NOTE *Surgery*

Central venous blood gas and acid-base status in conscious dogs and cats

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ABSTRACT. To determine the reference level of central venous oxygen saturation ($ScvO_2$) and clinical efficacy of central venous blood gas analysis, partial pressures of oxygen and carbon dioxide, pH, oxygen saturation, base excess (B.E.) and HCO_3 concentration were compared between simultaneously obtained central venous and arterial blood samples from conscious healthy 6 dogs and 5 cats. Comparisons between arteriovenous samples were performed by a paired *t*-test and Bland-Altman analysis. Between arteriovenous samples, B.E. showed good agreement, but there were significant differences in other parameters in the dogs, and no good agreement was detected in cats. The $ScvO_2$ in dogs and cats were 82.3 ± 3.5 and 62.4 ± 13.5%, respectively. Central venous blood gas analysis is indispensable, especially in cats.
KEY WORDS: acid-base status, canine, central venous oxygen saturation, feline

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Circulatory abnormalities lead to an imbalance between systemic oxygen delivery and oxygen demand, resulting in global tissue hypoxia. In critical care medicine, hemodynamic optimization is an important goal to achieve a balance between oxygen delivery and oxygen demand and to prevent tissue hypoxia [21]. More recently, early goal-oriented manipulation of cardiac preload, afterload and contractility to achieve a balance between systemic oxygen delivery and oxygen demand was shown to be effective at improving survival rates in humans with severe sepsis and septic shock [2]. End points used to confirm the achievement of such a balance include normalized values for central venous oxygen saturation ($ScvO_2$) and arterial lactate concentration, base excess, and pH [7]. This therapeutic strategy has been endorsed by the international guidelines for management of severe sepsis and septic shock [5] and provided a trend toward improved outcomes of cardiac arrest survivors in human [9].

In dogs and cats, the placement of central venous catheter through the jugular vein is a relatively common technique in referral and/or emergency veterinary hospitals, and it provides easy access for venous blood sampling, drug and fluid administration, and monitoring of central venous pressure during intensive fluid therapy. Moreover, it is recommended that hemodynamic function should be optimized according to observations on $ScvO_2$, blood lactate concentration, and central venous and arterial blood pressure in dogs and cats with critical illness [3, 4] and under post cardiac arrest care [8]. Decreased $ScvO_2$ may be caused by decreased oxygen delivery and be associated with tissue hypoxia [21]. Actually, a decreased $ScvO_2$ was detected in anesthetized dogs with experimental hemorrhage or hypoxia [20]. In addition, it was reported that the lower $ScvO_2$ and lower base excess (B.E.) were clinically relevant predictors of mortality in canine intensive care [4, 13]. Therefore, central venous blood gas analysis will also provide important information for a hemodynamic optimization in dogs and cats similar to humans. However, there is very little information about the recommended target values for hemodynamic optimization in dogs and cats. So far the target value of $ScvO_2$ in dogs and cats [3, 4, 8] was extrapolated from early goal-directed hemodynamic therapy in human medicine [21].

The purpose of this study was to clarify the reference level of values for $ScvO_2$ and clinical efficacy of central venous blood gas analysis in healthy conscious dogs and cats. The results of this study would show the basic $ScvO_2$ data for hemodynamic optimization and the relationship between central venous and arterial blood gas analysis in conscious dogs and cats.

Six adult beagle dogs (3 males and 3 females) that weighed 11.0 ± 1.4 kg (mean ± standard deviation) and 5 adult purpose bred cats (2 males and 3 females) that weighed 4.1 ± 0.7 kg were used in this study. Central venous and arterial blood samples were simultaneously obtained from the catheter placed at dorsal pedal artery and central vein in conscious dogs and cats. The Animal Care and Use Committee of Rakuno Gakuen University approved these experiments (approved No: VH24B7 and VH24B8). All the animals were judged to be in good to excellent health based upon a physical examination, complete blood cell count and chemical analysis.

The animals had been withheld from food for 12 hr,

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Table 1. Central venous and arterial blood gas parameters in dogs and cats

	Central venous blood	Arterial blood	Bias	Presision	*r*
Dogs					
pH	7.382 [0.020]**	7.413 [0.023]	–0.032	0.016	0.740
PO_2 (mmHg)	50.7 [3.8]**	106.2 [5.3]	–55.5	5.4	0.315
PCO_2 (mmHg)	42.5 [2.1]**	36.7 [2.9]	5.8	2.8	0.426
SO_2 (%)	82.3 [3.5]**	97.8 [0.4]	–15.5	3.6	–0.233
HCO_3 (mmol/*l*)	24.9 [1.7]*	23.2 [1.9]	1.8	1.2	0.792
B.E. (mmol/*l*)	–0.0 [1.8]	-0.7 [1.8]	0.7	0.8	0.907†
Cats					
pH	7.304 [0.031]**	7.380 [0.019]	–0.076	0.018	0.854
PO_2 (mmHg)	38.8 [6.1]**	112.0 [3.2]	–73.2	6.6	0.078
PCO_2 (mmHg)	40.8 [3.7]**	29.0 [1.4]	11.8	3.1	0.573
SO_2 (%)	62.4 [13.5]**	98.0 [0.0]	–35.6	13.5	N.D.
HCO_3 (mmol/*l*)	20.1 [1.1]**	17.0 [1.3]	3.1	0.9	0.705
B.E. (mmol/*l*)	–5.6 [1.1]	–6.6 [1.2]	1.0	0.9	0.740

Blood gas parameters were reported as mean [standard deviation]. Significant difference between central venous and arterial blood gas parameters (*: $P<0.05$, **: $P<0.01$). PO_2: partial pressure of oxygen; PCO_2: partial pressure of carbon dioxide; SO_2: oxygen saturation of hemoglobin; HCO_3: bicarbonate concentration; B. E.: base excess. Bias: mean values of the difference between central venous and arterial blood gas parameters; Precision: standard deviation of the bias; *r*: correlation coefficient (†: $P<0.05$). N.D.: not determined.

but allowed free access to water before the experiments. The dogs or cats anesthetized with mask or box induction with sevoflurane (Sevoflo, DS Pharma Animal Health Co., Osaka, Japan) in oxygen (OS anesthesia), respectively. All the animals were oro-tracheally intubated and then instrumented 3 catheters under OS anesthesia at 3.0% of sevoflurane vaporizer dial setting. In each animal, 22-guage and 24-guage catheters (Supercath, Medikit Co., Tokyo, Japan) were placed into the cephalic vein and dorsal pedal artery, respectively. An 18-guage catheter with 30 cm in length (Intravascular Catheter Kit, Medikit Co.) was also placed into the cranial vena cava through the right jugular vein after the cervical catheter site was aseptically prepared and infiltrated with 1 mg/kg of 2% lidocaine (2% Xylocaine, AstraZeneca, Osaka, Japan). A position of the tip of central venous catheter was appraised by its insertion length and confirmed by pressure waveform. The animals were infused lactated Ringer's solution (Solulact, Terumo Co., Tokyo, Japan) at a rate of 10 m*l*/kg/hr through the catheter placed into the cephalic vein during OS anesthesia. After the completion of catheter placements, the animals were ceased the administration of sevoflurane and extubated the tracheal tube when their laryngeal reflex was recovered.

All the animals had rested in a quiet room for 1 hr after the extubation and stabilized their cardio-respiratory status. Then, arterial and central blood samples (1 m*l* each) were simultaneously withdrawn from the arterial and central venous catheters in each animal. The animals were remained in standing position with minimal manual restraint during the blood collection. Each blood sample was collected into a plastic syringe that was heparinized with liquid containing 1,000 unit/m*l* of sodium heparin (Novo-heparin for injection, Mochida Pharmaceutical Co., Tokyo, Japan) by an evacuation technique to minimize the sample dilution [13]. Air bubbles in the syringe were immediately expelled following the blood collection. These blood samples were analyzed immediately after the collection (<5 min) to measure partial pressures of oxygen (PO_2) and carbon dioxide (PCO_2), and pH using a blood gas analyzer (GEM Premier 3000, Instrumentation Laboratory, Tokyo, Japan). In addition, bicarbonate concentration (HCO_3), B.E. and oxygen saturation (SO_2) were calculated automatically. The pH, PO_2 and PCO_2 were corrected for the rectal temperature determined immediately after the blood collection in each animal.

The data were reported as mean ± standard deviation. The differences between central venous and arterial parameters were analyzed by a paired *t* test. A Bland-Altman analysis [19] was used to assess agreement between the paired central venous and arterial blood gas parameters. Bias was defined as the mean values of the difference between the paired central venous and arterial blood gas parameters in each animal species. Precision was defined as standard deviation of the bias. Limits of agreement and 95% confidence interval of minimal detectable change were defined as bias ± 1.96 × precision and 1.96 × precision, respectively. The correlation coefficient (*r*) was calculated using regression analysis. A value of $P<0.05$ was considered significant.

Rectal temperatures determined immediately after the blood collection were 38.0 ± 0.5°C and 38.0 ± 0.7°C in the dogs and cats, respectively. The central venous and arterial blood gas parameters in dogs and cats are summarized in Table 1. The Bland-Altman plots in each parameter are shown in Fig. 1. In the dogs, significant differences between central venous and arterial blood were detected in pH ($P<0.001$), PO_2 ($P<0.001$), PCO_2 ($P<0.001$), SO_2 ($P<0.001$) and HCO_3 ($P=0.013$). Significant correlations between central venous and arterial blood gas parameters were detected in B.E. ($r=0.907$, $P=0.013$). Compared to the corresponding arterial

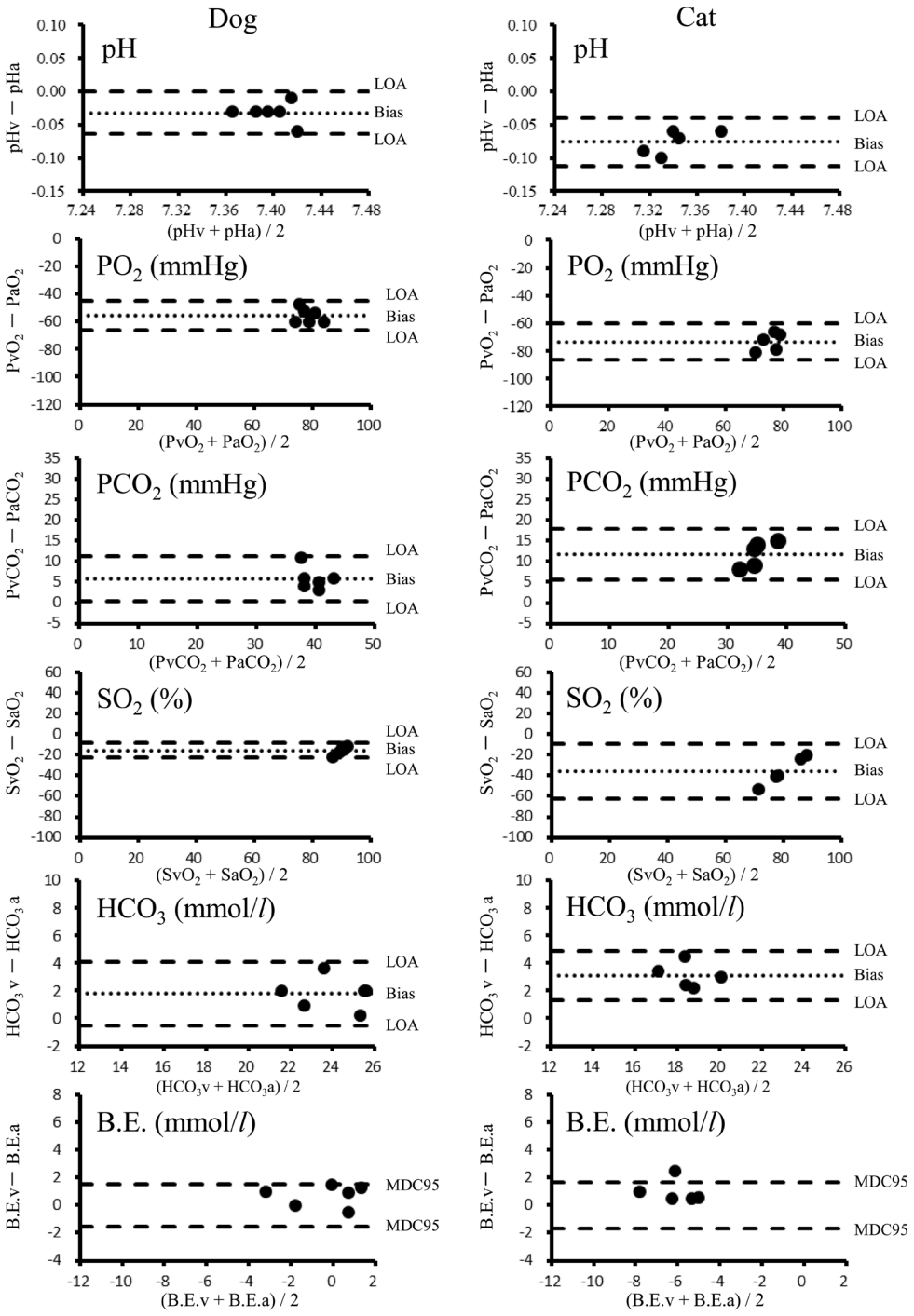

Fig. 1. Bland-Altaman plots between the arterial and central venous blood gas parameters in dogs and cats. Bland-Altman analysis was applied to examine limits of agreement on pH, partial pressures of oxygen (PO_2) and carbon dioxide (PCO_2), oxygen saturation (SO_2), HCO_3 concentration and base excess (B.E.) between arterial and central venous blood gas analysis. Each Bland-Altman plot was made from paired arterial and central venous samples simultaneously collected from conscious healthy 6 dogs (figures on left side) and 5 cats (figures on right side), respectively. Bias was defined as the mean values of the difference between the paired arterial and central venous blood gas parameters in each animal species. Precision was defined as standard deviation of the bias. Limits of agreement (LOA) and 95% confidence interval of minimal detectable change (MDC95) were defined as bias ± 1.96 × precision and 1.96 × precision, respectively. pHa: arterial pH, pHv: central venous pH, PaO_2: arterial PO_2, PvO_2: central venous PO_2, SaO_2: arterial SO_2, SvO_2: central venous SO_2, HCO_3a: arterial HCO_3 concentration, HCO_3v: central venous HCO_3 concentration, B.E.a: arterial B.E., B.E.v: central venous B.E.

parameters, the central venous blood gas analysis showed lower values in pH (limits of agreement: −0.032 ± 0.031), PO_2 (−55.5 ± 10.6 mmHg) and SO_2 (−15.5 ± 7.1%) and higher values in PCO_2 (5.8 ± 5.5 mmHg) and HCO_3 (1.8 ± 2.3 mmol/*l*). There was no systemic bias between central venous and arterial blood samples in B.E. (95% confidence interval of minimal detectable change: 1.5 mmol/*l*).

In the cats, significant differences between central venous and arterial blood were detected in pH ($P<0.001$), PO_2 ($P<0.001$), PCO_2 ($P<0.001$), SO_2 ($P<0.001$) and HCO_3 ($P<0.001$). There were no significant correlations between central venous and arterial blood gas parameters. Compared to the corresponding arterial parameters, the central venous blood gas analysis showed lower values in pH (limits of agreement: −0.076 ± 0.036), PO_2 (−73.2 ± 12.3 mmHg) and SO_2 (−35.6 ± 26.5%) and higher values in PCO_2 (11.8 ± 6.1 mmHg) and HCO_3 (3.1 ± 1.8 mmol/*l*). There was no systemic bias between central venous and arterial blood samples in B.E. (95% confidence interval of minimal detectable change: 1.7 mmol/*l*).

The arterial blood gas and acid-base values (pH, PO_2, PCO_2, SO_2, HCO_3 and B.E.) reported in this study are similar to those previously reported in the normal conscious dogs [1, 15] and cats [17]. Blood gas and acid-base status in conscious animals are easily affected hyperventilation related to fear and increase in muscular activity related to struggling during blood collection [6]. Blood gas and acid-base measurements can be also affected *in vitro* errors including air contamination, dilution of blood samples with anticoagulant and inappropriate storage of samples [11]. In this study, blood samples were obtained from the arterial and central venous catheters without struggling in all the dogs and cats. It was reported that the evacuated syringe technique using in this study enabled to limit the dilution of blood sample by anticoagulant within 4% [14]. In addition, we expelled immediately the air presenting in a sampling syringe and performed the blood gas analysis within 5 min after the blood collection. We surmise that these methods would minimize the errors in blood gas analysis in this study.

In this study, the $ScvO_2$ in conscious dogs and cats were 82.3 ± 3.5% and 62.4 ± 13.5%, respectively. In dogs, it was reported that $ScvO_2$ less than 68% was associated with increased mortality risk in critically ill dogs [13]. The $ScvO_2$ level of our cats was lower than this cut-off level for dogs. The $ScvO_2$ and arterial SO_2 values were calculated from the hemoglobin-oxygen dissociation curve of human blood by the blood gas analyzer in this study. These results may provide overestimation of the actual SO_2 values in dogs and cats, because the PO_2 value at 50% of saturation in hemogrobin with oxygen for human is slightly lower than that for dogs and much lower than that for cats [12]. Furthermore, body temperature, hydrogen ion, 2,3-diphosphoglycerate and/or PO_2 also affect the standard hemogrobin-oxygen dissociation curve [12]. Nevertheless, we believe that the lower $ScvO_2$ in healthy conscious cats is notable for setting a goal-directed hemodynamic optimization protocol in cat. Further investigation is necessary to confirm the recommended target values of $ScvO_2$ for hemodynamic optimization, especially in cats.

In this study, the central venous blood gas values obtained from the dogs were similar to those of peripheral and mixed venous blood reported in the normal conscious dogs [1, 15]. In our dogs, the central venous PCO_2 and HCO_3 showed a small overestimation of the corresponding arterial parameters, and the central venous pH showed a little underestimation of arterial pH. Significant correlations and a small random error in B.E. were detected between the central venous and arterial samples. On the other hand, the PO_2 and SO_2 showed rather big differences between central venous and arterial samples. Ilkiw *et al.* [15] reported that several venous sites (mixed venous, jugular venous and cephalic venous blood) accurately reflect the acid-base status of the healthy conscious dogs. Our results reconfirmed that the B.E. between the central venous and arterial samples were agreed in healthy conscious dog although the other venous acid-base status (i.e. pH, PCO_2 and HCO_3) may be affected by the higher venous PCO_2, compared to arterial samples.

The central venous blood gas values obtained from our cats were similar to those of samples collected from the jugular vein in healthy conscious cat [17]. In our cats, the central venous PCO_2 and HCO_3 overestimated, and pH, PO_2 and SO_2 underestimated the corresponding arterial parameters. In addition, a cat showed the higher value than the 95% confidence interval of minimal detectable change between the central venous and arterial samples in B.E., even though only a small random error in B.E. between the venous and arterial samples was detected. It is notable that somewhat big limits of agreement between the central venous and arterial blood were detected in pH and PCO_2 of our cat, compared to those of the dogs. Blood carbon dioxide is present in three different forms: dissolved, bound as bicarbonate or bound as carbamate. The majority of carbon dioxide in plasma and erythrocytes is bound as bicarbonate resulting from carbon dioxide hydration/dehydration reactions accelerated by carbonic anhydrase. Isozyme carbonic anhydrase-I with a relatively lower specific activity occurred in the red blood cells of almost all mammals except for the cat family, by contrast, isozyme carbonic anhydrase-II occurs in all mammals [10]. We consider that the difference of carbon anhydrase activity between animal species might affect the buffering capacity of carbon dioxide in blood and this result in the large gradient between arterio-venous PCO_2 in cat. In addition, we speculate that higher PCO_2 in the central venous blood induced lowering the pH in the central venous samples. Middleton *et al.* [17] also reported that arterial blood was preferred for evaluating the acid-base status, oxygenation and ventilation in conscious healthy cat. Therefore, all the central venous blood gas parameters were not practical alternatives to the corresponding arterial blood gas parameters in cats.

Several studies have showed the reliability and accuracy of central venous blood gas in acid-base monitoring as an alternative to arterial blood gas analysis in human intensive care [16, 18]. However, our study showed central venous blood sample was not preferred for evaluating the acid-base status, oxygenation and ventilation, compared to arterial blood sample even in healthy conscious animals, especially in cats. These results suggest that both arterial and central

venous blood access are indispensable for the intensive care in dogs and cats.

In conclusion, this study provides the basic central venous blood gas parameters including $ScvO_2$ in healthy conscious dogs and cats. In addition, we consider both arterial and central venous blood gas analysis would be indispensable for evaluating hemodynamic optimization as well as acid-base, oxygenation and ventilation status, especially in critically ill animals.

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