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Exploring oxygen reserve index for timely detection of deoxygenation in canine patients recovering from anesthesia

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ABSTRACT

Pulse oximetry (SpO_2) identifies a decrease in the partial pressure of oxygen (PaO_2) when it falls below 80 mmHg, while oxygen reserve index (ORi), a dimensionless index ranging from 0 to 1, detects PaO_2 changes between 100 and 200 mmHg. This study investigates the usefulness of ORi in detecting impending deoxygenation before traditional SpO_2. Fifty-one dogs undergoing anesthesia were mechanically ventilated maintaining a fraction of inspired oxygen of 0.50 and an ORi of 1. Animals were classified according to their body condition score (BCS) as normal-fit (BCS 4–5/9), overweight (BCS 6–7/9), or obese (BCS 8–9/9). At the end of the procedure, dogs were placed in sternal recumbency, and after 10 min disconnected from the ventilator and maintained in apnea. ORi added warning time was determined at various ORi values as the time difference in reaching SpO_2 of 95% from ORi of 0.9 and 0.5, compared to the SpO_2 warning time from SpO_2 of 98%. During apnea, ORi decreased before noticeable SpO_2 changes. An ORi of 0.9 anticipated an SpO_2 of 95% in normal-fit dogs by 87 (33−212) [median (range)] seconds or in those with a BCS $\geq$ 6/9 by 49 (7–161) seconds. Regardless of the BCS class, the median time from ORi of 0.5 to SpO_2 of 95% was 30–35 s. ORi declined from 0.9 to 0.0 in 68 compared to 33 s between normal-fit and obese dogs ($p < 0.05$). In dogs, ORi added warning time could facilitate timely intervention, particularly in obese patients.

1. Introduction

Arterial blood gas analysis represents the gold standard for monitoring arterial partial pressure of oxygen (PaO_2); however, it requires arterial blood collection, provides intermittent information, and involves additional expenses. The use of pulse oximetry (SpO_2) for estimating PaO_2 is a non-invasive and user-friendly method, but it may delay the detection of impending decreases in arterial oxygen levels. Pulse oximetry typically displays values >97% during hyperoxemia (PaO_2 > 100 mmHg), only showing lower values when PaO_2 drops below 80 mmHg (Nitzan et al., 2014). An $SpO_2 \geq 95\%$ is considered clinically acceptable, while values below this threshold indicate a hypoxic condition (Nitzan et al., 2014).

Recently, Masimo Corporation introduced the oxygen reserve index (ORi) for use in human clinical practice. The ORi is a dimensionless index that, according to the manufacturer, ranges from 0.0 (indicating no reserve or PaO_2 < 100 mmHg) to 1.0 (indicating high reserve or PaO_2 > 200 mmHg). It employs the same pulse co-oximetry technology to provide a continuous estimation of blood hemoglobin saturation with oxygen, with ORi combining information from both arterial and venous blood absorption at various wavelengths (Szmuk et al., 2016). In some studies, conducted in human patients, a positive moderate to strong correlation was observed between ORi, and PaO_2 ranging from 100 to 200 mmHg (Applegate et al., 2016; Vos et al., 2019; Bathe et al., 2022; Cheng et al., 2022; Fadel et al., 2023). In veterinary medicine, ORi was investigated in anesthetized donkeys, revealing only a mild correlation with PaO_2 (Bellini et al., 2021), and in anesthetized dogs, demonstrating a higher correlation (Watanabe et al., 2023; Zanusso et al., 2023a). Moreover, the index has shown itself to be a reliable trending variable, suggesting that relative changes in ORi predict consistent changes in PaO_2 with good sensitivity in humans and in dogs (Vos et al., 2019; Zanusso et al., 2023a). The device also shows the pulsatile index (PI), which assesses signal quality at the sensor application site and is affected by local perfusion and vascular tone (Endo et al., 2020). Human studies have demonstrated that the use of ORi in apneic patients can offer a clinically significant median warning time of 31 to 87 s before any substantial decrease in SpO_2 occurs (Szmuk et al., 2016; Tsymbal et al., 2021). The index was applied to monitor the response to oxygen

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administration in sedated dogs; indeed ORi increased as the fraction of inspired oxygen (FiO_2) rose, indicating its utility in monitoring abrupt changes in oxygen content (Bellini and De Benedictis, 2023).

In healthy anesthetized dogs, hypoxemia is rare due to the high fraction of inspired oxygen delivered. However, certain patients, such as obese dogs or those with lung dysfunctions, may experience oxygen disturbances that persist during recovery due to compromised ventilatory function, leading to a worsening of PaO_2 levels (Grubb, 2010; Martin-Flores et al., 2020). The functional residual capacity (FRC) is the volume of gas that remains in the lungs at the end of passive exhalation, and during apnea, it serves as a reserve of oxygen (Tourneux et al., 2008). A negative correlation has been demonstrated between the percentage of body fat and FRC in anesthetized obese dogs (Araos et al., 2021).

In apneic patients after induction of anesthesia, ORi provides an early warning compared to SpO_2, and the additional warning time given by ORi was shorter in subjects classified as obese compared to those with a normal body mass index (Tsymbal et al., 2021). No study has investigated the use of ORi to anticipate impending desaturation in apneic and hyperoxemic dogs, and whether the rate of ORi decline is associated with the body condition score (BCS).

The primary objective of this study is to investigate whether ORi can increase the warning time to detect deoxygenation compared with SpO_2 in apneic dogs with different BCS, recovering from anesthesia. A second aim is to investigate whether there are differences in the ORi warning time between overweight and obese dogs compared with those with a normal weight.

We hypothesized that the ORi decrease occurs over a sufficiently extended duration to enable interventions that can prevent the development of hypoxemia irrespective of dogs' BCS.

2. Material and methods

2.1. Animals

This prospective observational study was approved by the Ethical Committee of the University of Padova (OPBA Authorization 55/2021). The study enrolled 51 adult client-owned dogs of various breeds admitted to the University Veterinary Teaching Hospital for elective surgical procedures under general anesthesia. Inclusion criteria were age $\geq$ 8 months, American Society of Anesthetists (ASA) risk score of I and II, and anesthesia duration between 1.5 and 2 h. We excluded animals with BCS $<$ 4 out of 9 (Laflamme, 1997), those undergoing thoracic surgery, and dogs with a clinical history of respiratory problems within the preceding 3 weeks, such as cough, labored and difficult breathing, or nasal discharge. A complete blood cell count, which included the measurement of hemoglobin concentration (Hb), was performed on all animals within a maximum of 2 days before anesthesia.

Dogs were stratified into three groups based on their BCS. Dogs with a BCS ranging from 4/9 to 5/9 were categorized as “normal”, while “overweight” animals had a BCS of 6/9 and 7/9. “Obese” dogs were identified by a BCS of 8/9 and 9/9.

2.2. Anesthesia

Food, but not water, was withheld 8 h prior to anesthesia. Premedication was administered with methadone (Semfortan 10 mg/ml, Dechra Veterinary Products S.r.l., Turin, Italy) 0.1–0.2 mg/kg alone or in combination with dexmedetomidine 2–4 μg/kg (Dexdomitor 0.5 mg/mg, Vétoquinol Italia S.r.l., Forlì, Italy) intramuscularly before intravenous catheter placement. General anesthesia was induced with propofol (PropoVet 10 mg/ml, Zoetis Italia S.r.l., Rome, Italy) 2–5 mg/kg intravenously (IV). Immediately after orotracheal intubation, dogs were mechanically ventilated under pressure-control mode with a peak inspiratory pressure of 10–12 cmH_2O and an apparatus intrinsic positive end expiratory pressure of 2–3 cmH_2O. Anesthesia was maintained with sevoflurane (SevoFlo, Zoetis Italia S.r.l., Rome, Italy) or isoflurane (Isoflo, Zoetis Italia S.r.l., Rome, Italy) carried in a mixture of oxygen and air to obtain a fraction of inspired oxygen (FiO_2) of 0.50. Respiratory rate was adjusted to maintain an end-tidal pressure of carbon dioxide ($EtCO_2$) between 35 and 45 mmHg. During maintenance of anesthesia, dogs were placed in different recumbent positions based on the type of surgical procedure they underwent. Monitoring during general anesthesia included SpO_2, continuous electrocardiogram (ECG), oscillometric blood pressure [systolic (SAP), mean (MAP), and diastolic (DAP) pressure], $EtCO_2$, FiO_2 and esophageal temperature. A multiparameter monitor (Datex S/5; GE Healthcare; Helsinki, Finland) continuously displayed those parameters. Lactate Ringer's solution (B. Braun Vet Care Ringer Lattato, B. Braun Milano S.p.a., Milan, Italy) 3–5 ml/kg/h was infused IV during the procedure. FiO_2 was increased at the discretion of the anesthetist if SpO_2 was $<$98%, and the animal was removed from the study.

2.3. ORI and SpO_2 measurements

At least 10 min before the end of the surgery, a multi-wave pulse CO-oximeter (Radical-97, Masimo Corp., CA, USA) was attached to monitor ORi and SpO_2. The adhesive sensor (Rainbow Lite SET-1 Neo; Masimo Corp., CA, USA) was applied circumferentially around the tongue and then connected to the CO-oximetry. The width of the tongue was measured using a caliper, before the probe was applied. The animal was included if the pulse rate recorded by the CO-oximeter matched the heart rate measured by ECG, the displayed plethysmogram was stable, and FiO_2, SpO_2 and ORi were 0.5, 100% and 1, respectively. At the end of the surgical procedure, dogs were placed in sternal recumbency and maintained ventilated for 10 min. After that period, anesthetic delivery and mechanical ventilation were interrupted, and the dog was disconnected from the breathing system, initiating the de-oxygenation phase (Fig. 1). The values of ORi and SpO_2 during this de-oxygenation phase were constantly monitored until SpO_2 reached 95%. At this point, mechanical ventilation was resumed with the ventilator settings used before the beginning of the de-oxygenation phase, and an FiO_2 of 1 was administered for 2 min (re-oxygenation phase). At the end of the re-oxygenation period, SpO_2 and ORi were noted, and the dogs were allowed to recover from anesthesia. Only dogs that remained apneic until SpO_2 95% were included in the study.

All the procedures were video recorded, and during apnea, the time to observe a decrease in ORi value to 0.9, 0.5, and 0.0, or an SpO_2 of 98% and 95% were noted. The times required to reach an SpO_2 of 95% starting from an ORi of 0.9, 0.5, or an SpO_2 of 98% were labeled in Fig. 1 as “ORi 0.9 warning”, “ORi 0.5 warning”, and “SpO_2 warning”, respectively. The time to decrease from ORi 0.9 to ORi 0.0 was defined as “ORi decrease”. The “SpO_2 recovery” is the time for SpO_2 to return to values of 98% during the re-oxygenation phase.

The values of PI and pulse rate (PR) were recorded at reached timepoints of ORi 0.9, ORi 0.5, ORI 0.0, SpO_2 98% and SpO_2 95%. Mean arterial blood pressure (MAP) and esophageal body temperature were measured immediately before the interruption of mechanical ventilation and at the end of the re-oxygenation phase. Mean values of PI, PR, MAP and esophageal temperature were calculated for data analysis.

2.4. Statistical analysis

The primary aim of this study was to compare the warning time provided by ORi in dogs with different BCS. Based on a median (minimum-maximum) time of 11.7 (4–41) seconds to successfully endotracheally intubate dogs (Langton and Blevins, 2021), we considered a statistically relevant difference between ORi and SpO_2 warning time to be 35 s. The standard deviation was estimated to be 17 s based on a prior study investigating SpO_2 decreasing time in anesthetized dogs, after 3-min of flow-by pre-oxygenation (Ambros et al., 2018). Assuming an alpha and a power of 0.05 and 0.8, respectively, the sample size was 12

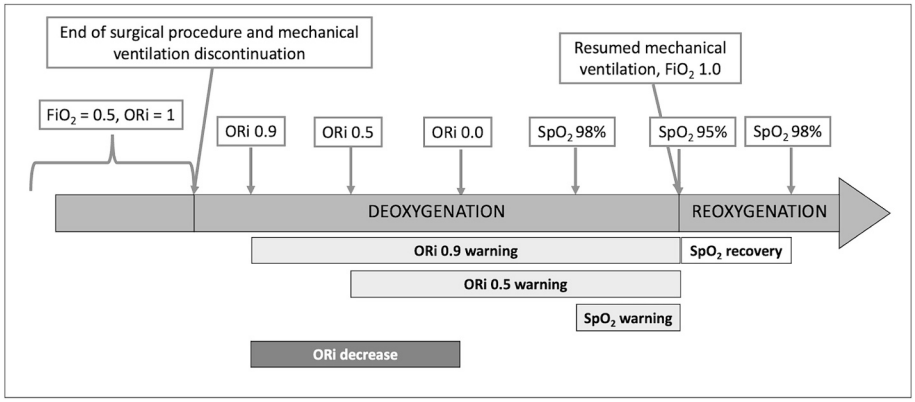

Fig. 1. Study protocol, including the time points for data collection regarding the oxygen reserve index (ORi) and pulse oximetry oxygen hemoglobin saturation (SpO_2), and the definition of the variables measured between those time points. FiO_2 is the fraction of inspired oxygen.

dogs for each class of BCS. We planned to enroll 17 patients in each group to account for potential early withdrawal or errors in data collection.

All statistical analysis was performed using RStudio (RStudio, PBC, Boston, MA, US) as interface for R (The R Foundation for Statistical Computing, Vienna, Austria).

Continuous variables were assessed for normal distribution using a Shapiro–Wilk test. Age, weight, Hb, tongue width, and the mean values of PI, PR, MAP, and esophageal body temperature were compared among the three groups with a one-way ANOVA or a Kruskal-Wallis rank-sum test as appropriate.

Linear regression analysis was used to investigate the type of relationship between the timing of "ORi 0.9 warning," "ORi 0.5 warning," and "SpO_2 warning". To determine if ORi can significantly extend the warning time for impending deoxygenation compared with traditional pulse oximetry, "SpO_2 warning" was compared with "ORi 0.9 warning" and "ORi 0.5 warning", in each group. Moreover, to examine differences in overweight and obese dogs compared to normal patients, we compared the timing of "ORi 0.9 warning", "ORi 0.5 warning", "ORi decrease", "SpO_2 warning", and "SpO_2 recovery" between pairs of groups (normal-overweight, normal-obese). To assess these comparisons, a Student's *t*-test was performed for normally-distributed data, while Mann–Whitney was used for non-normally distributed values.

3. Results

3.1. Animals

No animals exhibited complications during the perioperative period. Forty-seven animals maintained a stable ORi value of 1 and SpO_2 of 100% at the conclusion of the surgery, with a FiO_2 of 0.5. Thirty-eight patients achieved a SpO_2 of 95% while remaining apneic. However, an obese dog was excluded due to abnormal CO-oximeter readings. In this animal, ORi decreased after SpO_2, and it remained 1 even when SpO_2 was 95%. Thirty-seven dogs were finally included, 27 females and 13 males. "Normal", "overweight" and "obese" dogs were 12, 13, and 12, respectively. Patient characteristics are summarized in Table 1. No statistically significant differences were found among the groups in terms of age, weight, preoperative Hb, tongue width, PI, PR, MAP, and esophageal body temperature.

3.2. ORi and SpO_2 decrease times

In all 37 dogs, ORi decreased before any SpO_2 changes, and the decrease of ORi from 1 to 0 occurred prior to the decrease of SpO_2 from 98% to 95% (Fig. 2). Overall, the median (min-max) values of "ORi 0.9 warning", "ORi 0.5 warning", and "SpO_2 warning" were 57.00 (7–212), 33.00 (4–128), and 7.00 (1–62), respectively.

Table 1
Demography and vital variables during apnea. Values were expressed as mean ± standard deviation, or as median (minimum–maximum). Dogs were classified based on their body condition score (BCS) as "normal" (BCS 4–5/9), "overweight" (BCS 6–7/9), or "obese" (BCS 8–9/9).

Parameter	"normal"	"overweight"	"obese"
Age (months)	63.0 ± 53.2	97.5 ± 40.6	89.1 ± 38.9
Weight (Kg)	20.3 ± 12.8	20.7 ± 12.6	21.5 ± 10.2
Breed (number)	American Staffordshire terrier (1) Bernese Mountain dog (1) Bichon Frisè (1) Border Collie (1) Golden retriever (1) Greyhound (1) Labrador retriever Mixed breed (3) Pug (1) West Highland White terrier (1)	American Staffordshire terrier (1) Australian shepherd (1) Bull terrier (1) French Bulldog (1) Jack Russell terrier (1) Lagotto (1) Mixed breed (5) Siberian Husky (1) Swiss shepherd (1)	Australian Cattle dog (1) Brittany spaniel (1) Cavalier King Charles Spaniel (2) French Bulldog (1) German Pinscher (1) Labrador retriever (3) Mixed breed (3)
Pre-operative Hb (g/dl)	17.6 ± 2.4	17.2 ± 2.5	15.1 ± 3.4
PI	0.95 (0.40–2.10)	1.02 (0.15–2.10)	0.91 (0.37–5.33)
PR (bpm)	85.6 ± 19.8	90.2 ± 24.0	92.0 ± 29.9
MAP (mmHg)	78.8 (65.6–107.6)	81.4 (66.7–104.8)	84.7 (53.4–146.8)
Temp (°C)	36.9 ± 1.2	36.8 ± 1.0	37.4 ± 1.1
Tongue width (cm)	0.5 (0.4–0.6)	0.6 (0.5–0.8)	0.6 (0.2–0.9)

Hb: Hemoglobin, PI: Perfusion Index, PR: pulse rate, MAP: mean arterial blood pressure, Temp: body temperature.

A statistically significant correlation was found using linear regression analysis between "ORi 0.9 warning" and "SpO_2 warning" in all groups ($p < 0.001$ in "normal", $p < 0.001$ in "overweight", $p = 0.003$ in "obese"), while "ORi 0.9 warning" was significantly correlated with "ORi 0.5 warning" only in "normal" ($p = 0.002$) and in "overweight" dogs ($p = 0.015$).

Within each group, statistically significant differences were identified between "SpO_2 warning" and "ORi 0.9 warning" or "ORi 0.5 warning". The "ORi 0.9 warning" and "ORi 0.5 warning" were significantly different only within the "normal" and "overweight" but not in "obese" dogs (Fig. 3). Among groups, a statistically significant difference was found only in "ORi decrease" between "normal" and "obese" dogs ($p = 0.028$) (Table 2). During the reoxygenation phase, in all animals SpO_2 increased to 98% and ORi reached a value of 1 within 2 min after resuming ventilation.

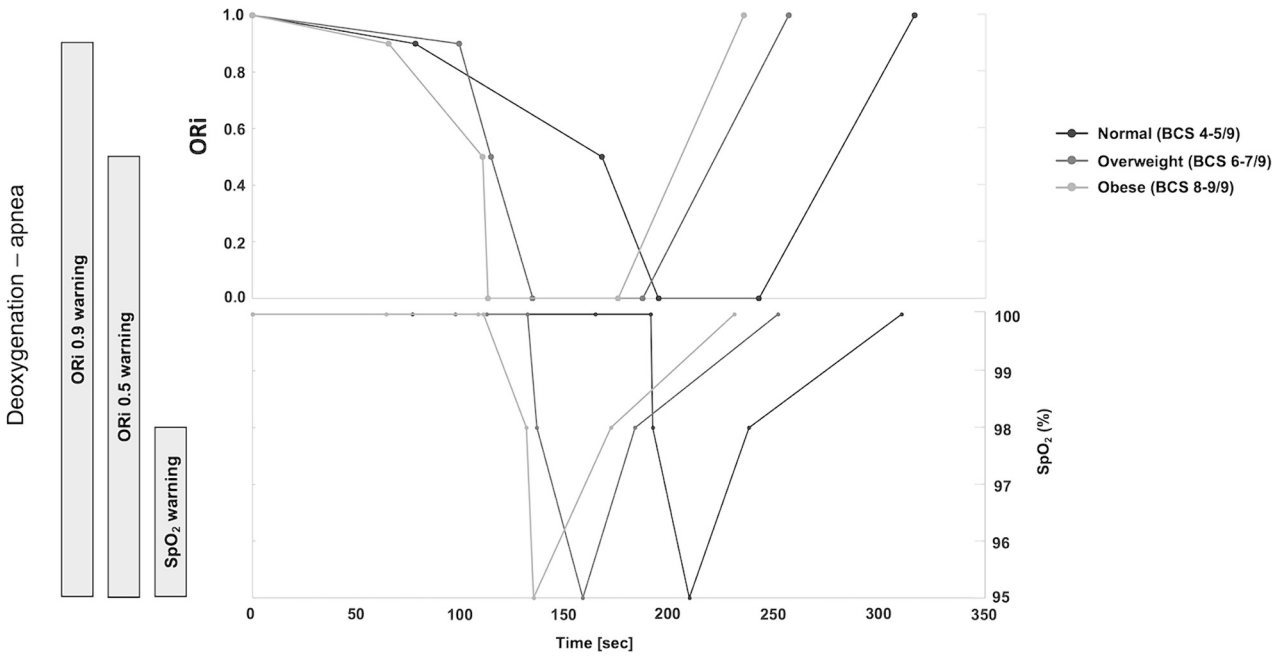

Fig. 2. Trend over time of oxygen reserve index (ORi) and oxygen saturation (SpO_2) in dogs classified based on their body condition score (BCS). See Fig. 1 for further explanation.

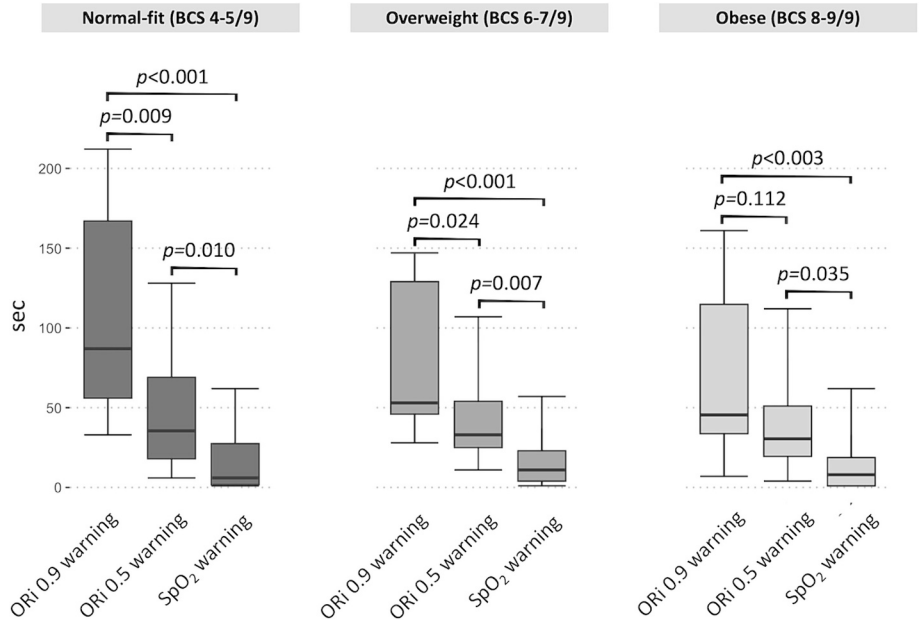

Fig. 3. Comparisons of recorded times of oxygen reserve index (ORi) and oxygen saturation (SpO_2) within the three groups.
ORi 0.9 warning: time from ORi 0.9 to SpO_2 95%, ORi 0.5 warning: time from ORi 0.5 to SpO_2 95%, SpO_2 warning: time from SpO_2 98% to SpO_2 95%.
A p-value <0.05 is considered statistically significant.

4. Discussion

This study is the first to investigate whether the decrease in ORi in apneic dogs can offer a clinically relevant warning time for an impending worsening in the oxygenation. It could potentially serve as a diagnostic tool, adding information that may not be detected by SpO_2 alone.

Pulse oximetry is a valuable tool to monitoring oxygenation status and is recommended in anesthetized veterinary patients to prevent deoxygenation (Grubb et al., 2020). However, SpO_2 does not provide a warning of impending arterial deoxygenation until PaO_2 falls below approximately 80 mmHg, due to the sigmoidal nature of the hemoglobin saturation curve in relation to PaO_2. On the other hand, ORi can detect changes in arterial oxygen content within the PaO_2 range of 100 to 200 mmHg. In veterinary medicine, the correlation between ORi and PaO_2 varied depending on the study considered, ranging from mild to moderate moderate (Bellini et al., 2021; Watanabe et al., 2023; Zanusso et al., 2023a). Moreover, the monitor due to an elevated specificity and sensitivity, is capable of detecting consistent variations in ORi that corresponded to changes in PaO_2 (Applegate et al., 2016; Vos et al., 2019; Yoshida et al., 2020; Zanusso et al., 2023a). For these reasons, ORi could serve as a non-invasive monitoring tool that early detect an

Table 2
Recorded times of oxygen reserve index (ORi) and oxygen saturation (SpO_2) in dogs during apnea. Dogs were classified based on their body condition score (BCS) as "normal" (BCS 4–5/9), "overweight" (BCS 6–7/9), or "obese" (BCS 8–9/9). Values were expressed as mean ± standard deviation, or as median (minimum–maximum).

Time	normal	overweight	obese
ORi 0.9 warning (*sec*)	87.0 (33–212)	53.0 (28–147)	45.5 (7–161)
ORi 0.5 warning (sec)	35.5 (6–128)	33.0 (11–107)	30.5 (4–112)
ORi decrease (sec)	68 (28–210)*	38 (23–123)	33 (5–139)
SpO_2 warning (sec)	6 (1–62)	11 (1–57)	8 (1–62)
SpO_2 recovery (sec)	12.0 (1–46)	25.0 (1–91)	23.5 (1−101)

ORi 0.9 warning: time from ORi 0.9 to SpO_2 95%, ORi 0.5 warning: time from ORi 0.5 to SpO_2 95%, ORi decrease: time from ORi 0.9 to ORi 0.0, SpO_2 warning: time from SpO_2 98% to SpO_2 95%, SpO_2 recovery: time from SpO_2 95% to SpO_2 98%, * statistically significant difference between "obese" and "normal" dogs.

impending deterioration in arterial oxygenation status compared with SpO_2 during anesthesia.

We considered 0.9 and 0.5 as arbitrary ORi warning values. The threshold of ORi 0.9 was chosen as it closely aligns with the upper limit of ORi sensing range for PaO_2. At the time of oxygenation interruption, our patients presented an ORi of 1 after having received an FiO_2 of 0.50. As ORi began to decrease, we identified a value of 0.9 as the initial clear indication of impending deterioration in oxygenation status. The threshold of 0.5 was consider as an ORi cut-off value above 0.53 indicates a PaO_2 higher than 150 mmHg with good sensitivity and specificity (Zanusso et al., 2023a). A PaO_2 above 150 mmHg represents a reasonably safe level of oxygenation during anesthesia exceeding the commonly considered lower limit of 100 mmHg under anesthesia. Moreover, in a human study involving adult patients, an ORi value of 0.55 was chosen as a warning value (Cheng et al., 2022).

In humans, ORi has been demonstrated to decrease before any changes in SpO2 in both adult and pediatric patients. The median ORi warning time was clinically relevant, ranging between 31 and 145 s (Szmuk et al., 2016; Tsymbal et al., 2021; Cheng et al., 2022; Saraçoğlu et al., 2022).

In our study, the median warning times provided by both ORi 0.9 and ORi 0.5 can be considered clinically significant across all canine groups. Values of ORi 0.9 and 0.5 anticipated the decrease of SpO_2 to 95% by at least a median of 30 s in all categories of body condition. This time could be sufficient for administering oxygen to the patient or even inserting an orotracheal tube. In a recent study, the median time required for a qualified veterinary surgeon to successfully intubate a dog was 11.7 s, ranging from 4 to 41 s (Langton and Blevins, 2021).

However, within each group, high variability was observed in ORi warning times, particularly for the "ORi 0.5 warning". For instance, in normal dogs, this time ranged from 6 to 128 s, while in obese dogs, it varied from 4 to 112 s. This variability might be associated with the chosen of ORi cut-off in our study. We do not exclude the possibility that selecting other ORi warning values between 0.9 and 0.0 might have resulted in less variability in times among subjects. This is because in the current study the decrease in ORi from 0.9 to 0.0 was not constant. The variability could be represented by a wide range of PaO_2, from 150 to 250 mmHg, associated with an ORi of 1 (Zanusso et al., 2023a). However, a significant variability in ORi warning time, from ORi alarm to SpO_2 98%, was also observed in human pediatric patients, with values ranging from 0 to 221 s (Szmuk et al., 2016). The variability may also result from an intraoperative ventilation mode not targeted to achieve a tidal volume based on the actual body weight among variable BCS classes, but rather based on a constant airway pressure among groups. Monitoring lung mechanics with spirometry would have provided information regarding tidal volume at the end of anesthesia and before ventilator disconnection. However, standardizing tidal volume during mechanical ventilation is challenging among patients with different BCS. Araos et al. (2021) reported that the percentage of body fat is positively correlated with the percentage of lung hypoaerated area, and overinflation of the non-dependent portion is more common at high tidal volumes. The same authors suggest that ventilating with tidal volume calculated based on ideal rather than the current weight, associated with a low peak inspiratory pressure of around 12 cmH_2O, may control lung overdistention during a tidal breath.

In this study, no statistically significance difference was found in ORi warning times among normal dogs compared with overweight and obese dogs. However, differences in the pattern of ORi decrease between groups might be observed by examining the median values of ORi warning times. While the "ORi 0.9 warning" time was higher in normal dogs compared to obese patients, the "ORi 0.5 warning" time was very similar across groups. Thus, ORi appears to decrease more gradually in normal-fit dogs compared to obese animals, which exhibited a more rapid decline in ORi from 0.9 to 0.5. In humans, ORi warning time, from ORi alarm to SpO_2 of 95% or 94%, was significantly shorter in morbidly obese patients compared individuals with a regular body mass index (Tsymbal et al., 2021; Saraçoğlu et al., 2022). In this study, although ORi warning times were not significantly different between groups, the ORi decrease time from 0.9 to 0 was significantly shorter in obese dogs compared with normal-fit dogs. This suggests a faster decline in arterial oxygenation in obese dogs during apnea.

Obesity in dogs may cause mechanical dysfunction of the airways, increasing expiratory resistance and decreasing functional residual capacity (FRC) (Bach et al., 2007; Araos et al., 2021). In anesthetized animals, the compliance of the respiratory system was inversely correlated with the BCS, decreasing by 19% in dogs with a BCS > 6/9 compared to normal-fit dogs (Asorey et al., 2020). Respiratory system compliance is affected by both chest-wall compliance and lung compliance. The former may depend on fat distribution. In obese patients, the accumulation of adipose tissue in and around the ribs, diaphragm, and abdomen contributes to a decrease in chest wall compliance, reducing thoracic cavity size through cranial shift of the diaphragm (Morooka et al., 2004). In deeply sedated dogs, oxygenation in obese animals was frequently non-optimal, but it improved after weight loss, mainly due to a decrease in fat deposition in the thorax (Mosing et al., 2013). Thus, obese dogs are more prone to rapid decline in blood oxygen level compared with normal-fit dogs, and they require accurate monitoring for early identification and, if necessary, correction of critical oxygen content. Results from this study suggest that monitoring ORi could be valuable in obese patients, as it can anticipate an oxygenation impairment, especially given the increasing prevalence of obesity in the canine population (McGreevy et al., 2005; Love and Cline, 2015). However, overweight likely does not significantly restrict respiratory mechanics as obesity does. In this study, the absence of a statistically significant difference in ORi decrease time between normal and overweight dogs may be related to the limited impact of overweight on respiratory function.

Obese dogs experienced a faster decline in oxygenation compared with normal dogs until reaching normoxemia. Beyond this point, no significant difference in oxygenation was observed up to an SpO_2 equal to 95%. Similar trends were noted in humans, where significant differences were found in ORi warning time but not in SpO2 warning time between normal and obese patients (Tsymbal et al., 2021).

In this study, no difference between normal and obese dogs was detected in the SpO_2 rising time, from 95% to 98%. However, the recovery time for SpO_2 was longer in obese dogs, suggesting more challenging reoxygenation in these patients, likely due to the respiratory alterations in this class of animals. During the reoxygenation phase, SpO_2 increased before ORi in all dogs. Through the deoxygenation phase, ORi decreased before SpO_2 in all dogs except for one obese dog, which was excluded from the study. In this animal, ORi decreased after SpO_2, and its values was 1 although SpO_2 was 95%. A misreading of ORi was suspected, as the perfusion index (PI) measured by the CO-oximeter was 5.3. In a recent investigation involving anesthetized dogs, it has been demonstrated that ORi showed a poor correlation with PaO_2 when

the monitor detected a PI above 2 (Zanusso et al., 2023b). While the possibility of inaccurate readings due to abnormal local perfusion could not be entirely ruled out in other dogs, it was deemed unlikely, given that the PI remained between 0.2 and 2.1.

Our study presents some limitations. One of these is due to the index itself, whose measurement is influenced by several uncontrolled patient-related variables. Only 50% of the expected variation in the ORi is predicted by PaO_2 (Zanusso et al., 2023a), and the remaining portion suffers from the effects of other factors not considered in this study, such as those that shift the hemoglobin oxygen saturation curve. Moreover, the study population was predominantly composed of females, reflecting the population referred for clinical reasons. Furthermore, the distribution of females and males was not equal across groups, with females accounting for 50%, 62%, and 83% in "normal", "overweight" and "obese"' dogs, respectively. The highest percentage of females, particularly among "obese" dogs, might have influenced the results. Females tend to have a greater percentage of fat compared to males (Bredella, 2017). Thus, we cannot exclude the possibility that the sex distribution could have contributed to the shorter time of ORi decrease in obese patients compared to normal-fit dogs. Moreover, as ORi is measured based on hemoglobin saturation in venous and arterial blood, differences in decreasing time could be attributed to breed-related hemoglobin oxygen affinity (Clerbaux et al., 1993).

A further limitation is associated with the pressure-controlled ventilation instituted in dogs before apnea. In this ventilation mode, pressure is maintained constantly and independently of changes in compliance, resistance, and patient inspiratory effort. During pressure-controlled ventilation, volume becomes the dependent variable, leading to substantial variations in tidal volume (Vt) due to changes in the resistance or compliance of the respiratory system, or in the inspiratory effort of the patient. Reductions in compliance or increased resistance of the airway will lead to a lower delivered Vt. Conversely, an increase in compliance, a decrease in resistance, or an increase in patient inspiratory effort will elevate Vt (Garnero et al., 2013). Thus, dogs included in the study might have received varying Vt during ventilation and commenced apnea from different initial compliance values. This variability might have influenced the time for deoxygenation. Although no evidence exists for the best ventilation strategy in dogs, pressure-controlled ventilation theoretically offers beneficial effects, including a reduction in peak inspiratory pressure (PIP) associated with over-distension phenomena in the ventral and apical regions of the lungs. Additionally, improved oxygenation, particularly valuable in situations of severe hypoxemia, results from enhanced gas distribution within the alveolar spaces (Markström et al., 1996; Prella et al., 2002). Although intrapulmonary shunt and atelectasis may have developed intra-operatively, these were considered minimal as all dogs had an ORi of 1, indicating an estimated PaO_2 of at least 200–220 mmHg. Additionally, because the FiO_2 was set at 0.5, the PaO_2 could not exceed 250 mmHg. Despite the potential low tidal volume due to the ventilation mode, all dogs were close to the ideal PaO_2 value, although measuring the actual oxygen content would have necessitated a blood gas analyzer.

We finally selected two fixed values of ORi, 0.9 and 0.5. However, we cannot rule out the possibility that alternative ORi values might be more effective as warning thresholds during deoxygenation. Further investigations are needed to study the decreasing trend of ORi in dogs more accurately, helping to identify the ORi value at which the rapid decrease begins, as observed in humans (Szmuk et al., 2016; Yoshida et al., 2018).

5. Conclusions

In conclusion, the results of this study support the use of ORi in dogs during the recovery from anesthesia, overcoming the limitations of conventional pulse oximetry. The additional warning time offered by ORi provides clinician with enough time to enhance airway management and promptly seek assistance from experienced providers when necessary. Furthermore, ORi might serve as a valuable tool for a safe management of recovery, especially in obese dogs prone to impaired oxygenation status.

CRediT authorship contribution statement

Francesca Zanusso: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giulia Maria De Benedictis:** Writing – review & editing, Conceptualization. **Luca Bellini:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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