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Author: Osofsky, Steven A.

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A PRACTICAL ANESTHESIA MONITORING PROTOCOL FOR FREE-RANGING ADULT AFRICAN ELEPHANTS (*LOXODONTA AFRICANA*)

Steven A. Osotsky

Botswana Department of Wildlife and National Parks, P.O. Box 131, Gaborone, Botswana, Africa. Present address:
USAID Biodiversity Program c/o 121 Courthouse Road, SW, Vienna, Virginia 22180, USA

ABSTRACT: Twenty free-ranging adult African elephants (*Loxodonta africana*) in northern Botswana were immobilized with a mean (\pm SD) of 9.5 ± 0.5 mg etorphine hydrochloride and 2,000 IU hyaluronidase by intramuscular (IM) dart. The mean time to recumbency was 8.7 ± 2.4 min. All animals were maintained in lateral recumbency. The anesthesia monitoring protocol included cardiothoracic auscultation; palpation of auricular pulse for quality and regularity; checking of rectal temperature, and monitoring of respiratory and heart rates. Results of basic physiologic measurements were similar to those of previous field studies of African elephants immobilized with etorphine or etorphine-hyaluronidase. In addition, continuous real-time pulse rate and percent oxygen saturation of hemoglobin (SpO₂) readings were obtained on 16 elephants with a portable pulse oximeter. Duration of pulse oximetry monitoring ranged from 3 to 24 min (mean \pm SD = 8.2 ± 4.8 min). Differences between minimum and maximum SpO₂ values for any given elephant ranged from 1 to 6 percentage points, evidence for relatively stable trends. The SpO₂ readings ranged from 70% to 96% among the 16 elephants, with a mean of $87.3 \pm 2.8\%$. Fifteen of 16 elephants monitored with a pulse oximeter had mean SpO₂ values $\geq 81 \pm 2.4\%$, with 11 having mean SpO₂ values $\geq 85 \pm 1.5\%$. All 20 animals recovered uneventfully following reversal: diprenorphine at 23.3 ± 1.5 mg intravenous (IV) with 11.7 ± 0.5 mg IM, or 24 mg diprenorphine given all IV.

Key words: African elephant, *Loxodonta africana*, etorphine HCl, anesthesia, oxygen saturation, pulse oximetry.

INTRODUCTION

Use of etorphine hydrochloride with hyaluronidase to immobilize free-ranging elephants (*Loxodonta africana*) has been well documented (Wallach and Anderson, 1968; Harthoorn, 1976; Kock et al., 1993a). Other agents, including carfentanil, have been used successfully in the field (Raath, 1993) and in captivity (Jacobson et al., 1988). Hyaluronidase, by increasing tissue permeability and thus the absorption rate of the immobilizing agent used with it, has proven effective in reducing induction times in a variety of thick-skinned mammals (Harthoorn, 1976; Haigh, 1979; Kock, 1992).

Anesthetized, sternally recumbent elephants are at high risk for hypoxemia (Harthoorn, 1973b). Even unsedated, laterally recumbent, healthy African and Asian elephants can become hypoxemic (Honeyman et al., 1992). In species without the elephant's unique bulk and anat-

omy, etorphine produces respiratory depression (Harthoorn, 1973a).

The use of blood gas analysis has been reported in captive and free-ranging elephants, but no data from pulse oximetry in free-ranging African elephants were found (Heard et al., 1986; Kock et al., 1993b; Dunlop et al., 1994). Pulse oximetry monitoring has been applied in captive elephants, with one study involving an Asian elephant (*Elaphas maximus*) providing for favorable comparisons between percent oxygen saturation of hemoglobin (SpO₂) values from a pulse oximeter and measurements of arterial blood gases (Mihm et al., 1988).

Contemporary and historical field immobilization results have recently been compared, and reports on the use of pulse oximetry as part of the anesthesia monitoring protocol in free-ranging elephants were lacking (Kock et al., 1993a). Real-time pulse oximetry was evaluated as part of a practical anesthesia monitoring protocol for free-ranging African elephants.

MATERIALS AND METHODS

Twenty elephants were immobilized in October 1992 ($n = 12$) or May 1993 ($n = 8$) as part of the Botswana Department of Wildlife and National Park's elephant habitat utilization research program, relying predominantly on the use of radio collars. All 20 elephants were captured in northern Botswana (capture sites: 17°50' to 19°32'S; 23°00' to 27°07'E). Environmental temperatures varied from 21 C to 35 C (mean \pm SD = 27.1 \pm 4.3 C) during capture exercises. Based on visual size comparisons at the time of darting, 17 elephants were judged to be adult females, one was a younger adult female, and two were adult males. All 20 elephants were found in groups ranging from three to 69 individuals (mean = 31). All dartings were performed using the Palmer Cap Chur® Long-Range Projector with 3 ml darts attached to 65 mm long, 5 mm wide side-bore collared elephant needles (Photo Agencies, Johannesburg, Republic of South Africa). The first two animals were darted from ground vehicles, and the other 18 from a helicopter.

All elephants were immobilized with a mean (\pm SD) of 9.5 \pm 0.5 mg etorphine hydrochloride (M99—4.9 or 9.8 mg/ml, Kruger-Med Pharmaceuticals, Johannesburg, Republic of South Africa) and 2000 IU hyaluronidase (Hyalase, Zimethicals, Harare, Zimbabwe). Reversal of etorphine was accomplished with diprenorphine hydrochloride at 23.3 \pm 1.5 mg intravenous (IV) with 11.7 \pm 0.5 mg intramuscular (IM), or 24 mg diprenorphine given all IV (M5050—12 mg/ml, Kruger-Med Pharmaceuticals).

All animals were darted in the left side, with darts targeted at large muscle groups in the left hind quarters. Dart impact sites were the lateral thigh ($n = 9$), hip ($n = 7$), cranial thigh ($n = 2$), caudal thigh ($n = 1$), and caudodorsal abdomen ($n = 1$). All accessible dart sites were treated by infusion with an antibiotic preparation consisting of 500,000 IU potassium penicillin G, 1,000,000 IU procaine penicillin, and 500 mg neomycin (Neomastitar, Phenix S. A., Johannesburg, Republic of South Africa).

A sterile ophthalmic ointment (Lacrilube, Allergan Pharmaceuticals, Johannesburg, Republic of South Africa) was applied to the exposed eye of each elephant prior to blindfolding with a soft towel. Blood and fecal samples were obtained. Shoulder height was measured from the most dorsal point of the shoulder to the most distal part of the foot along as straight a line as possible down the side of the leg. Weights of elephants were estimated, based on subjective evaluations of body condition, shoulder height measurements, and average weights derived

from the literature (Harthoorn, 1976; Estes, 1991).

Time to first effect was the period from darting to the first observed signs of etorphine's effect, which usually consisted of a combination of slowing of the gait, lagging behind the herd, foot dragging, head weaving, stumbling or mild ataxia, and lack of trunk coordination. Time to recumbency was defined as the time from darting to sternal or lateral recumbency. Time to first arousal post-diprenorphine was the time from administration of diprenorphine to any change or combination of changes observed, including ear movements, head movements, increased depth or rate of respirations, trunk movements, vocalizations, leg movements, or a sudden attempt at rocking into sternal. Total elapsed time was the time from darting to standing.

The anesthesia monitoring protocol included cardi thoracic auscultation; palpation of auricular pulse for quality and regularity; checking of distal rectal temperature with a human digital thermometer, and monitoring of respiratory and heart rates. Respiratory rates were obtained during auscultation, by watching chest excursions, and by checking air movements at the tip of the trunk. Heart rates obtained during auscultation, auricular pulse rates, and oximeter-recorded pulse rates were compared to ensure accuracy. Continuous real-time pulse rate and percent oxygen saturation of hemoglobin (SpO₂) readings were obtained on 16 elephants with a portable pulse oximeter. In October 1992, the Nellcor N-180 (Nellcor, Inc., Hayward, California, USA) was used, while the Nellcor N-20P (Nellcor, Inc.) was used in May 1993. Human disposable SpO₂ sensors (Oxisensor D-25, Nellcor, Inc.) were attached to wooden clothespins, the mouths of which had been modified to fit on an elephant's ear. Readings were taken from the dependent ear in all cases. Gentle scraping of epithelium with a scalpel blade (without eliciting hemorrhage) was sometimes needed to get good recordings from the ear, as reported by Allen (1992). A pulse oximetry sensor was attached to each elephant as soon as it was observed to be safely anesthetized in lateral recumbency. The site of attachment was covered with a hat or towel so sunlight would not interfere with the sensor's operation. The pulse oximeter was detached immediately prior to administration of the anesthetic reversal agent. Reported SpO₂ and pulse rate values represent means for any given minute, and all times are rounded to the nearest minute. Minute 1 was defined as starting when the dart first hit an elephant.

RESULTS

All elephants were successfully immobilized with a single intramuscular dart and all were safely approached and handled with this drug combination. Shoulder height ranged from 2.40 to 2.87 m (mean \pm SD = 2.62 ± 0.12 m). The mean estimated weight was 4,300 kg.

Three of the elephants went into right lateral recumbency during anesthetic induction, six went into left lateral, and 11 went down in sternal recumbency. All sternally recumbent animals were pushed into lateral recumbency to preclude respiratory compromise, yielding eight animals in right lateral and 12 animals in left lateral recumbency.

The time to first effect ranged from 1.6 to 9.5 min (mean \pm SD = 3.8 ± 1.8 min). All elephants were deemed safely immobilized in sternal or lateral recumbency between 4.9 and 14.3 min post-darting (mean \pm SD = 8.7 ± 2.4 min). The time to first arousal post-diprenorphine ranged from 1.3 to 4.0 min (mean \pm SD = 2.2 ± 0.67 min). Anesthesia was reversed uneventfully in all elephants, and all were standing between 1.8 and 9.6 min post-administration of diprenorphine (mean \pm SD = 3.6 ± 2.1 min). Total elapsed time of procedures ranged from 21.9 to 39.4 min (mean \pm SD = 29.6 ± 4.8 min).

Rectal temperatures ranged from 35.6 to 37.8 C (mean \pm SD = 36.4 ± 0.72 C). Respiratory rates ranged from 4 to 12 breaths per min. Averaging the data from the 16 pulse oximeter-monitored elephants for each minute, the mean pulse rate ranged from 43 to 54 beats per min (mean \pm SD = 48 ± 2.4 beats per min) (Fig. 1). Assessing the 16 elephants individually, pulse rates ranged from 34 to 80 beats per min. Heart rates obtained from auscultation as well as palpation of the auricular pulse were intermittently compared to readings obtained from the pulse oximeter, and used confirmed to the machine's accuracy.

Differences between minimum and

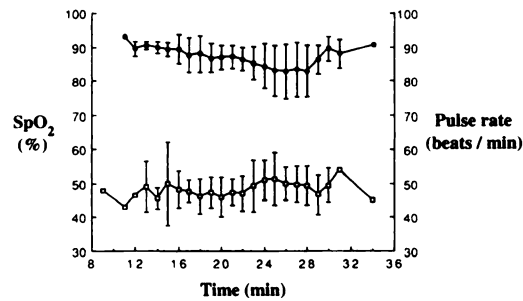


FIGURE 1. Mean (\pm SD) percent oxygen saturation of hemoglobin (SpO₂) and pulse rate profiles for 16 adult African elephants (15 females, one male) anesthetized with a combination of etorphine and hyaluronidase. (●) = SpO₂ (%). (□) = Pulse rate (per min). Individual elephants may have had gaps in their SpO₂/pulse rate records for a variety of reasons, including occasional sensor detachment, intermittent failure to obtain a reading, or lapses in manual recording of data from the pulse oximeter that lacked a built-in printer. Thus, not all 16 elephants have contributed data to each point on the graph. Minute 1 started when the dart first hit the elephant.

maximum SpO₂ values for any given elephant ranged from 1 to 6 percentage points, evidence for relatively stable trends. The SpO₂ readings ranged from 70% to 96% among the 16 elephants, with the overall mean (\pm SD) SpO₂ being $87.3 \pm 2.8\%$ (Fig. 1). The duration of pulse oximetry monitoring for the 16 individual elephants ranged from 3 to 24 min (mean \pm SD = 8.2 ± 4.8 min). Four of the 20 elephants attached to a pulse oximeter did not yield pulse oximetry readings.

DISCUSSION

Individual elephants may have had gaps in their SpO₂/pulse records for a variety of reasons, including occasional sensor detachment, intermittent failure to obtain a reading, or lapses in manual recording of data from the pulse oximeter that lacked a built-in printer (Nellcor N-180). Thus, not all 16 elephants were used for each of the points in Figure 1. Nine minutes was the quickest time post-darting that it was possible to reach at least one animal and successfully determine a pulse rate. Eleven minutes was the quickest time post-darting that it was possible to reach at least one

animal and successfully start to record pulse oximeter readings because a number of other anesthetic monitoring and research activities were being carried out simultaneously. Thirty-four minutes was the longest time post-darting that the pulse oximeter was still on at least one elephant. The times to recumbency post-darting and times to standing post-reversal observed in this study are deemed safe for free-range elephants. Anesthetic event parameters, rectal temperatures, pulse rates, and respiratory rates obtained here were similar to those of previous field studies of African elephants immobilized with etorphine or etorphine-hyaluronidase (Wallach and Anderson, 1968; Ebedes, 1975; Kock et al., 1993a; b). All 20 elephants appeared healthy.

All sixteen elephants monitored with a pulse oximeter had relatively stable SpO₂ as well as pulse rate profiles for the duration of monitoring. Why we could not obtain pulse oximeter readings from four of the 20 elephants is uncertain. The sensor clips may have made insufficient contact or conversely placed too much pressure on ears of certain thicknesses. Some ear margins, which vary in thickness along the ear as well as between individuals, may have been too thick to allow for adequate transmission or photodetection. Insufficient scraping of pigmented epithelium may have been a factor. It is possible one or more elephants were hypotensive, although auricular pulses, as monitored on the non-dependent ear, generally felt strong, and opioids are usually associated with hypertension in African elephants (Raath, 1993). It is more likely that the position of the dependent ear sometimes diminished its perfusion. Application of pulse oximetry sensors to the non-dependent ear would be worth evaluating in comparison to the technique applied here. Alternative anatomic sites were not evaluated in this study. Other reported causes of failure to obtain pulse oximetry readings include anemia, excessive motion, unblocked ambient light, the presence of ex-

ogenous intravascular dyes, and methemoglobinemia (Allen, 1992). These were not factors in this study.

A pulse oximeter can detect arterial oxygen desaturation even before heart rate, respiratory pattern, or blood pressure abnormalities are manifested (Kelleher, 1989). Hypoxemia-related anesthetic mortalities can thus be better prevented when SpO₂ is monitored (Cote' et al., 1988; Allen, 1992). Monitoring trends in oxygenation as indicators of cardiorespiratory sufficiency in nondomestic animal patients can be accurately done with pulse oximeters originally designed for human use (Allen, 1992). While slight differences in absolute values of SpO₂ readings may occur when different anatomic sites such as ears, lips, tongue, vulva, tail, finger, toe, calcaneal skin web, prepuce, or rectal mucosa are used for sensor attachment (Erhardt et al., 1990; Whitehair et al., 1990; Allen, 1992; Jacobson et al., 1992), the overall trend of readings over time should not be affected.

In human anesthesia, a serious hypoxemic event for anesthetized patients receiving supplemental oxygen (Coté et al., 1988) or for patients breathing room air postoperatively (Tyler et al., 1985) is deemed to have occurred when SpO₂ ≤ 85%. In one major human clinical study there was no relationship between oximeter-documented desaturation and anesthesia team-recognized cyanosis: arterial desaturation can precede hypoxemia-related clinical signs (Coté et al., 1988).

Comparisons between human studies and results from field immobilizations of wild animals can be helpful, but must be made with caution. Each of the 16 elephants in this study was breathing undiluted air, under the influence of a drug known to cause some degree of respiratory depression. Clinically, they all appeared to handle anesthesia well. Fifteen of 16 elephants monitored with a pulse oximeter had mean (±SD) SpO₂ values ≥81 ± 2.4%, with 11 having mean (±SD) SpO₂ values ≥85 ± 1.5%. Blood gas analysis

concurrent with pulse oximetry monitoring would have augmented interpretation of these pulse oximetry measurements, but was not available for this study. Whatever future research reveals, we recommend the carrying of an emergency kit that includes a supply of supplemental oxygen.

Most species' hemoglobin absorption spectra have not been evaluated (Erhardt et al., 1990), although elephant hemoglobin has been examined from a variety of perspectives (Riggs, 1963; Kleihauer et al., 1965; Riegel et al., 1967; Dhindsa et al., 1972). Based on comparative work on respiratory physiology, elephant blood has a higher affinity for oxygen than human blood, with elephants having the largest red blood cells among land mammals (Bartels et al., 1963; Hawkey and Dennett, 1989). As pulse oximeters measure oxygen saturation directly, they are not affected by this difference in affinity.

Real-time observation of SpO₂ trends can be a practical, valuable adjunct to elephant anesthesia monitoring protocols in the field or captive setting. Future research, aimed at investigating the red and infrared absorption spectra of the hemoglobins of wildlife species and emphasizing blood gas analysis concurrent with pulse oximetry, should facilitate going beyond the current necessary focus on trends, allowing SpO₂ measurements to be more subject to quantitative interpretation.

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