

Assessment of Clinical and Laboratory Variables as a Guide to Packed Red Blood Cell Transfusion of Euvolemic Anemic Dogs

C. Kisielewicz, I. Self, and R. Bell

Background: There are no standardized guidelines for determining the likelihood that euvolemic anemic dogs will benefit from transfusion of packed red blood cells (pRBC).

Objectives: To report clinical and laboratory variables of dogs receiving pRBC transfusion, which could guide transfusion of other anemic dogs.

Animals: Twenty-four client-owned anemic dogs receiving pRBC transfusion.

Methods: Prospective study; 30 transfusions assessed. Clinical findings (mucosal color, pulse quality, heart rate, respiratory rate, mentation/exercise tolerance) before and after transfusion were evaluated by the anemic dog clinical assessment score (ADCAS). Hemoglobin concentration, hematocrit, venous oxygen content (CvO₂), and lactate concentration were measured from blood samples taken before and after transfusion. These results were not used for case management.

Results: All ADCAS variables decreased significantly with transfusion ($P < .001$); the total score was $\geq 5/12$ before transfusion, and $\leq 3/12$ in all cases that were deemed to no longer require transfusion. Hematocrit and CvO₂ were $<17\%$ and <5 mL/dL, respectively, in 83% of cases before transfusion and hemoglobin concentration was <5.8 g/dL in 80%. Hemoglobin concentration, hematocrit, and CvO₂ increased significantly with transfusion ($P < .001$); lactate concentration decreased significantly ($P = .006$).

Conclusions and Clinical Importance: Clinical and laboratory variables improved significantly after transfusion of pRBC. By identifying how transfusion affected these variables, it was possible to recognize clinical (ADCAS) and laboratory (hemoglobin, CvO₂, lactate) variables, which could be useful in guiding the decision to transfuse dogs with similar presentations.

Key words: Anemia; Hemoglobin; Objective clinical assessment; Venous oxygen content.

Blood transfusions are important for the management of severe anemia in dogs. Transfusion of blood restores tissue perfusion by increasing blood oxygen carrying capacity and improving oxygen delivery (DO₂) to tissues. Several factors should be considered when deciding to transfuse blood including the risks of transfusion reactions and disease transmission, costs involved, and difficulties acquiring blood products. Transfusions should therefore be restricted to animals with clear indication of the need for transfusion.^{1–4}

There are no universal, standardized, objective guidelines established for assessing whether people or dogs could benefit from transfusion. A critical hemoglobin concentration, a level below which cellular metabolism becomes compromised, signifying that transfusion would be beneficial, remains undetermined despite clinical and experimental studies in people and an experimental study in dogs.^{5–10} Current procedures involve assessing hemoglobin concentration and

Abbreviations:

ADCAS	anemic dog clinical assessment score
bpm	beats per minute
CvO ₂	venous oxygen content
DO ₂	oxygen delivery
Hb	hemoglobin
IMHA	immune-mediated hemolytic anemia
IMTP	immune-mediated thrombocytopenia
pRBC	packed red blood cell
PvO ₂	venous partial pressure of oxygen
rpm	respirations per minute
SvO ₂	venous oxygen saturation of hemoglobin

subjectively interpreting clinical examination findings, with the possibility of interobserver variability.^{3,11} Few studies record the use of the clinical signs of severe anemia as part of the decision-making process.^{3,6,12}

Markers of impaired cellular oxygenation, such as increased lactate concentration, and decreased DO₂ and cellular oxygen extraction, have been investigated alongside hemoglobin concentration to better determine whether transfusion might be required in anemic people.^{13,14} Hyperlactatemia develops as a result of decreased DO₂ and subsequent tissue hypoxia and therefore in euvolemic, anemic dogs, it could suggest a requirement for blood transfusion.¹⁵ Central venous oxygen saturation has been investigated as an approximation of DO₂ in critically ill dogs, but requires cranial vena cava sampling.¹⁶ Venous oxygen content (CvO₂) has not been reported for evaluation of tissue oxygen status or DO₂; however, it could provide a less invasive surrogate measure of DO₂. An increase in CvO₂ after transfusion, in the absence of supplemental

From the Queen Mother Hospital for Animals, Royal Veterinary College, Hatfield, Hertfordshire UK (Kisielewicz, Self); and Dick White Referrals, Cambridge, Cambridgeshire UK (Bell). Results of a pilot study involving part of the results of this study were presented at the BSAVA Congress 2012, Birmingham, UK. This study was performed at the University of Glasgow Small Animal Hospital, School of Veterinary Medicine, Bearsden Road, Glasgow, UK.

Corresponding author: C. Kisielewicz, Queen Mother Hospital for Animals, Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Hertfordshire AL9 7TA, UK; e-mail: carkis13@yahoo.com.

Submitted May 21, 2013; Revised October 6, 2013; Accepted November 18, 2013.

Copyright © 2014 by the American College of Veterinary Internal Medicine

oxygen administration and hypovolemia, would suggest improved DO_2 .

As there are no standardized approaches to determine when anemic dogs require pRBC transfusion, this study aimed to evaluate the effect of pRBC transfusion on hemoglobin concentration, hematocrit, CvO_2 , lactate concentration, and standardized clinical assessment of anemic dogs, all of which were hypothesized to improve after transfusion, with a view to identifying levels of these variables, common to all included dogs, which could be extrapolated to other anemic dogs as guidelines to assist with the decision to transfuse.

Materials and Methods

This study was approved by the University Ethics and Welfare Committee. Anemic (hematocrit $<37\%$) client-owned dogs admitted to the hospital that were deemed to require pRBC transfusion were included in this prospective study (October 2010–July 2012). Decision to transfuse and pRBC volume administered were independently determined by the attending clinician, who was aware of hematocrit and clinical examination findings, but blinded to anemic dog clinical assessment score (ADCAS), lactate concentration, and oxygenation values; these results were not used for case management. Dogs receiving supplemental oxygen and those with primary cardiorespiratory disease or dyspnea were excluded from the study. Dogs with neuromuscular or orthopedic disease affecting ambulation were excluded. Dogs deemed to be dehydrated, hypovolemic, or hyperbilirubinemic, and any cases of suspected transfusion reaction requiring specific treatment were also excluded. These were all considered possible confounding factors that could influence blood oxygenation, laboratory variable evaluation, or clinical examination assessment.

Age, sex, weight, diagnosis, and duration of anemia were recorded. An experienced clinical pathologist assessed for signs of regeneration (polychromasia, anisocytosis) on blood smear examination when reticulocyte count was not measured.¹⁷ The duration of anemia was determined based on the duration of clinical signs, documented anemia, or both (whichever was greater); dogs were separated into acute (<2 weeks) or chronic (>2 weeks) groups.

Dogs were blood typed (Rapid Vet-H Canine blood typing kit^a) (DEA-1.1 positive or negative) before transfusion and type compatible pRBC units^b were administered (DEA-1.1 negative blood was administered to dogs whose blood type could not be determined). Blood volume administered was based on the formula: volume (mL) of pRBC = (desired PCV–recipient PCV)/donor PCV \times body weight (kg) \times 90.¹⁸ The target PCV was determined at the discretion of the attending clinician; arbitrary hospital recommendation was to achieve a PCV of 20–30% after transfusion. Cross-matching (Rapid Vet-H Companion animal crossmatch kit^a) was performed in dogs that had previously received a transfusion. Transfusions were completed without concurrent medications or intravenous fluids. Volume of blood

administered, transfusion duration, and transfusion reactions were recorded.

Clinical Assessment

An anemic dog clinical assessment score (ADCAS), scored out of 12, evaluating 5 clinical variables, was designed (Table 1). Variables included mucus membrane color (compared to photographs depicting each category) (Fig 1), pulse quality, heart rate, respiratory rate, and mentation and exercise tolerance. Scores were given for each variable based on the severity of the abnormality (brackets indicate score): normal (0), mild (1), moderate (2), and severe (3). Heart and respiratory rates were categorized as normal, mildly increased (1), and moderately to severely increased (2). The same clinician examined every dog, immediately before and after transfusion, to avoid interobserver variation and was not involved in transfusion decision, but was not blinded to transfusion status.

Laboratory Variables

A venous blood sample was taken before and within 1 hour after transfusion for PCV measurement. Both blood samples were taken from the same vein. Lactate concentration (Accutrend Lactate Meter^c) and oxygenation values (venous partial pressure of oxygen, PvO_2 , and venous oxygen saturation of hemoglobin, SvO_2), hemoglobin concentration and hematocrit, from blood gas analysis (Opti-Critical Care Blood Gas Analyser^c), were assessed within 5 minutes of sample collection from surplus blood. CvO_2 was calculated from the formula: $([\text{hemoglobin}] \times \text{SvO}_2/100 \times 1.34) + (\text{PvO}_2 \times 0.003)$.¹⁹ Blood samples were taken anaerobically with heparinized syringes.^d

Statistical Analysis

Descriptive statistics were performed on all data. The normality of distribution of continuous variables was assessed with the Anderson–Darling test. Normally distributed data were summarized with mean \pm standard deviation, and nonparametric and categorical data with median (range). Clinical scores and variables were compared by the Wilcoxon signed rank test. The actual increase in hematocrit was compared with the estimated increase with a paired *t*-test. Laboratory variables measured before and after transfusion were compared by paired *t*-tests. Associations between the duration, and etiology of anemia as well as the presence of regeneration and clinical variables before transfusion were assessed with the Kruskal–Wallis test. *P* values $< .05$ were considered statistically significant. All analyses were performed by a statistical software package.^e

Results

Twenty-four dogs of various breeds were included, with a total of 30 transfusion cases; 2 dogs received 2

Table 1. Anemic dog clinical assessment score (ADCAS).

	Normal (0)	Mild (1)	Moderate (2)	Severe (3)
Mucosa color	Salmon pink (Fig 1A)	Slightly pale (Fig 1B)	Moderately pale (Fig 1C)	Severely pale (Fig 1D)
Pulse quality	Normal	Bounding	Weak	Weak
Heart rate	65–109 bpm ²¹	110–140 bpm	>140 bpm	>140 bpm
Respiratory rate	15–24 rpm ²⁰	25–40 rpm	>40 rpm	>40 rpm
Mentation/exercise tolerance	BAR, walking	Quiet, able to walk	Lethargic, able to stand	Lethargic, unable to stand

bpm, beats per minute; rpm, respirations per minute.



Fig 1. Mucosal scoring system, A—score 0, B—score 1, C—score 2, and D—score 3.

transfusions and 2 dogs received 3 (as several days elapsed between transfusions, these were treated as unrelated cases). There were 14 female neutered, 1 female entire, 7 male neutered, and 2 male entire dogs. Dogs were a median of 6 years of age (range 0.5–9 years) and weighed a median of 21 kg (range 6–50 kg). Ten dogs were blood type DEA-1.1 positive and 12 were DEA-1.1 negative; auto-agglutination interfered with blood type interpretation in 2 dogs. Cross-matching was performed in 6 dogs before transfusion. Twenty-one dogs (27/30 transfusions) had jugular venipunctures; the 3 dogs with immune-mediated thrombocytopenia (IMTP) had cephalic venipunctures.

Anemia duration was 5 days, 2–40 days (median, range); further categorization of dogs based on duration, type, and etiology of anemia is given in Table 2.

Table 2. Duration, type, and etiology of anemia for 30 transfusion cases.

	Regenerative Anemia	Nonregenerative Anemia	Total Dogs (Transfusions)
Acute anemia	2 GI hemorrhage 3 IMTP 11 IMHA	2 IMHA 1 GI hemorrhage	19 (23)
Chronic anemia		1 GI hemorrhage 2 myelodysplasia 2 IMHA*	5 (7)
Total dogs (Transfusions)	16 (20)	8 (10)	24 (30)

GI, gastrointestinal; IMHA, immune-mediated hemolytic anemia; IMTP, immune-mediated thrombocytopenia; IMHA*, immune-mediated hemolytic anemia affecting bone marrow precursors.

Transfusion duration was 5 hours (3–6 hours) with a volume of 320 mL (160–450 mL) equating to 14.8 mL/kg (7.1–41.7 mL/kg) of pRBC; mean age of pRBC units was 12.7 ± 6.7 days (mean \pm SD). Transfusion was deemed by the attending clinician, independently of the ADCAS, lactate concentration, and oxygenation values, to be successful in 21 dogs (27/30 transfusions) based on improvement in clinical examination findings and increase in hematocrit. Dogs 6 (immune-mediated hemolytic anemia, IMHA), 13, and 18 (IMTP) were independently thought, by the attending clinician, to have unsuccessful transfusions based on insufficiently increased hematocrits and persistent tachycardia, tachypnea, and bounding pulses suggesting ongoing tissue hypoxia and requirement for further transfusion.

Clinical Variables

All variables in the ADCAS, including the total score, decreased significantly with transfusion ($P < .001$; Table 3). All cases had a total ADCAS of $\geq 5/12$ before transfusion. After transfusion, all cases, except for those that remained transfusion-dependent (dogs 6, 13, and 18), had a total score $\leq 3/12$.

Heart rate was 131 bpm before transfusion (100–196 bpm), 96 bpm after transfusion (66–148), with a decrease of 45 bpm (–88 to 0 bpm). It was >100 bpm in all dogs, and >120 bpm in 27/30 cases before transfusion and this decreased to ≤ 100 bpm in all except for dogs 6, 13, and 18. Respiratory rate was 48 rpm before transfusion (16–112 rpm), 30 rpm after transfusion (12–112 rpm), with a decrease of 22 rpm (–68 to 12 rpm). Heart and respiratory rates decreased significantly with transfusion ($P < .001$).

Dogs with regenerative IMHA had higher heart and respiratory rates before transfusion, $P < .001$ and

Table 3. Change in laboratory variable values after 30 transfusions. *P* value is for the comparison between values before and after transfusion.

	Before Transfusion	After Transfusion	Δ Transfusion	RI	<i>P</i> Value
PvO ₂ (mmHg)	36 ± 8.1	35.3 ± 6.9	-0.7 ± 11.5	Unknown	.733
SvO ₂ (%)	68.3 ± 9.3	66.6 ± 8.5	-1.7 ± 12.8	Unknown	.471
Hb (g/dL)	4.8 ± 1.2	8.4 ± 1.7	3.6 ± 2.1	12–18	<.001
Hematocrit (%)	14.6 ± 3.4	25.4 ± 5.1	10.8 ± 6.0	37–55	<.001
CvO ₂ (mL/dL)	4.5 ± 1.2	7.7 ± 1.9	3.1 ± 2.3	14–14.5 ¹²	<.001
Lactate (mmol/L)	3.0 ± 1.9	2.4 ± 1.3	-0.6 ± 1.1	<2.5	.006

Values denote mean ± SD.

Δ Transfusion, change with transfusion; RI, reference interval; PvO₂, venous partial pressure of oxygen; SvO₂, venous oxygen saturation of hemoglobin; Hb, hemoglobin; CvO₂, venous oxygen content.

P = .004, respectively. Dogs with acute onset and regenerative anemia had a higher pulse quality score (*P* = .001) and were more lethargic (*P* = .02) with a higher total ADCAS before transfusion (*P* < .001).

Laboratory Variables

Hemoglobin concentration, hematocrit, and CvO₂ increased significantly with transfusion (*P* < .001), and lactate concentration decreased significantly (*P* = .006), whereas PvO₂ and SvO₂ did not change significantly (*P* = .733 and *P* = .471, respectively) (Table 4). The increase in hematocrit was not significantly different from the estimated increase (*P* = .056). Hemoglobin concentration, hematocrit, and CvO₂ increased in all cases except for dog 6, where these variables decreased from 6.3 g/dL, 20%, and 6.88 mL/dL to 6.1 g/dL, 19%, and 4.63 mL/dL, respectively. Eighty-three percent (25/30) of transfusions were administered to dogs with a hematocrit <17%, and CvO₂ <5 mL/dL before transfusion. Eighty percent of transfusion cases (24/30) had a hemoglobin concentration <5.8 g/dL before transfusion. After transfusion, CvO₂ remained <5 mL/dL in dogs 6 (4.6 mL/dL) and 13 (3.6 mL/dL), but not in dog 18 (5.5 mL/dL); these dogs were still deemed to be transfusion-dependent. Dog 11, which had acute-onset, regenerative IMHA, had a hemoglobin concentration and hematocrit of 5.2 g/dL and

16.5%, respectively, after transfusion, but was not considered clinically transfusion-dependent despite these levels. All other dogs had hemoglobin concentration >5.8 g/dL and hematocrit >17% after transfusion.

Lactate concentration was abnormal in 16/30 (53%) cases before transfusion. Hyperlactatemia resolved in 4/16 cases after transfusion and improved, but remained high in 12/16 cases after transfusion. Results from cephalic samples were not higher than those acquired from jugular samples.

Discussion

The results of this study show that both clinical examination findings, assessed by the ADCAS, and laboratory variables (hemoglobin concentration, hematocrit, CvO₂, and lactate concentration) improve significantly after transfusion of pRBC to anemic dogs. Clinical and laboratory variables were recorded before transfusion and values of these variables were identified at a time that corresponded to a clinical decision to administer a transfusion, thereby fulfilling the study objectives.

The ADCAS was designed to assist with the identification of anemic dogs that would likely benefit from transfusion by allowing a more objective and standardized assessment of clinical examination findings. A mild abnormality for an assessed variable received a lower score compared with more severe abnormalities. The higher the total score achieved, the more likely a dog in this study was to require transfusion when compared with scores after transfusion. All scores improved significantly after transfusion. A “transfusion-need scale” was previously designed to guide transfusion decision using the clinical signs of anemia;¹⁴ however, it relies heavily on the PCV of the dog, which is an unreliable indicator of the need for transfusion.³ There are few studies in human and veterinary medicine, which have investigated using the easily recognizable clinical examination findings of anemic patients for making decisions regarding transfusion.^{3,6} This has led to what are described as “weak” recommendations, by the American Association of Blood Banks, based on this limited evidence, to consider clinical signs of anemia in addition to hemoglobin concentration assessment to guide transfusion

Table 4. Change in clinical variable scores after 30 transfusions. *P* value is for the comparison between values before and after transfusion.

	Before Transfusion	After Transfusion	Δ Transfusion	<i>P</i> Value
MM color	2 (1–3)	1 (0–2)	-1 (-3 to 0)	<.001
Pulse quality	1 (0–2)	0 (0–0)	-1 (-2 to 0)	<.001
HR score	1 (0–2)	0 (0–2)	-1 (-2 to 0)	<.001
RR score	2 (0–2)	1 (0–2)	-1 (-2 to 0)	<.001
Mentation/Ex	2 (0–3)	1 (0–2)	-1 (-2 to 1)	<.001
Total	7 (5–10)	2 (0–6)	-5 (-8 to -1)	<.001

Values denote Median (range).

Δ Transfusion, change with transfusion; MM, mucus membrane; HR, heart rate; RR, respiratory rate; Ex, exercise tolerance.

therapy of anemic people.¹¹ Clinical examination findings attributable to reduced oxygen carrying capacity of a population of anemic dogs before transfusion are reported in this study. By correlating a change in these variables with a clinical interpretation of whether transfusion had been deemed successful or otherwise, the usefulness of assessing these variables in combination with laboratory variables when deciding to transfuse dogs has been demonstrated.

All ADCAS variables improved significantly after transfusion. Abnormalities in individual variables could nonspecifically indicate a variety of conditions, but considered together, they are the most commonly assessed clinical variables in anemic dogs and people when deciding whether a transfusion could be beneficial.^{3,6,12} Heart and respiratory rates are the most objective variables in the ADCAS and are weighted differently from the other variables. Subjectivity was minimized as mucosal color was compared with photographs. Mentation and exercise tolerance were assessed together as these were likely to be equally affected in anemic dogs. Pulse quality was the most subjective variable and therefore the same clinician performed all clinical examinations, thus minimizing subjectivity.

Most dogs were initially tachycardic and tachypneic, and these variables decreased significantly with transfusion. Despite the wide body weight variation in the included dogs, resting heart and respiratory rates in normal dogs have been determined to be unrelated to bodyweight.^{20,21} Classification of tachycardia and tachypnea based on severity is rarely described and so ranges were arbitrarily chosen.^{19–21}

The total score decreased significantly in all cases. It remained high in 3 dogs after transfusion and within the range of scores seen for cases before transfusion. These dogs were deemed to have continued signs of severe anemia (tachycardia, tachypnea, bounding pulses), suggesting further need for transfusion. Although each individual ADCAS variable improved significantly after transfusion, the scoring system provides a stronger guideline for transfusion decision when assessed as a whole, as there are likely less differential diagnoses possible when all 5 variables are abnormal.

Dogs with acute, regenerative anemia were more lethargic, tachycardic, and tachypneic, with more severe pulse quality abnormalities before transfusion compared with dogs with chronic, nonregenerative anemia; mentation/exercise tolerance was similar between groups. Hematocrits before transfusion were not markedly different between regenerative and nonregenerative anemia cases. These findings reflect the understanding that dogs with acute anemia require days to develop systemic compensatory mechanisms to anemia, which become exhausted quicker than in cases of chronic anemia, and that clinical signs of anemia are more apparent in dogs with acute anemia than those with chronic anemia at a similar hematocrit.³ Despite the variation in clinical examination findings before transfusion, the response to transfusion was comparable in all dogs; underlying disease was

therefore an unlikely explanation of the difference in ADCAS variables between cases of acute and chronic anemia before transfusion.

Hemoglobin concentration, hematocrit, and subsequently CvO₂ increased significantly after pRBC transfusion in this study. Hemoglobin concentrations at which dogs in this study were deemed to require transfusion, based on assessment by the attending clinician, were recorded. The difference between the hematocrits of cases of acute, regenerative and chronic, nonregenerative anemia before transfusion was minimal (data not shown). Hemoglobin is the major determinant of both blood oxygen content and DO₂.¹⁴ Various studies have attempted to identify the hemoglobin concentration or hematocrit threshold level, suggesting that transfusions should be administered at the latest when hemoglobin concentration is <5–8 g/dL in people and hematocrit <10% in dogs.^{5–10} Hemoglobin was <5.8 g/dL in 80% of the included cases before transfusion and although not a confirmed threshold level, this concentration could assist with transfusion decision in dogs in combination with ADCAS findings.

CvO₂ increased significantly after transfusion. There was no clear difference between values for cases of acute compared with chronic anemia before and after transfusion (data not shown). This variable was selected as a potential surrogate marker of DO₂ because of ease of sample collection and measurement. An increase in CvO₂ after transfusion suggests concurrent DO₂ improvement, which itself is considered a surrogate marker for tissue oxygenation.^{13,14} Mathematical models have been designed to reliably convert venous oxygenation values to arterial equivalents for use in critically ill people to minimize the need for arterial punctures.²² These could be extrapolated to the veterinary field in the future lending further weight to the use of venous rather than arterial values, allowing assessment of CvO₂ rather than arterial oxygen content. The increase in CvO₂ mirrored the increase in hemoglobin concentration and as hemoglobin is a major determinant of DO₂, it is likely that DO₂ improved as well, although this was not confirmed. CvO₂ has not been previously assessed to guide transfusion therapy, but it did not appear to offer more information than hemoglobin measurement in this study.

Neither PvO₂ nor SvO₂ changed significantly with transfusion decreasing in some cases and increasing in others after transfusion with no discernible pattern. As anemia and subsequent increased oxygen extraction leads to PvO₂ and SvO₂ reduction,²³ it could have been expected that these variables would increase after transfusion, although arterial partial pressure of oxygen and hemoglobin oxygen saturation do not change after blood transfusion in people.¹³ If DO₂ improved with increased hemoglobin, then PvO₂ and SvO₂ should not be considered surrogate markers of DO₂ based on this study.

Lactate concentration decreased significantly with pRBC transfusion. It was high in 53% of cases before transfusion and remained increased in 40% of cases

after transfusion. Lactate concentration before transfusion of dogs with hemolysis appeared to be higher than that seen in cases of hemorrhage or chronic anemia (data not shown). As a surrogate marker of tissue oxygenation, lactate allows approximation of severity of tissue hypoperfusion and hypoxia, and monitoring serial measurements over time enables assessment of treatment response.²⁴ Lactate could guide transfusion therapy.¹⁵ Lactate concentration did not reliably differentiate between cases that would benefit from further blood transfusion in this study as only 10% of transfusion cases (25% of those with ongoing hyperlactatemia) were deemed to have continuing clinical signs of anemia (tachycardia, tachypnea, bounding pulses). The hyperlactatemia after transfusion was unlikely because of hypoperfusion, as hypovolemic dogs were excluded. It could have resulted from persisting tissue hypoxia caused by anemia, which might only have resolved hours after transfusion or it was possibly a result of microcirculatory perfusion derangements related to underlying disease.^{25,26} Lactate concentrations do not vary significantly between arterial and venous samples, but have been shown to be lower in jugular compared with cephalic venous samples²⁷, a finding that was not mirrored in this study.

There were several limitations to this study. Only 30 transfusion cases were included during the study period. Four dogs had multiple transfusions in this study; however, as the clinical examination and laboratory variables were assessed immediately before and after transfusion, previous transfusions were unlikely to have a marked impact on the results of these. Type II statistical error could have influenced the lack of significance of PvO₂ and SvO₂ changes after transfusion. Despite low case numbers, there were statistically significant changes in hemoglobin concentration, hematocrit, CvO₂, lactate concentration, and the ADCAS variables. The ADCAS contained some subjective variables, including pulse quality and mucus membrane color in particular. Subjectivity was minimized as the same clinician performed all clinical examinations, but bias could have been introduced as the clinician was not blinded to the transfusion status of dogs. Future studies are needed to validate the ADCAS to statistically prove its reproducibility and reliability; the same score should be achieved in a particular dog (taking exclusion criteria into consideration), whatever the experience of the veterinary professional assessing it. Anemia cases of different etiologies were not specifically excluded, so as to reflect the variety of cases seen in this hospital. There were, however, extensive exclusion criteria applied to minimize confounding factors, which restricted the population of dogs in the study and could limit the usefulness of these variables for cases of anemia from other causes. Consideration should be given to these criteria if applying the results from this study to other anemic dogs. The dogs in this study were presented to a referral institution, which could have introduced bias into case selection. As many veterinary practices do not store blood transfusion products, cases of severe ane-

mia are often referred. Cases with less severe anemia would not likely require transfusion and therefore, it is likely that the dogs in this study reflect the general population of anemic dogs that would likely require transfusion. The authors were the primary clinicians of <17% of the cases included, which minimized any bias toward deciding to initiate transfusion. All other cases were independently managed by other clinicians.

In summary, this study describes the clinical examination and laboratory parameter changes that occur with transfusion of pRBC to anemic dogs. The ADCAS allowed clinical examination findings to be more objectively included in the decision-making process; the higher the score, the more likely a blood transfusion would be clinically beneficial. Concentrations of hemoglobin, hematocrit, and CvO₂ below which, most included dogs were given a transfusion, were reported. These variables could be used to provide objective criteria of transfusion dependency in dogs. A single universal transfusion trigger does not exist, but the variables described in this study could be extrapolated to other anemic dogs and collectively used to guide the decision to transfuse alongside clinician judgment, providing that the exclusion criteria are taken into consideration.

Footnotes

- ^a DMS Laboratories, Flemington, NJ
 - ^b Canine pRBC, Pet Blood Bank, Loughborough, UK
 - ^c Roche Diagnostics, West Sussex, UK
 - ^d Pre-heparinized syringe sampler, Sanguis Counting, Numbrecht, Germany
 - ^e Minitab 16, Coventry, UK
-

Acknowledgments

The authors acknowledge the statistical advice given by Dr David Brodbelt, Veterinary Epidemiology, Economics and Public Health, Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Hertfordshire, AL9 7TA, UK.

Conflict of Interest Declaration: Authors disclose no conflict of interest.

References

1. Callan MB, Oakley DA, Shofer FS, Giger U. Canine red blood cell transfusion practice. *J Am Anim Hosp Assoc* 1996; 32:303–311.
2. Howard A, Callan B, Sweeney M, Giger U. Transfusion practices and costs in dogs. *J Am Vet Med Assoc* 1992;201:1697–1701.
3. Prittie JE. Triggers for use, optimal dosing, and problems associated with red cell transfusions. *Vet Clin North Am Small Anim Pract* 2003;33:1261–1275.
4. Wardrop KJ, Reine N, Birkenheuer A, et al. Canine and feline blood donor screening for infectious disease. *J Vet Intern Med* 2005;19:135–142.

5. Carson JL, Noveck H, Berlin JA, Gould SA. Mortality and morbidity in patients with very low postoperative Hb levels who decline blood transfusion. *Transfusion* 2002;42:812–818.
6. Carson JL, Terrin ML, Noveck H, et al. Liberal or restrictive transfusion in high-risk patients after hip surgery. *N Engl J Med* 2011;365:2453–2462.
7. Hebert PC, Wells G, Blajchman MA, et al. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. Transfusion Requirements in Critical Care Investigators, Canadian Critical Care Trials Group. *N Engl J Med* 1999;340:409–417.
8. Viele MK, Weiskopf RB. What can we learn about the need for transfusion from patients who refuse blood? The experience with Jehovah's Witnesses. *Transfusion* 1994;34:396–401.
9. Weiskopf RB, Viele MK, Feiner J, et al. Human cardiovascular and metabolic response to acute, severe isovolemic anemia. *J Am Med Assoc* 1998;279:217–221.
10. Schwartz S, Frantz RA, Shoemaker C. Sequential hemodynamic and oxygen transport responses in hypovolemia, anemia, and hypoxia. *Am J Physiol Heart Circ Physiol* 1981;241:864–871.
11. Carson JL, Grossman BJ, Kleinman S, et al. Red blood cell transfusion: A clinical practice guideline from the AABB. *Ann Intern Med* 2012;157:49–58.
12. Kerl ME, Hohenhaus AE. Packed red blood cell transfusion in dogs: 131 cases (1989). *J Am Vet Med Assoc* 1993;202:1495–1499.
13. Saugel B, Klein M, Hapfelmeier A, et al. Effects of red blood cell transfusion on hemodynamic parameters: A prospective study in intensive care unit patients. *Scand J Trauma Resusc Emerg Med* 2013;21:1–7.
14. Holahan ML, Brown AJ, Drobatz KJ. The association of blood lactate concentration with outcome in dogs with idiopathic immune-mediated hemolytic anemia: 173 cases (2003-2006). *J Vet Emerg Crit Care* 2010;20:413–420.
15. Cassut M, Seifert B, Pasch T, et al. Factors influencing the individual effects of blood transfusions on oxygen delivery and oxygen consumption. *Crit Care Med* 1999;27:2194–2200.
16. Hayes GM, Mathews K, Boston S, Dewey C. Low central venous oxygen saturation is associated with increased mortality in critically ill dogs. *J Small Anim Pract* 2011;52:4333–4440.
17. Hodges J, Christopher MM. Diagnostic accuracy of using erythrocyte indices and polychromasia to identify regenerative anemia in dogs. *J Am Vet Med Assoc* 2011;238:1452–1458.
18. Short JI, Diehl S, Seshadri R, Serrano S. Accuracy of formulas used to predict post-transfusion packed cell volume rise in anemic dogs. *J Vet Emerg Crit Care* 2012;22:428–434.
19. Haskins S, Pascoe PJ, Ilkiw JE, et al. Reference cardiopulmonary values in normal dogs. *Comp Med* 2005;55:156–161.
20. Rishniw M., Ljungvall I, Porciello F, et al. Sleeping respiratory rates in apparently healthy adult dogs. *Res Vet Sci* 2012;93:965–969.
21. Ferasin L, Ferasin H, Little CJL. Lack of correlation between canine heart rate and body size in veterinary clinical practice. *J Small Anim Pract* 2010;51:412–418.
22. Toftegaard M, Rees SE, Andreassen S. Evaluation of a method for converting venous values of acid-base and oxygenation status to arterial values. *Emerg Med J* 2009;26:268–272.
23. Klein HG, Spahn DR, Carson JL. Red blood cell transfusion in clinical practice. *Lancet* 2007;370:415–426.
24. Green TI, Tonozzi CC, Kirby R, Rudloff E. Evaluation of initial plasma lactate values as a predictor of gastric necrosis and initial and subsequent plasma lactate values as a predictor of survival in dogs with gastric dilatation-volvulus: 84 dogs (2003-2007). *J Vet Emerg Crit Care* 2011;21:36–44.
25. Steffes CP, Bender JS, Levison MA. Blood transfusion and oxygen consumption in surgical sepsis. *Crit Care Med* 1991;19:512–517.
26. Morisaki H, Sibbald WJ. Tissue oxygen delivery and the microcirculation. *Crit Care Clin* 2004;20:213–223.
27. Hughes D, Rozanski ER, Shofer FS, et al. Effect of sampling site, repeated sampling, pH, and PCO₂ on plasma lactate concentration in healthy dogs. *Am J Vet Res* 1999;60:521–524.