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SHORT COMMUNICATION

# Two methods to adapt the human haemoglobin–oxygen dissociation algorithm to the blood of white rhinoceros (*Ceratotherium simum*) and to determine the accuracy of pulse oximetry

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## Abstract

**Objectives** To adapt the algorithm for the calculation of oxygen saturation to the blood characteristics of the white rhinoceros by two different methods and to determine the accuracy of conventional pulse oximetry measurements.

**Study design** Adaptation of two mathematical models of the oxygen dissociation curve (ODC).

**Animals** Twenty-five captive white rhinoceros (*Ceratotherium simum*), including 12 males and 13 females, aged 6–32 years.

**Methods** During 33 anaesthetic events, 94 arterial blood gas samples with 72 simultaneous pulse oximetry measurements were analysed. The calculation of oxygen saturation was adapted to the characteristics of rhinoceros blood using two different methods. Firstly, a mathematical model developed in 1984 and, secondly, an oxygen status algorithm (OSA) produced by the same developer in 2005 were tested for their applicability for clinical use.

**Results** When arterial partial pressure of oxygen is >7.98 kPa (60 mmHg), oxygen saturation exceeds 95%. At partial pressures of 6.12–6.52 kPa (46–49 mmHg) Method 1 determined oxygen saturations of 92.5–95.3% and Method 2 oxygen saturations of 90.2–91.6%. Both methods resulted in similar ODCs and accounted for the low p50 value of rhinoceros blood. Method 1 provided better adaptation in respect to the physiological parameters of the rhinoceros, especially with regard to the Bohr effect, than Method 2. Pulse oximetry was an unreliable method of monitoring arterial oxygen saturation during general anaesthesia in this species.

**Conclusion** Adapting the oxygen saturation algorithm to consider the left shift of the ODC provides a useful tool for monitoring oxygen status, especially as pulse oximetry is insufficiently accurate. Experimental determination of the complete Hill curve is required to further validate and optimize the algorithm for use in the white rhinoceros.

**Clinical relevance** The method will facilitate the accurate interpretation of oxygen saturation calculated by blood gas analysis in white rhinoceros.

*Keywords* blood gas, *Ceratotherium simum*, haemoglobin saturation, oxygen dissociation curve, pulse oximetry.

## Introduction

Achieving general anaesthesia in large quadrupeds, such as the white rhinoceros (*Ceratotherium simum*

*simum and cottoni*), is a challenging task for veterinarians but is indispensable in conservation management and medical interventions. Close monitoring of arterial oxygen saturation by blood gas analysis and pulse oximetry during anaesthesia is essential as hypercapnia and, especially, hypoxemia are reported during general anaesthesia in white rhinoceros. Blood gas analysis and pulse oximetry are two methods of ensuring the adequate monitoring of oxygen status in the arterial blood. Its continuous monitoring, low cost and simple application makes pulse oximetry very popular, whereas blood gas analysis is more costly and is discontinuous. Both methods have one big disadvantage: they are validated for use in humans or, in the best case, in domestic animals, but not in wildlife. Today, pulse oximetry shows good accuracy in pets such as dogs (Burns et al. 2006) and farm animals. Pulse oximetry devices generally do not overestimate oxygen saturation significantly (Matthews et al. 2003; Burns et al. 2006). A pulse oximeter estimates oxygen saturation ($SpO_2$) based on light absorbance of defined wavelengths of human oxy- and deoxyhaemoglobin. Variant human haemoglobins are responsible for low $SpO_2$ measurements (Verhovsek et al. 2010). Measuring the arterial pressure of oxygen ($PaO_2$), the unbound oxygen content in the blood, with a blood gas analyser is, by contrast, species-independent. Generally $SpO_2$ and oxygen saturation by the blood gas analyser ($SaO_2$) should correlate closely. In the majority of animals the standard measurements are satisfactory, but in species with extreme p50 values (partial pressure at which haemoglobin is 50% saturated with oxygen), such as the white rhinoceros (Baumann et al. 1984), or extreme adaptations to physiological changes in pH or 2,3-diphosphoglycerate (2,3-DPG), such as in camels, this may not be the case. The algorithm for calculating oxygen saturation in blood gas machines requires haemoglobin-specific validation. Humans show a p50 of about 3.99 kPa (30 mmHg), whereas the p50 at a pH of 7.4 and temperature of 37 °C in rhinoceros is extremely low at 2.66 kPa (20 mmHg). With decreasing pH, oxygen binding affinity decreases more than in humans because of the strong Bohr effect of −0.62, whereas oxygen affinity changes little with 2,3-DPG and adenosine triphosphate (ATP) (Baumann et al. 1984). The reason for this special characteristic of rhinoceros haemoglobin may reflect a specific glutamic acid residue at position β2 in haemoglobin (Mazur et al. 1982). However, other than in Ball et al. (2011), this fact has rarely been considered in evaluations of the oxygen status of the anaesthetized white rhinoceros.

The algorithm to calculate oxygen saturation ($sO_2$) can be adapted to calculate species-specific $sO_2$ values, if data on the p50, Bohr effect, effect of 2,3-DPG and ATP (Mazur et al. 1982; Baumann et al. 1984) and physiological blood chemistry (Citino & Bush 2007) are available, as they are for the white rhinoceros. Herein, we present two methods to adapt the algorithm for species-specific validation by empirical fitting throughout the entire Hill curve.

## Materials and methods

Captive white rhinoceros (*C. s. simum and cottoni*) of both sexes at reproductive age were anaesthetized during the years 1999–2003 within the European Endangered Species Programme (EEP) for serial clinical reproductive monitoring to elucidate the causes of female and male reproductive failure. All procedures were conducted according to the guidelines of the ethics committee of the University of Veterinary Medicine Vienna and the respective legislation in the countries in which the procedures were performed. Clinical examinations of the reproductive organs included transrectal ultrasonography, electroejaculation and artificial inseminations under general anaesthesia. A sternal or lateral recumbent state was achieved with a combination of detomidine–HCL (Domosedan; Orion Corp., Finland), butorphanol (Torbugesic; Fort Dodge Animal Health, IA, USA) and etorphine–acepromazine (Large Animal Immobilon; C-Vet Veterinary Products, UK).

Heart rate (HR; beats minute$^{-1}$), arterial oxygen saturation ($SpO_2$; %) by pulse oximeter placed at the ear after skin scraping (Nellcor NP-20; Tyco Healthcare Group LP, Nellcor Puritan Bennett Group, CA, USA), and respiratory frequency ($f_R$, breaths minute$^{-1}$) were recorded. Within the frame of routine anaesthetic monitoring, heparinized anaerobic blood samples were collected from an auricular artery and immediately processed with a portable blood gas analyser (i-Stat; SDI Sensor Devices, WI, USA). During 33 anaesthetic events in 25 individual rhinoceros, 94 blood samples were taken and analysed [mean ± standard (SD) deviation: 2.85 ± 1.30 samples per procedure; 12 males with a mean ± SD age of 20.0 ± 7.2 years (range: 6–32 years); 13 females with a mean ± SD age of 25.6 ± 7.2 years (range: 8–31 years)]. Two

 