Evaluation of the performance of two new generation pulse oximeters in cats at different probe positions and under the influence of vasoconstriction

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Abstract

Objectives The aim of this study was to compare the failure rate of two new generation pulse oximeters at different probe positions, and with and without vasoconstriction, in anaesthetised cats.

Methods This prospective clinical study included 103 cats in which the new generation pulse oximeters, the Rad-5 (Masimo) and EDAN H100N (EDAN), were evaluated. Premedication consisted of the vasoconstrictive drug combination butorphanol (0.2 mg/kg IV) and dexmedetomidine (5 µg/kg IV), or butorphanol only (0.2 mg/kg IV). Pulse oximeter failure rate at the tongue was compared between both groups. Pulse oximeter failure rate was also analysed at the alternative probe positions of the lip, pinna, knee fold and toe in the butorphanol group. Student's *t*-test, Wilcoxon matched pairs signed rank test, Mann–Whitney U-test, Friedman test and χ² test were performed. A *P* value <0.05 was considered to be statistically significant.

Results Overall failure to achieve an adequate signal was 37.6% with the Masimo and 48.0% with the EDAN pulse oximeter (*P* <0.0001). At the standard probe position on the tongue, the Masimo failed in 4.5%, while the EDAN failed in 35.3% (*P* <0.0001). Vasoactive premedication increased the failure rate for the Masimo from 3.8% to 5.2% (*P* = 0.3414) and for the EDAN from 22.4% to 49.0% (*P* <0.0001). At the alternative probe positions of the lip and knee fold, failure rates for the Masimo were lower (39.7% and 81.4%) than with the EDAN (52.6% and 94.4%; *P* = 0.0231 and *P* = 0.0005, respectively), while the Masimo failed more often at the pinna (63.5%) than the EDAN (47.4%; *P* = 0.0044). At the alternative probe position of the toe, the failure rate for the Masimo (32.7%) was not different from the EDAN (38.5%; *P* = 0.7547).

Conclusions and relevance The Masimo pulse oximeter had lower signal failure rates at the standard probe position on the tongue and at 2/4 alternative probe positions. The standard probe position on the tongue had the lowest failure rate for both devices. Dexmedetomidine-induced vasoconstriction increased the failure rate for the EDAN but not for the Masimo pulse oximeter.

Keywords: Anaesthesia; measurement failure; dexmedetomidine; oxygen saturation

Introduction

Cats are at greater risk of anaesthesia-related death (0.11–0.24%) than dogs (0.05–0.17%).[1,2] The primary causes of preanaesthetic death are cardiovascular and/or respiratory related.[1] Monitoring of cardiovascular function, including pulse oximetry, leads to a reduced risk of anaesthetic fatalities in cats compared with no pulse monitoring.[2,3] Recording of oxygen saturation (SpO₂) by pulse oximetry decreases the odds ratio of perianaesthetic death in cats under general anaesthesia to 0.1.[2] The

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accuracy and failure rate of pulse oximeters varies widely, depending on the model used.[4]

The major limitations of pulse oximetry in clinical settings arise from decreased peripheral perfusion, probe position, calibration assumptions, optical interference and signal artefact.[5] In cats, failure in measurements and low signal qualities are frequently observed, making pulse oximetry a challenging monitoring tool.[4]

The tongue is usually used as the standard location for pulse oximetry measurement in animals, but it might not be accessible during some veterinary procedures, such as dentistry and intra-oral surgery. Alternative locations in cats include the pinna, lip, metacarpus and metatarsus.[4]

Alpha (α)2-adrenoceptor agonists with high affinity for α2A and α2B receptors, such as medetomidine and dexmedetomidine, are commonly used for premedication in cats.[6,7] Perioperative administration of dexmedetomidine provides sedation, reduces the dose of isoflurane, thiopental and propofol, and the activation of the sympathetic nervous system.[7,8] However, peripherally, vascular α_2- and α_1-adrenergic receptors are activated, causing vasoconstriction and a baroreceptor-mediated reflex bradycardia.[7] The use of dexmedetomidine as premedication decreases peripheral arteriolar blood flow, especially in the skin, and can therefore decrease pulse oximeter signal quality.[9–11]

New generation pulse oximeters were developed to improve performance, even in poor signal conditions (eg, motion artefacts and decreased local perfusion).[12] New generation pulse oximeters use different signal extraction technologies, depending on the manufacturer. The Nellcor OxiMax system is based on the resistor calibration technique; it communicates with the monitor, analyses the signal and relocates the sensor's individual calibration curve in the sensor. The Masimo pulse oximeter system applies signal extraction technology (SET), which is based on conventional red and infrared photoplethysmographic signals. Additionally, it employs a constellation of advanced techniques, including radiofrequency and light-shielded optical sensors, digital signal processing and adaptive filtration, to analyse SpO$_2$.[13,14]

The purpose of this study was to evaluate the performance of two new generation pulse oximeters with and without the vasoconstrictive effects of dexmedetomidine and at various probe positions in cats.

Materials and methods

Animals
This prospective clinical study was approved by our institutional ethics committee (approval number 16-04-10-13). In total, 103 client-owned cats that underwent general anaesthesia for various diagnostic procedures (eg, gastroduodenoscopy, tracheoscopy, colonoscopy and ultrasound-guided biopsy) were enrolled. Cats were excluded if they were anaemic, with a haematocrit <0.2 l/l; had dyshaemoglobinaemia or severe cardiac arrhythmia,

such as a second- or third-degree atrioventricular block and premature ventricular contractions; if they received other vasoactive medication as included in the study protocol; or if hypotension (mean arterial pressure <60 mmHg) or hypothermia (temperature <37°C) occurred during anaesthesia. The mean ± SD age of the cats was 9.5 ± 4.7 years and they had a median body weight of 4.2 kg (range 1.4–13.2). The most common breeds were domestic shorthair (n = 76), Maine Coon (n = 9) and British Shorthair (n = 7); other breeds were represented with four or fewer individuals. Health status was determined by physical examination and preanaesthetic clinical chemistry and complete blood count. According to these results, cats were assigned an American Society of Anesthesiologists (ASA) risk score. Animals of ASA status 5, as well as animals in which pulse oximetry would not have been possible due to the procedure (eg, dental cleaning), or if measurements would have caused additional risk to the patient, were excluded.

Premedication and anaesthesia
According to ASA status, cats were assigned to one of two premedication protocols used as standard for non-painful clinical procedures. Following the placement of a venous catheter, cats of ASA 1 and 2 status (DEX group) received butorphanol (0.2 mg/kg IV [Alvegesic; CP-Pharma]) in combination with dexmedetomidine (5 µg/kg IV [Dexdomitor; Orion Corporation]). Cats of ASA 3 status received butorphanol alone (0.2 mg/kg IV; BUT group). Anaesthesia was induced with propofol (1–8 mg/kg IV to effect [Narcofol; CP-Pharma]). After loss of jaw tone, orotracheal intubation with a low pressure–high volume cuff polyvinylchloride tube was performed and anaesthesia was maintained with sevoflurane (SevoFlo; Abbott Laboratories) in oxygen delivered with a circle system (Fabius Tiro; Drägerwerk). Depth of anaesthesia was adapted on the planned procedure at the discretion of the anaesthetist. A balanced isotonic electrolyte solution (Sterofundin ISO; B Braun Melsungen) was administered during anaesthesia intravenously at 10 ml/kg/h. Perianaesthetic monitoring included electrocardiogram (ECG), oscillometric mean arterial blood pressure and capnography via a multiparameter monitor (Life Scope I, BSM-2301; Nihnon Khoden). Hypothermia was prevented by passive and active warming methods. If normocapnia (end-tidal CO$_2$ 35–45 mmHg) was not maintained by spontaneous ventilation, cats were mechanically ventilated using a pressure-controlled mode with a peak inspiratory pressure of 10 mbar.

Pulse oximeters
The Masimo Rad-5, applying SET, and the EDAN H100N (EDAN), using Nellcor OxiMax technology (Nellcor Puritan Bennett), pulse oximeters were compared. All measurements were performed simultaneously with both pulse oximeters, three times per probe position.

The readings were recorded by video camera. Recording started 1 min after the pulse oximeter signal was stable, after repositioning the sensor. Analysis and transfer to a spreadsheet was performed after the animal recovered from anaesthesia. With the Masimo, failure was defined as the perfusion index (PI), Signal IQ (which describes the confidence of the SpO_2 reading), SpO_2 and/or pulse rate not being displayed. With the EDAN, failure was defined as no regular plethysmography pulse wave being visible, or no PI and/or no SpO_2 and/or no pulse rate being displayed, and/or a 'weak signal' sign appearing. Failure was also defined for both devices as the pulse rate of the device differing more than 10 beats per minute (bpm) from the heart rate of the ECG.

Comparison of failure rate under the influence of vasoconstriction

To evaluate the influence of normal and reduced perfusion on pulse oximetry signal quality using the standard probe position, the probe was placed next to the midline of the tongue. Care was taken to avoid optic shunting. Failure rate was then compared for each anaesthesia premedication group (DEX vs BUT). The BUT group contained 52 cats (mean age 10.0 ± 4.5 years; mean weight 4.46 ± 1.72 kg) and the DEX group included 51 cats (mean age 9.0 ± 4.8 [$P = 0.2506$]; mean weight 4.50 ± 1.73 kg [$P = 0.8353$]).

Comparison of signal quality at different probe positions

To evaluate signal quality at different probe positions, the pulse oximeter probe of both devices was also placed in all 52 cats in the BUT group on the alternative probe positions of the upper lip, pinna, knee fold and fourth toe of the hindlimb. In the BUT group, the order that the probes were placed on the tongue, lip, pinna, knee fold or toe was randomised by writing each of the positions on a piece of paper and drawing these from an envelope. Failure rate was then compared for the alternative probe positions, as well as for the standard probe position of the tongue.

Statistical analysis

Statistical analysis was performed with GraphPad Prism 5 (version 5.04). Normality of the data was analysed by the D'Agostino and Pearson omnibus test. Parametric and normally distributed data are presented as mean ± SD. Non-parametric data are presented as median and range. Patient age was analysed by the Student's *t*-test. Body weight was analysed using the Mann–Whitney U-test. Failure rates were compared via the χ^2 test. A *P* value <0.05 was considered to be statistically significant.

Results

Overall failure rate

The overall failure rate at all probe positions, in both premedication groups, was 37.8% with the Masimo (n = 353/933 measurements) and 50.3% with the EDAN (n = 469/933 measurements) (*P* <0.0001). At the standard probe position of the tongue, the overall failure rate was 4.5% for the Masimo (n = 14/309 measurements), while the EDAN failed in 109/309 measurements (35.3%; *P* <0.0001 [Table 1]).

Comparison of failure rate under the influence of vasoconstriction

Vasoactive premedication with dexmedetomidine increased the failure rate at the tongue from 3.8% (n = 6/156) in the BUT group to 5.2% (n = 8/153) in the DEX group (*P* = 0.3414) with the Masimo; and from 22.4% (n = 35/156) in the BUT group to 48.4% (n = 74/153) in the DEX group (*P* <0.0001) for the EDAN (Table 1).

The failure rate in both groups (using the tongue position) was not different using the Masimo (*P* = 0.559) but was higher in the DEX group with the EDAN (*P* <0.0001).

The PI was higher in the BUT group without vasoconstriction (Masimo: 0.2 [range 0.1–0.9]; EDAN: 0.5 [0.2–0.8]) compared with the DEX group with vasoconstriction (Masimo: 0.1 [range 0.1–0.8; *P* <0.0001]; EDAN: 0.2 [range 0.1–0.9; *P* <0.0001]).

Table 1 Failure rates of two new generation pulse oximeters (the Masimo Rad-5 and the EDAN H100N) at the standard probe position (tongue) in cats with different premedication protocols, as well as at all probe positions (tongue, upper lip, pinna, knee fold and toe)

	Masimo		EDAN		*P* value*
	n	Signal failure	n	Signal failure	
All measurements	933	353 (37.8)	933	469 (50.3)	<0.0001
Tongue total	309	14 (4.5)	309	109 (35.3)	<0.0001
Tongue BUT	156	6 (3.8)	156	35 (22.4)	<0.0001
Tongue DEX	153	8 (5.2)	153	74 (48.4)	<0.0001

*Compared by the χ^2 test
Data are n (%)
BUT = butorphanol 0.2 mg/kg IV; DEX = butorphanol 0.2 mg/kg IV + dexmedetomidine 5 µg/kg IV

Table 2 Failure rates of two new generation pulse oximeters (the Masimo Rad-5 and the EDAN H100N) at alternative probe positions in anaesthetised cats without vasoconstrictive drugs

	Masimo		EDAN		P value*
	n	Signal failure	n	Signal failure	
Lip	156	62 (39.7)	156	82 (52.6)	0.0231
Pinna	156	99 (63.5)	156	74 (47.4)	0.0044
Knee fold	156	127 (81.4)	156	147 (94.2)	0.0005
Toe	156	51 (32.7)	156	57 (36.5)	0.7547

*Compared by the χ^2 test
Data are n (%)

Table 3 Causes of measurement failure of two new generation pulse oximeters (the Masimo Rad-5 and the EDAN H100N) in anesthetised cats with and without vasoconstrictive drugs

	Masimo						EDAN						
Cause of failure	n	No Signal IQ	No PI	No SpO$_2$	No pulse	Total failure	n	No curve	Weak signal	No PI	No SpO$_2$	No pulse	Total failure*
DEX tongue	153	8	8	8	8	8	153	21	35	66	26	26	74
BUT tongue	156	6	6	6	6	6	156	16	20	28	18	19	35
BUT lip	156	61	60	62	61	62	156	63	71	73	70	70	82
BUT pinna	156	99	99	98	98	99	156	18	42	54	46	46	74
BUT knee fold	156	127	126	127	127	127	156	80	128	75	134	135	147
BUT toe	156	51	51	51	50	51	156	20	41	20	44	45	57

Signal IQ = confidence of the SpO$_2$ reading; PI = perfusion index; curve = plethysmography curve; total failure = number of measurements assessed as failure; BUT = butorphanol 0.2 mg/kg IV; DEX = butorphanol 0.2 mg/kg IV + dexmedetomidine 5 µg/kg IV

Comparison of signal quality at different probe positions

In the BUT group, 156 measurements were also performed at each of the alternative probe positions. At the lip and knee fold positions, the Masimo failed less often (39.7% and 81.4%, respectively) than the EDAN (52.6% and 94.2% [$P = 0.0231$ and $P = 0.0005$], respectively). At the pinna, the Masimo failed more often (63.5%) than the EDAN (47.4%; $P = 0.0044$). At the toe position, the failure rate of the Masimo (32.7%) was not significantly different compared with the EDAN (36.5% [$P = 0.7547$]; Table 2).

Comparing each pulse oximeter at all of the different probe positions, the Masimo failed less often at the tongue, followed by the toe, lip, pinna and knee fold. Differences between all positions were statistically significant ($P < 0.05$), except between the toe and the lip ($P = 0.1951$). The EDAN failed less often at the tongue, followed by the toe, pinna, lip and knee fold. Differences between all positions were statistically significant ($P < 0.05$), except between the toe and the pinna ($P = 0.0512$) and between the pinna and the lip ($P = 0.365$). Causes of failure of measurements are presented in Table 3.

Discussion

In the cats included in this study, the overall signal failure rate was lower using the new generation pulse oximeter

Masimo (37.8%) vs the EDAN (50.3%). Previous studies have mostly evaluated conventional pulse oximeters. One study evaluated the general failure rate of pulse oximeters in cats at different probe positions with different pulse oximeters, using non-vasoconstrictive premedication at the tongue, lip, pinna, toe and prepuce or vulva. Failure was defined as no SpO$_2$ or pulse rate readings. The failure rate of SpO$_2$ measurement was 0–31%; the failure of pulse reading was 32–57% at all probe positions.[4] In a study evaluating a conventional pulse oximeter (Ohmeda, Biox 3740), an acceptable pulse oximeter signal was obtained at the tongue in 92% of reading attempts in dogs and cats.[15] In isoflurane-anaesthetised foals, using a Nellcor 200 pulse oximeter, no failure to read SpO$_2$ was reported at any of the probe positions (tongue, lip, pinna, forehead and tail base) with different pulse oximeter transducers.[16] The general failure rate in anaesthetised llamas and alpacas with a SDI Vet/OX 4402 pulse oximeter at different probe positions was 13.5%.[17] The failure rates of five different pulse oximeters at different probe positions in horses varied from 0% to 60%. In dogs, the failure rate ranged from 0% to 20%.[4] The overall failure rate in the present study was in the upper range of the previously reported failure rates but was influenced by the definition of signal failure and poorly perfused probe positions.

At the tongue, which is the standard pulse oximeter site in anaesthetised cats, the failure rate of the Masimo was lower than with the EDAN. No studies in cats evaluating the failure rates of new-generation pulse oximeters at the tongue are available. In sheep, using the Masimo SET technology, as used in the present study, there was a 0% failure rate, despite hypotension, poor perfusion and anaemia.[18] With the new generation pulse oximeters, the failure rate in cats in the present study was higher than in sheep.

The failure rate of the EDAN pulse oximeter was influenced by dexmedetomidine-induced vasoconstriction, while the failure rate of the Masimo was not significantly increased in the present study. Peripheral vasoconstriction at the skin is a common problem when trying to obtain a stable SpO_2 signal.[19] The present study, which applied the EDAN pulse oximeter with Nellcor OxiMax technology, confirmed these findings. A dexmedetomidine-induced decrease in perfusion has previously been shown in mice and dogs.[6,20] In order to not change the standard anaesthesia protocol and not to cause severe side effects, the dose of dexmedetomidine (5 µg/kg) used in cats in the present study was lower than that used in other veterinary studies (25–75 µg/kg).[21,22] This could have reduced the vasoconstrictive effect. Higher doses of dexmedetomidine may have caused a higher failure rate.

Alternative probe positions investigated in the present study had a wide variation in failure rates of between 29% and 93%. The lowest failure rate was observed at the toe. The highest failure rates were observed at the lip, pinna and knee fold (with both devices). These high failure rates are critical as re-placement of the pulse oximeter probe is required multiple times if no adequate signal is displayed. The high failure rate was influenced by the anatomy of the position in relation to the pulse oximeter probe, tissue properties, pigmentation and fur.

Most of the alternative probe positions are very small in size or have very thin tissue. This lack of tissue causes a decrease of the probe contact and probe pressure, which leads to weakening of the signal. A small anatomical structure, such as feline lips and toes, can lead to optic shunting of the infrared and red light-emitting diode (LED) light of the pulse oximeter probe and cause signal failure.[23,24] Some alternative probe positions, such as the pinna and knee fold, have weak perfusion and thin tissue. This may lead to decreased contact of the pulse oximeter probe with the tissue and a signal failure. Most of the alternative positions are pigmented. Dark pigmentation of the skin may interfere with the ability to obtain reliable pulse oximeter results. In humans, the influence of skin pigmentation on signal quality or oxygen saturation displayed by the pulse oximeter was not observed.[25,26]

Alternative probe positions have been studied previously. In dogs, the pinna was demonstrated to have a high failure rate and inconsistent signal quality, and therefore is a less acceptable position for oximetry.[27,28] These findings were also observed in cats in the present study.

At the fourth toe, no significant difference in failure rate was found between the two instruments. Owing to the low failure rate (approximately 30%), this position can be considered to be a satisfactory second choice. Pulse oximeter measurements applying conventional (older generation) oximetry at the toe of dogs and cats were successful and could also be accomplished in awake patients.[4,29,30]

In anaesthetised llamas and alpacas, the nasal septum was the preferred alternative probe position, with a failure rate of 3%, followed by the lip (20%), vulva (39%) and prepuce (40%). The pinna and scrotum had a failure rate of >50%, using a veterinary pulse oximeter (SID Vet/Ox 4403).[16] The nasal septum and vulva were not used as probe positions in cats in the present study as these were too small for fixation of the probe.

The present study had several limitations. The failure rate could have been lower if an equilibration time of more than 1 min was allowed. Multiple approaches to obtain an acceptable reading might also reduce the failure rate.

Cats were divided according to their ASA status, with ASA 1 and 2 cats receiving dexmedetomidine and butorphanol premedication, and ASA 3 cats receiving butorphanol only for premedication. It cannot be excluded that ASA 3 and 4 cats could have had reduced perfusion before anaesthesia vs ASA 1 and 2 cats. However, the PI was higher in the BUT group (ASA 3) than in the DEX group (ASA 1 and 2).

In some studies, the fur at the alternative probe positions was clipped so that it would not interfere with the signal.[4,27] In this study, the fur was not clipped before measurement as this would not be performed in routine anaesthetic procedures.

The time interval from premedication until pulse oximeter analysis at the last probe position was a maximum of 30 mins. During this period, the effect of the premedication and induction agent might have decreased and the effect of the inhalant anaesthetic could have increased, leading to variations in vessel tone and therefore in the results. Randomisation of the probe position sequence was performed to reduce the influence of a decreased effect of premedication with time.

SpO_2 values were not compared with arterial blood gas analysis as that was not an objective of this study. In future studies, to evaluate the accuracy of the pulse oximeter readings, an arterial blood gas analysis should be performed.

Conclusions

The Masimo pulse oximeter had a significantly lower failure rate compared with the EDAN in anaesthetised cats. Dexmedetomidine-induced vasoconstriction influenced the failure rate of the EDAN but not of the Masimo. The probe positions with the lowest failure rate were the tongue and the toe.

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