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

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ABSTRACT: Twenty free-ranging adult African elephants (*Loxodonta africana*) in northern Botswana were immobilized with a mean (±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 (SpO_2) readings were obtained on 16 elephants with a portable pulse oximeter. Duration of pulse oximetry monitoring ranged from 3 to 24 min (mean ±SD = 8.2 ± 4.8 min). Differences between minimum and maximum SpO_2 values for any given elephant ranged from 1 to 6 percentage points, evidence for relatively stable trends. The SpO_2 readings ranged from 70% to 96% among the 16 elephants, with a mean of 87.3 ± 2.8%. Fifteen of 16 elephants monitored with a pulse oximeter had mean SpO_2 values ≥81 ± 2.4%, with 11 having mean SpO_2 values ≥85 ± 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 anatomy, 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 (SpO_2) 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 ±SD = 27.1 ± 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 (±SD) of 9.5 ± 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 ± 1.5 mg intravenous (IV) with 11.7 ± 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 cardiothoracic 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 (SpO_2) 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 SpO_2 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 SpO_2 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 ±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 ±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 ±SD = 8.7 ± 2.4 min). The time to first arousal post-diprenorphine ranged from 1.3 to 4.0 min (mean ±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 ±SD = 3.6 ± 2.1 min). Total elapsed time of procedures ranged from 21.9 to 39.4 min (mean ±SD = 29.6 ± 4.8 min).

Rectal temperatures ranged from 35.6 to 37.8 C (mean ±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 ± 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 maximum SpO_2 values for any given elephant ranged from 1 to 6 percentage points, evidence for relatively stable trends. The SpO_2 readings ranged from 70% to 96% among the 16 elephants, with the overall mean (± SD) SpO_2 being 87.3 ± 2.8% (Fig. 1). The duration of pulse oximetry monitoring for the 16 individual elephants ranged from 3 to 24 min (mean ± SD = 8.2 ± 4.8 min). Four of the 20 elephants attached to a pulse oximeter did not yield pulse oximetry readings.

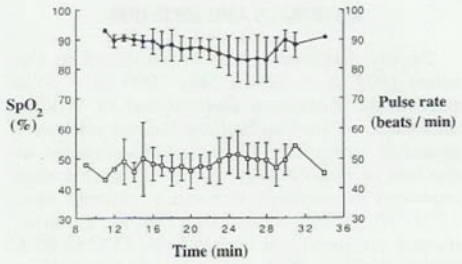

FIGURE 1. Mean (±SD) percent oxygen saturation of hemoglobin (SpO_2) and pulse rate profiles for 16 adult African elephants (15 females, one male) anesthetized with a combination of etorphine and hyaluronidase. (●) = SpO_2 (%). (□) = Pulse rate (per min). Individual elephants may have had gaps in their SpO_2/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.

DISCUSSION

Individual elephants may have had gaps in their SpO_2/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 SpO_2 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 obtained pulse oximetry readings include anemia, excessive motion, unblocked ambient light, the presence of exogenous 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 SpO_2 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 SpO_2 readings may occur when different anatomic sites such as ears, lips, tongue, vulva, tail, finger, toe, calcanean 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 $SpO_2 \leq 85\%$. 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 unadulterated 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 ($\pm$SD) SpO_2 values $\geq 81 \pm 2.4\%$, with 11 having mean ($\pm$SD) SpO_2 values $\geq 85 \pm 1.5\%$. Blood gas analysis

ncurrent with pulse oximetry monitoring ould have augmented interpretation of ese pulse oximetry measurements, but s not available for this study. Whatever ture research reveals, we recommend e carrying of an emergency kit that in- ides a supply of supplemental oxygen.

Most species' hemoglobin absorption ectra have not been evaluated (Erhardt al., 1990), although elephant hemoglo- n has been examined from a variety of rspectives (Riggs, 1963; Kleihauer et al., 65; Riegel et al., 1967; Dhindsa et al., 72). Based on comparative work on re- ratory physiology, elephant blood has a gher affinity for oxygen than human ood, with elephants having the largest l blood cells among land mammals (Bar- s et al., 1963; Hawkey and Dennett, 89). As pulse oximeters measure oxygen uration directly, they are not affected by s difference in affinity.

Real-time observation of SpO_2 trends n be a practical, valuable adjunct to el- hant anesthesia monitoring protocols in field or captive setting. Future re- urch, aimed at investigating the red and rared absorption spectra of the hemo- bins of wildlife species and emphasizing ood gas analysis concurrent with pulse metry, should facilitate going beyond current necessary focus on trends, al- ving SpO_2 measurements to be more ject to quantitative interpretation.

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LITERATURE CITED

EN, J. L. 1992. Pulse oximetry; everyday uses in a zoological practice. The Veterinary Record 130: 354–355.

ITELS, H., P. HILPERT, K. BARBEY, K. BETKE, K. RIEGEL, E. M. LANG, AND J. METCALFE. 1963. Respiratory functions of blood of the yak, llama, camel, Dybowski deer, and African elephant. American Journal of Physiology 205: 331–336.

TÉ, C. J., E. A. GOLDSTEIN, M. A. COTÉ, D. C. HOAGLIN, AND J. F. RYAN. 1988. A single-blind study of pulse oximetry in children. Anesthesiology 68: 184–188.

DHINDSA, D. S., C. J. SEDGWICK, AND J. METCALFE. 1972. Comparative studies of the respiratory functions of mammalian blood VIII. Asian elephant (*Elaphas maximus*) and African elephant (*Loxodonta africana africana*). Respiratory Physiology 14: 332–342.

DUNLOP, C. I., D. S. HODGSON, R. C. CAMBRE, D. E. KENNEY, AND H. D. MARTIN. 1994. Cardiopulmonary effects of three prolonged periods of isoflurane anesthesia in an adult elephant. Journal of the American Veterinary Medical Association 205: 1439–1444.

EBEDES, H. 1975. The immobilization of adult male and female elephant *Loxodonta africana*, Blumenbach with etorphine and observation on the action of diprenorphine. Madoqua 9: 19–24.

ERHARDT, W., C. LENDL, R. HIPP, G. VON HEGEL, G. WIESNER, AND H. WIESNER. 1990. The use of pulse oximetry in clinical veterinary anaesthesia. Journal of the Association of Veterinary Anaesthesiology 17: 30–31.

ESTES, R. D. 1991. The behavior guide to african mammals. University of California Press, Berkeley, California, pp. 259–267.

HAIGH, J. C. 1979. Hyaluronidase as an adjunct in an immobilizing mixture for moose. Journal of the American Veterinary Medical Association 175: 916–917.

HARTHOORN, A. M. 1973a. Review of wildlife capture drugs in common use. *In* The capture and care of wild animals, E. Young (editor). Human and Rousseau Publishers Ltd., Pretoria, Republic of South Africa, pp. 14–34.

———. 1973b. The drug immobilization of large herbivores other than the antelopes. *In* The capture and care of wild animals, E. Young (editor). Human and Rousseau Publishers Ltd., Pretoria, Republic of South Africa, pp. 51–61.

———. 1976. The chemical capture of animals. Bailliere Tindall, London, United Kingdom, 416 pp.

HAWKEY, C. M., AND T. B. DENNETT. 1989. Color atlas of comparative veterinary hematology. Iowa State University Press, Ames, Iowa, pp. 9, 16–17.

HEARD, D. J., E. R. JACOBSON, AND K. A. BROCK. 1986. Effects of oxygen supplementation on blood gas values in chemically restrained, juvenile African elephants. Journal of the American Veterinary Medical Association 189: 1071–1074.

HONEYMAN, V. L., G. R. PETTIFER, AND D. H. DYSON. 1992. Arterial blood pressure and blood gas values in normal standing and laterally recumbent African (*Loxodonta africana*) and Asian (*Elaphas maximus*) elephants. Journal of Zoo and Wildlife Medicine 23: 205–210.

JACOBSON, E. R., G. V. KOLLIAS, D. J. HEARD, AND R. CALIGIURI. 1988. Immobilization of African elephants with carfentanil and antagonism with

nalmefene and diprenorphine. Journal of Zoo and Wildlife Medicine 19: 1–7.

JACOBSON, J. D., M. W. MILLER, N. S. MATTHEWS, S. M. HARTSFIELD, AND K. W. KNAUER. 1992. Evaluation of accuracy of pulse oximetry in dogs. American Journal of Veterinary Research 53: 537–540.

KELLEHER, J. F. 1989. Pulse oximetry. Journal of Clinical Monitoring 5: 37–62.

KLEIHAUER, E., I. O. BUSS, C. P. LUCK, AND P. G. WRIGHT 1965. Haemoglobins of adult and foetal African elephants. Nature 207: 424–425.

KOCK, M. D. 1992. Use of hyaluronidase and increased etorphine (M99) doses to improve induction times and reduce capture-related stress in the chemical immobilization of the free-ranging black rhinoceros (*Diceros bicornis*) in Zimbabwe. Journal of Zoo and Wildlife Medicine 23: 181–188.

———, R. B. MARTIN, AND N. KOCK. 1993a. Chemical immobilization of free-ranging African elephants (*Loxodonta africana*) in Zimbabwe, using etorphine (M99) mixed with hyaluronidase, and evaluation of biological data collected soon after immobilization. Journal of Zoo and Wildlife Medicine 24: 1–10.

KOCK, R. A., P. MORKEL, AND M. D. KOCK. 1993b. Current immobilization procedures used in elephants. *In* Zoo and wild animal medicine: Current therapy 3, M. E. Fowler (editor). W. B. Saunders Company, Philadelphia, Pennsylvania, pp. 436–440.

MIHM, F. G., C. MACHADO, AND R. SNYDER. 1988. Pulse oximetry and end-tidal CO_2 monitoring of an adult Asian elephant. Journal of Zoo Animal Medicine 19: 106–109.

RAATH, J. P. 1993. Chemical capture of the African elephant *Loxodonta africana*. *In* The capture and care manual, A. A. McKenzie (editor). Wildlife Decision Support Services CC and the South African Veterinary Foundation, Pretoria, Republic of South Africa, pp. 484–493.

RIEGEL, K., H. BARTELS, I. O. BUSS, P. G. WRIGHT, E. KLEIHAUER, C. P. LUCK, J. T. PARER, AND J. METCALFE. 1967. Comparative studies of the respiratory functions of mammalian blood IV. Fetal and adult African elephant blood. Respiratory Physiology 2: 182–195.

RIGGS, A. 1963. The amino acid composition of some mammalian hemoglobins: Mouse, guinea pig, and elephant. Journal of Biological Chemistry 238: 2983–2987.

TYLER, I. L., B. TANTISIRA, P. M. WINTER, AND E. K. MOTOYAMA. 1985. Continuous monitoring of arterial oxygen saturation with pulse oximetry during transfer to the recovery room. Anesthesia and Analgesia 64: 1108–1112.

WALLACH, J. D., AND J. L. ANDERSON. 1968. Oripavine (M.99) combinations and solvents for immobilization of the African elephant. Journal of the American Veterinary Medical Association 153: 793–797.

WHITEHAIR, K. J., G. C. WATNEY, D. E. LEITH, AND R. M. DEBOWES. 1990. Pulse oximetry in horses. Veterinary Surgery 19: 243–248.

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