapted and maladapted rhinoceros. Data were recorded in Excel spreadsheets (Microsoft Coporation 2007), and Stata Statistical Software (StataCorp 2009) version 11 was used to perform data formatting and statistical analysis. Data from each parameter were assessed for normality visually using a histogram with a density curve and more formally by using the Shapiro-Wilk test for normality. The distributions of each variable (mean, SD, percentage and 95% confidence interval [CI]) were calculated for rhinoceros that were boma-adapted and for those that were maladapted and compared using the Wilcoxon rank sum test. Relative risk (RR) and odds ratio (OR) were also calculated for dichotomous variables (i.e., sex, butorphanol administered in dart versus IV, standing versus recumbent posture) to compare the probabilities or odds of maladaptation between different groups using the chi-square and Fisher exact tests. Differences were considered statistically significant at $P<0.05$.

## RESULTS

Between 2009 and 2011, 96 free-ranging white rhinoceros (53 females and 43 males) were captured and held in the bomas between 8–187 d. Of these, 73 were subadults ranging in estimated age from 3–7 yr, with 23 adults aged $\geq 7$ yr. A total of 18 maladapted rhinoceros required early release (8–16 d after capture) and one animal died from suspected acute salmonellosis during the 3-yr study period (proportion of maladapted rhinoceros = 19.8%; 95% CI, 12.4%–29.2%). There were no statistical differences in sex

TABLE 1. Summary of demographic and immobilization variables and comparison between boma-adapted and maladapted white rhinoceros (*Ceratotherium simum*) captured between 2009 and 2011 in Kruger National Park, South Africa.

| Variable[a] | *n* | Mean | SD | p25 | Median | p75 | *P** |
|---|---|---|---|---|---|---|---|
| Time dart to ataxia (min) | | | | | | | 0.66 |
| Adapted | 67 | 3.9 | 2.3 | 2.67 | 3.48 | 4.65 | |
| Maladapted | 17 | 3.5 | 1.5 | 2.3 | 3.07 | 4.38 | |
| Time dart to immobilization (min) | | | | | | | 0.51 |
| Adapted | 66 | 8.5 | 5.0 | 4.90 | 6.58 | 11.38 | |
| Maladapted | 17 | 10.1 | 6.3 | 4.98 | 7.35 | 12 | |
| Time dart to reversal (min) | | | | | | | 0.77 |
| Adapted | 72 | 24.6 | 5.3 | 21.0 | 23.77 | 28.0 | |
| Maladapted | 18 | 24.4 | 5.9 | 24 | 26 | 40 | |
| Time immobilization to reversal (min) | | | | | | | 0.52 |
| Adapted | 60 | 15.9 | 5.5 | 11.7 | 15.9 | 18.5 | |
| Maladapted | 17 | 15.1 | 4.4 | 13.0 | 15.3 | 17.7 | |
| Distance before dart (m) | | | | | | | 0.09 |
| Adapted | 72 | 886 | 858 | 300 | 600 | 1,200 | |
| Maladapted | 18 | 548 | 580 | 200 | 350 | 800 | |
| Distance after dart (m) | | | | | | | 0.17 |
| Adapted | 72 | 824 | 485 | 500 | 800 | 1,000 | |
| Maladapted | 18 | 705 | 469 | 400 | 600 | 800 | |

[a] p25 = 25th percentile; p75 = 75th percentile.

* *P* value calculated using Wilcoxon rank sum test.

(54.2% versus 60.8% females; *P*=0.63) or age class (44.4% versus 39.1% adults; *P*=0.098) between rhinoceros that adapted to the boma and those that did not, respectively. Maladaptation occurred in 26.4% of female and 23.2% of male rhinoceros captured (RR=1.1; OR=1.2; *P*=0.70). Mean±SD body weights at capture in adapted (1,460±314 kg) and maladapted (1,526±287 kg) rhinoceros were not statistically different (*P*=0.42). Mean±SD environmental temperatures at the time of capture did not different significantly between adapted and maladapted rhinoceros, respectively (20.0±4.8 C versus 21.4±1.9 C; *P*=0.16).

Routes of butorphanol administration were compared to determine if this had an effect on boma adaptation. There was no significant difference in proportions of maladapted rhinoceros between groups (23.3% of animals administered butorphanol IV versus 28.6% IM by dart; RR=0.8; OR=0.76; *P*=0.55). There was no significant difference in the proportions of standing versus recumbent animals that were maladapted to the bomas (29.0% and 23.4%, respectively; RR=0.8; OR=0.75; *P*=0.54). The mean ±SD duration of immobilization did not differ between adapted (15.9±5.5 min) and maladapted (15.1±4.4 min) rhinoceros (*P*=0.52). Additional capture-related data are shown in Table 1. There were no values that showed a significant difference between boma-adapted and maladapted rhinoceros.

Arterial blood gas and heart and respiratory rate are summarized in Table 2. Overall, there were no significant differences in any of the measured values at 10–20 min postimmobilization between rhinoceros that eventually adapted to the bomas and those that were maladapted. Hematologic values were not significantly different between boma-adapted and maladapted rhinoceros (Tables 3 and 4). Similarly, serum biochemical values were not significantly different between the two groups except for lower median aspartate aminotransferase (AST; 68.4 and 53.4 U/L, respectively; *P*=0.0001), blood urea nitrogen (BUN; 3.25

TABLE 2. Comparison of blood gas and heart and respiration rate values measured at 10–20 mins postimmobilization in boma-adapted and maladapted white rhinoceros (*Ceratotherium simum*) captured between 2009 and 2011 in Kruger National Park, South Africa.

| Variable[a] | *n* | Mean | SD | p25 | Median | p75 | *P** |
|---|---|---|---|---|---|---|---|
| Respiration rate (breaths/min) | | | | | | | 0.78 |
| Adapted | 67 | 13.9 | 3.9 | 12 | 12 | 16 | |
| Maladapted | 16 | 13.6 | 3.9 | 11.5 | 12 | 17 | |
| Heart rate (beats/min) | | | | | | | 0.38 |
| Adapted | 67 | 110.8 | 22.4 | 96 | 108 | 132 | |
| Maladapted | 15 | 104.5 | 27.1 | 84 | 108 | 126 | |
| pH | | | | | | | 0.49 |
| Adapted | 64 | 7.2 | 0.1 | 7.14 | 7.21 | 7.28 | |
| Maladapted | 13 | 7.2 | 0.1 | 7.20 | 7.23 | 7.28 | |
| $PaCO_2$ (kPa) | | | | | | | 0.87 |
| Adapted | 64 | 8.05 | 1.57 | 7.28 | 7.74 | 9.27 | |
| Maladapted | 13 | 8.05 | 1.37 | 7.41 | 8.01 | 9.08 | |
| $PaO_2$ (kPa) | | | | | | | 0.84 |
| Adapted | 64 | 6.36 | 1.81 | 6.25 | 7.58 | 9.84 | |
| Maladapted | 12 | 6.34 | 2.03 | 4.85 | 5.92 | 7.85 | |
| BEecf (mmol/L) | | | | | | | 0.55 |
| Adapted | 64 | −3.5 | 7.0 | −8 | −3 | −1 | |
| Maladapted | 13 | −2.4 | 6.1 | −3 | −2 | 2 | |
| $HCO_3$ (mmol/L) | | | | | | | 0.55 |
| Adapted | 64 | 24.2 | 5.7 | 20.5 | 24.6 | 28.5 | |
| Maladapted | 13 | 25.23 | 5.25 | 24.4 | 25.4 | 28.6 | |
| $TCO_2$ (mmol/L) | | | | | | | 0.63 |
| Adapted | 64 | 26.1 | 6.0 | 22 | 26.5 | 31 | |
| Maladapted | 13 | 27.00 | 5.49 | 26 | 27 | 30 | |
| $SaO_2$ (%) | | | | | | | 0.97 |
| Adapted | 64 | 68.1 | 18.9 | 59 | 71 | 83 | |
| Maladapted | 12 | 68.67 | 18.13 | 53.5 | 73.5 | 85 | |
| Lactate (mmol/L) | | | | | | | 0.40 |
| Adapted | 51 | 10.6 | 5.5 | 6.3 | 10.2 | 14.2 | |
| Maladapted | 10 | 9.04 | 6.24 | 4.43 | 6.78 | 12.61 | |

[a] p25 = 25th percentile; p75 = 75th percentile; $PaCO_2$ = arterial partial pressure of carbon dioxide; PaO2 = arterial partial pressure of oxygen; BEecf = base excess in the extracellular fluid compartment; $HCO_3$ = bicarbonate; $TCO_2$ = total carbon dioxide; $SaO_2$ = arterial oxygen saturation.

* *P* value calculated using Wilcoxon rank sum test.

and 3.93 mmol/L, respectively; $P= 0.02$), and lower median phosphorus (P; 1.36 and 1.49 mmol/L, respectively; $P=0.048$) in the maladapted compared to the adapted rhinoceros (Tables 3 and 4).

Boma scores for the maladapted and adapted rhinoceros have been previously reported (Miller et al. 2016). The daily boma scores between adapted and maladapted rhinoceros did not start to vary significantly until day 8 (data available in Miller et al. 2016), with adapted rhinoceros scores increasing while maladapted animal scores remained low or declined, leading to release and one death (8–16 d postcapture).

## DISCUSSION

Boma maladaptation of free-ranging white rhinoceros is a recognized risk when translocating this species, although the underlying causes are largely unknown (Rogers 1993). The lack of adjustment to confinement results in loss of body condition and potentially

TABLE 3. Comparison of hematologic values collected from immobilized boma-adapted and maladapted white rhinoceros (*Ceratotherium simum*) captured between 2009 and 2011 in Kruger National Park, South Africa.

| Variable[a] | *n* | Mean | SD | p25 | Median | p75 | *P** |
|---|---|---|---|---|---|---|---|
| WBC ($\times 10^9$/L) | | | | | | | 0.74 |
| Adapted | 76 | 16.88 | 6.26 | 13 | 15 | 18.9 | |
| Maladapted | 18 | 16.42 | 7.50 | 11 | 15.4 | 21.2 | |
| Neutrophils (%) | | | | | | | 0.61 |
| Adapted | 76 | 43.10 | 10.25 | 37.5 | 45 | 50.5 | |
| Maladapted | 18 | 42.28 | 9.98 | 36 | 43.5 | 49 | |
| Lymphocytes (%) | | | | | | | 0.44 |
| Adapted | 76 | 25.54 | 8.70 | 20 | 25 | 30 | |
| Maladapted | 18 | 27.44 | 7.42 | 23 | 26 | 29 | |
| Monocytes (%) | | | | | | | 0.73 |
| Adaptive | 76 | 13.04 | 7.40 | 9 | 12 | 17 | |
| Maladaptive | 18 | 12.89 | 4.03 | 12 | 12.5 | 14 | |
| Eosinophils (%) | | | | | | | 0.49 |
| Adapted | 76 | 16.22 | 6.91 | 11 | 16 | 21 | |
| Maladapted | 18 | 14.78 | 5.96 | 11 | 14.5 | 18 | |
| Basophils (%) | | | | | | | 0.82 |
| Adapted | 76 | 1.05 | 3.06 | 0 | 0 | 0 | |
| Maladapted | 18 | 0.78 | 2.58 | 0 | 0 | 0 | |
| Bands (%) | | | | | | | 0.15 |
| Adapted | 76 | 0.40 | 1.46 | 0 | 0 | 0 | |
| Maladapted | 18 | 0 | 0 | 0 | 0 | 0 | |

[a] p25 = 25th percentile; p75 = 75th percentile; WBC = white blood cell.

* *P* value calculated using Wilcoxon rank sum test.

increased risk of disease and death. This study investigated demographic and capture-related factors that might influence white rhinoceros adaptation, to improve selection or immobilization techniques leading to a higher rate of success. Although approximately one in five of all white rhinoceros subjected to boma confinement were considered maladapted, there were no clinically significant differences in age, sex, body weight, immobilization variables, or physiologic measurements associated with the outcome.

Factors such as age, sex, and body condition have been linked to postcapture success of free-ranging wildlife. Age-related mortality has been observed in wild-caught Asian elephants (Lahdenperä et al. 2018). A study in North American wild ungulates observed that body condition and sex generally did not affect postcapture survival, although age was not investigated (Bender 2015). Although this has not been investigated systematically, younger rhinoceros have been reported to adapt better to bomas than do older animals (Rogers 1993). In our study, most captured rhinoceros were considered subadults (3 to <7 yr of age), based on selection criteria for translocation candidates. However, none of the demographic characteristics of the captured rhinoceros appeared to influence boma adaptation.

Immobilization techniques are known to affect the risks associated with capture-related morbidity and mortality (Arnemo et al. 2006). Helicopter-based capture of free-ranging wildlife is expected to cause short-term stress, which may play a role in acute adjustment to captivity (Arnemo et al. 2006; Hampton et al. 2016). Chase time, distance, and time to immobilization should be as short as possible to minimize exertion, hyperthermia, and risk of trauma (Meltzer and Kock 2012). In our current study, there were no statistical differences in multiple capture values between

TABLE 4. Comparison of serum biochemistry values from immobilized boma-adapted and maladapted white rhinoceros (*Ceratotherium simum*) captured between 2009 and 2011 in Kruger National Park, South Africa.

| Variable[a] | *n* | Mean | SD | p25 | Median | p75 | *P** |
|---|---|---|---|---|---|---|---|
| Albumin (g/L) | | | | | | | 0.08 |
| Adapted | 77 | 25 | 4 | 24 | 26 | 28 | |
| Maladapted | 19 | 27 | 2 | 25 | 27 | 28 | |
| ALP (U/L) | | | | | | | 0.34 |
| Adapted | 77 | 73.8 | 19.2 | 60.0 | 73.2 | 82.2 | |
| Maladapted | 19 | 69.0 | 16.8 | 56.4 | 66.0 | 83.4 | |
| AST (U/L) | | | | | | | 0.0001 |
| Adapted | 77 | 69.0 | 17.4 | 60 | 68.4 | 76.2 | |
| Maladapted | 19 | 52.8 | 15.0 | 42.0 | 53.4 | 59.4 | |
| Calcium (mmol/L) | | | | | | | 0.77 |
| Adapted | 77 | 3.00 | 0.20 | 2.90 | 3.00 | 3.15 | |
| Maladapted | 19 | 3.02 | 0.15 | 2.92 | 3.00 | 3.13 | |
| GGT (U/L) | | | | | | | 0.56 |
| Adapted | 77 | 14.4 | 4.8 | 10.8 | 13.2 | 16.2 | |
| Maladapted | 19 | 13.2 | 3.6 | 10.2 | 12.0 | 16.2 | |
| Total protein (g/L) | | | | | | | 0.36 |
| Adapted | 77 | 98 | 13 | 94 | 99 | 104 | |
| Maladapted | 19 | 97 | 04 | 94 | 96 | 101 | |
| Globulin (g/L) | | | | | | | 0.09 |
| Adapted | 77 | 74 | 09 | 69 | 73 | 79 | |
| Maladapted | 19 | 71 | 04 | 67 | 70 | 73 | |
| BUN (mmol/L) | | | | | | | 0.02 |
| Adapted | 77 | 3.93 | 1.07 | 3.21 | 3.93 | 4.64 | |
| Maladapted | 19 | 3.25 | 0.71 | 2.50 | 3.21 | 3.93 | |
| CPK (U/L) | | | | | | | 0.30 |
| Adapted | 77 | 201.6 | 72.0 | 155.4 | 187.2 | 226.2 | |
| Maladapted | 19 | 182.4 | 46.2 | 149.4 | 171.6 | 200.4 | |
| Phosphorus (mmol/L) | | | | | | | 0.048 |
| Adapted | 77 | 1.49 | 0.26 | 1.29 | 1.49 | 1.65 | |
| Maladapted | 19 | 1.36 | 0.19 | 1.23 | 1.32 | 1.49 | |
| Magnesium (mmol/L) | | | | | | | 0.37 |
| Adapted | 77 | 1.28 | 0.16 | 1.19 | 1.28 | 1.40 | |
| Maladapted | 19 | 1.28 | 0.08 | 1.15 | 1.23 | 1.32 | |

[a] p25 = 25th percentile; p75 = 75th percentile; ALP = alkaline phosphatase; AST = aspartate aminotransferase; GGT = gamma-glutamyl transferase; BUN = blood urea nitrogen; CPK = creatinine phosphokinase.

* *P* value calculated using Wilcoxon rank sum test.

boma-adapted and maladapted rhinoceros, including lactate levels as a measure of exertion. However, because data were collected under field conditions, there were several factors that could not be controlled, such as distances run or time for the drug to take effect. Regardless of the variation, factors associated with helicopter-based darting of white rhinoceros by an experienced team did not appear to predispose to boma maladaptation.

Immobilizing drugs used in white rhinoceros include potent opioids, such as etorphine, which result in severe hypoxemia and metabolic changes (Wenger et al. 2007; Miller et al. 2013; Buss et al. 2018). The animals in this study were physiologically compromised by the immobilization drugs and capture technique when compared to resting awake white rhinoceros (Citino and Bush 2007). All rhinoceros had elevated heart rates, metabolic acidosis, hypoxemia, and hypercapnia. Nevertheless, the immobilization protocol and resulting physiologic changes did not appear to influence the ability to adapt to boma conditions. Although the duration of immobilization was relatively short, the potential long-term effects of these acute changes on rhinoceros health are unknown and should be investigated.

Preexisting health abnormalities may predispose individual rhinoceros to maladaptation (Osofsky et al. 1996). Because apparently healthy free-ranging white rhinoceros were selected for capture, it was expected that hematologic and serum biochemistry panel values would be within normal ranges (Mathebula et al. 2012; Miller et al. 2015). The relatively high percentage of eosinophils in both groups was presumably due to the ecto- and endoparasite loads normally present in free-ranging rhinoceros. Overall, there were no clinically relevant statistical differences between adapted and maladapted rhinoceros, and values for both cohorts were within expected ranges. Although it is possible that the maladapted rhinoceros had underlying disease that was not reflected in the blood results, the overall results suggest that both groups of captured rhinoceros were healthy when placed in the bomas.

Fortunately, the number of maladapted rhinoceros included in the analyses was small. However, the small sample size, along with some missing data in both cohorts, probably affected the ability to find associations. Other limitations included the inherent variability present when capturing free-ranging animals and the single sampling point used for physiologic measurements. Ideally, serial sampling might provide insights into the longer-term adaption process, although opportunities to handle animals were limited. In addition, evaluation of ongoing stress was limited to observations used to determine the daily boma score for each rhinoceros.

Overall, our findings in this study did not identify obvious intrinsic or extrinsic factors that could explain maladaptation of certain individuals. Therefore, we hypothesized that the failure to adapt is more likely associated with the ongoing stress of holding rather than the acute stress of capture. Further investigations are needed to determine the etiology of maladaptation to improve the welfare of free-ranging white rhinoceros being confined to bomas.

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