Assessment of clinical application of pulse oximetry probes in llamas and alpacas

Tamara L. Grubb and David E. Anderson
Department of Veterinary Clinical Sciences, Ohio State University College of Veterinary Medicine, 601 Vernon Tharp Rd, Columbus, Ohio, 44201

Abstract

The placement and accuracy of pulse oximeter probes can vary markedly among species. For our study, we aimed to assess the accuracy of pulse oximetry and to determine the most clinically useful sites for probe placement in llamas and alpacas. The objectives included an analysis of pulse oximetry probes for accurate assessment of llamas and alpacas and to determine the best placement of the probes to achieve accurate readings. For study 1, saturation of haemoglobin with oxygen was measured in 184 arterial blood gas samples (SaO₂) using a co-oximeter and compared to saturation of haemoglobin with oxygen simultaneously measured using a pulse oximeter (SpO₂). The bias and precision for the SpO₂–SaO₂ difference was calculated and plotted on a Bland-Altman plot. For study 2, SpO₂ data was collected 624 times from a variety of sites [tongue (T), nasal septum (NS), lip (L), vulva (V), prepuce (P), ear (E), and scrotum (S)] and recorded based upon a percentage of successful readings. Results for study 1 revealed that SpO₂ was consistently 0 to −6% points different than SaO₂. The bias and precision of the SpO₂–SaO₂ difference was −2.6 ± 1.7%. Results for study 2 uncovered that 540 recordings were successful readings and were obtained from the tongue and nasal septum with 97% accuracy, the lip 80%, vulva 62%, prepuce 59%, ear and scrotum < 50%. We concluded that pulse oximetry probes provide reliable estimates of arterial haemoglobin oxygen saturation in llamas and alpacas and is most accurately read when placed on the nasal septum or tongue.

Keywords: alpaca, llama, pulse oximetry probe.

Introduction

Oxygen saturation of haemoglobin is measured in humans and other species using a co-oximeter as a reliable method to evaluate arterial blood samples for haemoglobin, but this equipment is expensive, can be unwieldy in field settings, and requires acquisition of an arterial blood sample (Clark et al. 1992). Haemoglobin saturation has also been monitored by evaluating mucous membrane colour but this method is crude at best and requires a minimum of 5 g/dL of unoxygenated haemoglobin (out of a total of approximately 15 g/dL) to produce cyanosis. Pulse oximeters, which emit infrared light, combine sophisticated technology in a portable, more cost-effective unit that utilises a non-invasive, painless surface electrode to determine the oxygen saturation of haemoglobin in arterial blood. Blood collection is not necessary and eliminates the potential for patient pain and undue stress. Hand-held, relatively inexpensive pulse oximeters are available and could be utilised clinically for patient monitoring in a wide range of situations (e.g. field anaesthesia) and locations (e.g. stall- or cage-side care).

Pulse oximeters measure arterial oxygen saturation at two wavelengths of light: a red (R) wavelength (generally 660 nm), where the absorbance of light by poorly oxygenated haemoglobin (HbO₂) is less than that of oxygen-saturated haemoglobin (Hb), and an infrared (IR) wavelength (generally 920–930 nm),
where the absorbance of light by oxygen-saturated haemoglobin is greater than that of poorly oxygenated haemoglobin (Clark et al. 1992; Mendelson 1992). In order to report the data as a percent (%) saturation, the R/IR wavelength ratio is compared to calibration curves programmed into the pulse oximeter. These calibration curves are based on data obtained from healthy human beings with spherical red blood cells and a fairly standard concentration of haemoglobin. Since these curves are determined from human data, the accuracy of pulse oximetry in each species should be validated. The use and accuracy of pulse oximetry has been documented in a number of veterinary species (Erhardt et al. 1989; Huss et al. 1995; Jacobson et al. 1992; Martinez et al. 1996; Vander et al. 1995; Whitehair et al. 1990) but has not been documented in llamas or alpacas. A recent evidence-based medical review of the literature found that saturation of haemoglobin with oxygen measured pulse oximetry (SpO2) typically under estimates saturation of haemoglobin with oxygen measured by blood gas analysis (SaO2) by 3–5% and is accurate at SaO2 > 70% (Shaughnessy & Hofmeister 2010). South American Camelids have ellipsoid red blood cells and different characteristics of haemoglobin (Hall et al. 1936). This difference stimulated interest in the assessment of pulse oximetry specific to the species for llamas and alpacas.

We hypothesised that pulse oximetry would be an accurate and reliable tool for the assessment of haemoglobin saturation and that SpO2 probe placement on a variety of non-pigmented, mucous membrane or thin-skinned areas would provide reliable measurements in llamas and alpacas. Part 1 of this study was designed to assess the accuracy of pulse oximetry in llamas and alpacas by comparing pulse oximetry data (SpO2) to data obtained using a co-oximeter (SaO2). Part 2 of this study was designed to determine the most useful site for pulse oximeter probe placement in camels.

**Materials and methods**

For this study, 80 Llamas and alpacas > 1 year of age that required blood gas analysis during surgical, diagnostic, treatment, or research purposes at our teaching hospital during a 12-month period were examined. The total study population included 48 males and 32 females ranging in age from 1 to 10 years (mean, 4.3 years). No camelids were sedated or anaesthetised specifically for this study. All patients that were sedated breathed room air (21% oxygen) and anaesthetised patients breathed 97% oxygen delivered via orotracheal intubation. The study was approved by the Institutional Laboratory Animal Care and Use Committee.

For part 1 of the study, arterial blood for blood gas analysis (PaO2, SaO2, PaCO2, pHa) was collected from the auricular artery either through a 20-G 1.5 inch (4 cm) Teflon catheter or by insertion of a 25-G 0.75 inch (1.65 cm) needle. In all cases, aseptic technique was used for blood collection, blood samples were collected into heparinised syringes, and samples were analysed within 10 minutes of collection using a co-oximeter (OSM3 Hemoximeter, Radiometer, Copenhagen, Denmark). Corrections were made for body temperature. Arterial blood for blood gases was collected simultaneous with recording of pulse oximetry (SpO2) data. Failure of the pulse oximeter to detect a pulse fairly rapidly and/or failure to produce a heart rate that matches the patient’s heart rate mean that the reading is unlikely to be accurate. Thus, if the pulse oximeter (SDI Vet/OX 4402, Sensor Devices Inc., Waukesha, Wisconsin) failed to display data within two minutes or if the heart rate determined by palpation of a peripheral artery did not match the heart rate displayed by the pulse oximeter, the blood collected for blood gas analysis was not used in this study. The full blood gas results were used for patient care decisions but only the SaO2 was used in this study.

For part 2 of this study, various anatomical sites (tongue, lip, nasal septum, ear, vulva, scrotum and prepuce) were selected for candidacy as pulse oximeter probe placement. A standard clip-type transmittance pulse oximeter probe similar to those used on human fingers was placed on one or more of the following sites: tongue, lip, ear, vulva, scrotum or prepuce. A C-clamp type transmittance probe was placed on the nasal septum. The C-clamp is a regular pulse oximeter probe placed into a clamp-type structure that allows placement of the probe on the nasal
septum. Saturation data was not recorded if the heart rate counted by manual palpation of a peripheral artery did not match the heart rate displayed by the pulse oximeter nor if the pulse oximeter failed to provide data within 2 min of attempting data acquisition.

**Statistical analysis**

Four variables were identified in part 1 of this project: fraction inspired oxygen concentration (FiO2; 21% vs. 97%); species (60 llamas, 40 alpacas); site of probe placement when arterial blood was collected; and method of measuring haemoglobin saturation (S_pO_2 vs. S_aO_2). An analysis of variance (ANOVA) for repeated measures was used to test the significance of the FiO2, species and probe site. Significance for all was set at $P < 0.05$. A Bland-Altman plot, in which differences between measurements (S_pO_2 – S_aO_2) are plotted against the mean of the two measurements (average of S_pO_2 and S_aO_2), was used to compare the methods of haemoglobin saturation if the FiO2, animal, and probe site were determined to be insignificant. The Bland-Altman method requires that two compared observations be independent of each other and is appropriate when comparing two indirect methods of measurement. The Bland-Altman analysis has been used in other evaluations of oxygen haemoglobin saturation (Whitehair et al. 1990). The bias (mean) and precision (standard deviation) of the differences between each method of measurement were also calculated.

The data for Part 2 were used to generate the percentage of successful data acquisition readings compared to the percentage of attempted readings for the pulse oximeter probe placed at various sites on the animals.

**Results**

Data from 60 llamas and 20 alpacas were included in the study. Procedure time ranged from 20 to 150 min (mean, 31 min). There was no significant difference (Table 1) in the S_pO_2–S_aO_2 difference between patients breathing 97% oxygen and those breathing room air (21% oxygen), nor was there a significant difference between species or probe placement sites. Thus, saturation data was pooled for all patients, rather than reported by separate species. However, species-specific data are available in Table 1.

**Part 1**

Saturation of haemoglobin with oxygen was measured in 184 arterial blood gas samples (S_aO_2) using a co-oximeter and compared to saturation of haemoglobin with oxygen simultaneously measured using a pulse oximeter (S_pO_2). The pulse oximeter consistently reported oxygen haemoglobin saturation to be 0 to –6% different from the co-oximeter. The bias and precision of the S_pO_2–S_aO_2 difference was $-2.6 \pm 1.7\%$ (Fig. 1).

**Part 2**

Six hundred and twenty-four (624) data collections were attempted from the pulse oximeter in various sites. Five hundred and forty (540 or 86.5%) of the

### Table 1

| Species | Number | % FiO_2 | Mean ± SD S_pO_2% | Mean ± SD S_aO_2% | S_pO_2–S_aO_2% |
|---------|--------|---------|-------------------|------------------|----------------|
| Llamas  | 22     | 21      | 94.8 ± 0.2        | 98.2 ± 0.4       | −3.4 ± 0.6     |
|         | 38     | 97      | 99.3 ± 0.1        | 100.7 ± 0.1      | −1.4 ± 0.2     |
| Alpacas | 6      | 21      | 95.4 ± 0.3        | 99.4 ± 0.4       | −4.0 ± 0.7     |
|         | 14     | 97      | 99.4 ± 0.0        | 101.0 ± 0.2      | −1.6 ± 0.2     |
| Total: 80 |      |         | 97.2 ± 0.7        | 99.8 ± 1.0       | −2.6 ± 1.7     |

All data are presented as mean ± standard deviation. There are no statistically significant differences in the data.
recordings were successful. Readings most consistently were obtained from the tongue and the nasal septum (121 successful readings out of 125 attempts for both sites; 97% success rate) but copious saliva production in most animals made frequent repositioning of the probe on the tongue necessary. Pulse oximetry attempts were consistent for the lip (100 out of 125; 80%). Pulse oximetry was less consistent when attempted from the vulva (27 out of 44; 61%), the prepuce (30 out of 50; 60%), or the ear and the scrotum (~60 out of 125 attempts for both sites; <50%). In all of these failed reading attempts, the pulse oximeter failed to detect a pulse for ≥2 min.

Discussion

In this study, the pulse oximeter proved to be a reliable monitor for oxygen saturation of haemoglobin in camelids under the conditions of the study. The most reliable and repeatable data was obtained when the probe was placed on the nasal septum (C-clamp) or the tongue (clip probe), but reliable and repeatable data were less consistently obtained when the probe was placed on other tissues.

Variations in probes, anatomical locations and clinical conditions can influence pulse oximetry (Shaughnessy & Hofmeister 2010; Chaffin et al. 1996; Matthews et al. 2003). The pulse oximeter depends on detection of pulsatile waveforms for determination of $S_o_2$ (Clark et al. 1992; Mendelson 1992). If pulsatile flow cannot be detected, the pulse oximeter will not read a value or will read an erroneous value. Pulsatile flow is difficult to detect if the tissue at the area chosen for probe placement is thick, haired, or pigmented; if the patient is moving; or if vasoconstriction has occurred secondary to factors such as hypovolaemia, hypotension, or hypothermia (Huss et al. 1995; Reich et al. 1996). Contrastingly, in dogs, a finger probe pulse oximetry was more accurate when applied to the tail as opposed to the ear when $Sa_o_2$ was <50% and an ear probe was less accurate on the tail as compared to the tongue when $Sa_o_2$ was >70% (Moen et al. 1991). Nevertheless, in our study, the thickness of skin, presence of hair or pigment, and unusual shape of the tissues selected for probe placement caused the greatest difficulty in obtaining a reading from the pulse oximeter. The standard clip probe is relatively short and does not always provide good tissue contact for surfaces like the prepuce, scrotum and vulva. These tissues are of varying thicknesses and ‘wedge’ shapes, and the pulse oximeter probe tended to dislodge easily. However, readings were inconsistent from these tissues even when the probe remained in place for long periods of time. Readings were most consistent when the clip probe was placed on the tongue and when the C-clamp probe was placed on the nasal septum. This may be because both the
tongue and the nasal septum are highly vascular tissues compared to the other tissues evaluated in this study. The tongue is commonly used for oximeter probe placement in veterinary species (Erhardt et al. 1989; Huss et al. 1995; Jacobson et al. 1992; Martinez et al. 1996; Vender et al. 1995; Whitehair et al. 1990). In our study, saturation data obtained when the pulse oximeter probe was on the tongue was repeatable and reliable, but the probe tended to require frequent repositioning as the duration of the surgery increased saliva production, making the tongue slick. The C-clamp generally stayed in place on the nasal septum and provided repeatable and reliable data from this site but did not tend to remain in place when used at any other site and thus was not evaluated at any other site. In a similar manner, C-clamps have also been used on the nasal septum of horses and provided S$_{\text{a}}$O$_2$ values with excellent correlation to S$_{\text{d}}$O$_2$ values (Jacobson et al. 1992). In horses, the most significant influence on accuracy of pulse oximetry were the type of pre-medication given, SaO$_2$, and mean arterial blood pressure (Watney et al. 1993).

In our study, pulse oximetry tended to slightly underestimate the arterial oxygen saturation as measured by the co-oximeter. This also has been noted in other species (Jacobson et al. 1992; Whitehair et al. 1990; Matthews et al. 1995). Conversely, the co-oximeter tended to overestimate the arterial oxygen saturation in our cameldids, as evidenced by S$_{\text{d}}$O$_2$ readings of 101–102%. Blood cannot be >100% saturated with oxygen and this error in data output was attributed to the fact that the oximeter was set for human values. Although the Radiometer co-oximeter measures haemoglobin saturation at standard wavelengths, in order to report the measurement in percent saturation, the wavelength measurements are compared to standard human oxygen–haemoglobin saturation curves similar or identical to those incorporated into pulse oximeters. The oxygen–haemoglobin dissociation curve is a graphic representation of the affinity of haemoglobin for oxygen based on the partial pressure of inhaled oxygen. The saturation curve of the llama is to the left (p50 = 23 mmHg) of that of the human being (p50 = 27 mmHg). Hall et al. 1936 Application of llama-derived R/IR ratios to human being-derived oxygen-haemoglobin dissociation curves would result in erroneous overestimation of arterial blood oxygen saturation. Although the Radiometer user’s manual states that the maximum range of arterial blood oxygen saturation that can be reported is 100%, obviously this is in error. This overestimation of arterial blood saturation resulted in a wider margin of error than would have been encountered if maximum saturation had been 100%. With the data as reported, 48% of the values for S$_{\text{a}}$O$_2$–S$_{\text{d}}$O$_2$ difference were ≥3%, however, only 29% of the differences were ≥3% when the data was normalised to 100% maximum saturation.

Another factor that could affect the accuracy of oximetry in cameldids is the fact that cameldids have small, ellipsoid red blood cells with an unusually high concentration of haemoglobin (Hall et al. 1936). In all species, the suspension of haemoglobin containing red cells in the blood can cause scattering of transmitted light and result in erroneously reported saturation values. The use of internal calibration curves for the pulse oximeter minimises or eliminates this problem; however, the assumption must be made that the red cell size and geometry of the patient is identical to that of the subjects whose data were used to generate the calibration curve (Clark et al. 1992). Although llama red blood cells are much smaller (MCV of 20–27 fL) than those of human beings (MCV of 82–100 fL) and this could affect pulse oximetry accuracy, pulse oximetry has been shown to be repeatable and reliable in sheep. (Erhardt et al. 1989) a species which also has small red blood cells (MCV of 25–50 fL).

For a robust comparison of two analysers half of the samples tested should be at the extremes of the reference range of the device. This is the main limitation of our study in that this was not achievable in our study because it was not appropriate to purposely create clinical abnormalities using client-owned animals. We were able to include a group at the high end of saturation by collecting samples from patients receiving 97% oxygen during anaesthesia but it was not appropriate to include a group at the low end of saturation, which would have required us to induce hypoxia in the patients. However, because
we tested the pulse oximeter in a clinical setting, our findings are relevant for clinical use of the monitor.

**Conclusion**

In spite of the inherent differences in camelid RBC indices, pulse oximeters provide reliable, repeatable estimates of arterial haemoglobin saturation in camelids. Data are most accurate when the pulse oximeter probe is placed on the nasal septum (C-clamp) or the tongue (clip clamp), although copious saliva production can make frequent repositioning on the tongue necessary.

**Acknowledgments**

The authors thank the patients, clients and clinicians at The Ohio State University College of Veterinary Medicine for cooperation in the conductance of this study.

**Source of funding**

The authors thank the Department of Clinical Sciences at Ohio State University for partial financial support of this study.

**Conflicts of interest**

The authors have no conflict of interest to report.

**Ethics statement**

The authors confirm that the ethical policies of the journal, as noted on the journal’s author guidelines page, have been adhered to and the appropriate ethical review committee approval has been received. The US National Research Council’s guidelines for the Care and Use of Laboratory Animals were followed.

**Contributions**

Dr. Grubb and Dr. Anderson contributed equally to the performance of this study and writing of the manuscript.

**References**

Chaffin M.K., Matthews N.S., Cohen N.D. & Carter G.K. (1996) Evaluation of puls oximetry in anesthetized foals using multiple combinations of transducer type and transducer attachment site. *Equine Veterinary Journal* 28, 437–445.

Clark J.S., Votteri B., Ariagno R.L., Cheung P., Eichhorn J.H., Fallat R.J. *et al.* (1992) Noninvasive assessment of blood gases. *American Review of Respiratory Disease* 145, 220–232.

Erhardt W., Lendl C., Hipp R., Schindele M. & Blümel G. (1989) Pulse oximetry – a non-invasive method for direct and continuous monitoring of oxygen saturation and pulse rate – comparative studies with blood gas analysis and hemoreflectometry in the dog, swine and sheep. *Berliner und Munchener Tierarztliche Wochenschrift* 102, 289–292.

Hall F.G., Dill D.B. & Guzman-Barron E.S. (1936) Comparative physiology in high altitudes. *Journal of Cellular and Comparative Physiology* 8, 301–313.

Huss B.T., Anderson M.A., Branson K.R., Wagner-Mann C.C. & Mann F.A. (1995) Evaluation of pulse oximeter probes and probe placement in healthy dogs. *Journal of the American Animal Hospital Association* 31, 9–14.

Jacobson J.D., Miller M.W., Matthews N.S., Hartsfield S.M. & Knauer K.W. (1996) Evaluation of accuracy of pulse oximetry in dogs. *American Journal of Veterinary Research* 53, 577–540.

Martinez E.A., Carroll G.L. & Hartsfield S.M. (1996) Evaluation of the Nonin 8600V veterinary pulse oximeter in anesthetized horses. *Journal of Veterinary Emergency and Critical Care* 9, 13–17.

Matthews N.S., Sanders E.A., Hartsfield S.M. & Mercer D. (1995) A comparison of 2 pulse oximeters in dogs. *Journal of Veterinary Emergency and Critical Care* 5, 116–120.

Matthews N.S., Hartke S. & Allen J.C. (2003) An evaluation of pulse oximeters in dogs, cats and horses. *Veterinary Anaesthesia and Analgesia* 30, 3–14.

Mendelson Y. (1992) Pulse oximetry: theory and applications for noninvasive monitoring. *Clinical Chemistry* 38, 1601–1607.

Moens V.Y., Gootjes P., Lagerweij E. & van Dijk P. (1991) Monitoring of the oxygen saturation of horses during halothane anesthesia using pulse oximetry in the nasal septum. *Berliner und Munchener Tierarztliche Wochenschrift* 104, 357–360.

Reich D.L., Timenko A., Bodian C.A., Kraidin J., Hofman J., DePerio M. *et al.* (1996) Predictors of pulse oximetry data failure. *Anesthesiology* 84, 859–864.

Shaughnessy M.R. & Hofmeister E.H. (2010) Vet med today: what is the evidence? *Journal of the American Veterinary Medical Association* 236, 55–56.
Vender J.R., Hand C.M., Sedor D., Tabor S.L. & Black P. (1995) Oxygen saturation monitoring in experimental surgery: a comparison of pulse oximetry and arterial blood gas measurement. *Laboratory Animal Science* **45**, 211–215.

Watney G.C.G., Norman W.M., Schumacher J.P. & Beck E. (1993) Accuracy of a reflectance pulse oximeter in anesthetized horses. *American Journal of Veterinary Research* **54**, 497–501.

Whitehair K.J., Watney G.C.G., Leith D.E. & Debowes R.M. (1990) Pulse oximetry in horses. *Veterinary Surgery* **19**, 243–248.