

Electrolyte and acid/base changes in dogs undergoing autologous blood transfusion via a cell salvage device

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Abstract – This study reports electrolyte and acid/base disturbances observed in clinical cases receiving autologous transfusion of blood processed by a cell salvage device. The records of 12 client-owned dogs that received an autologous transfusion via a cell salvage device with pre- and post-autologous transfusion blood work available were reviewed. Blood work from the 12 case dogs was compared to blood work from 12 control dogs with similar diseases. Control dogs received similar surgical treatment and were administered a similar volume per kg of packed red blood cells as case dogs, but did not undergo autologous transfusion. Case dogs that received autologous transfusion via a cell salvage device were significantly more likely to experience a decrease in ionized calcium and magnesium levels post-transfusion than were control dogs. Calcium and magnesium levels should be closely monitored during and after autologous transfusion. Calcium and/or magnesium supplementation may be required.

Résumé – **Changements électrolytiques et acido-basiques chez les chiens subissant une transfusion sanguine autologue à l'aide d'un dispositif de récupération des cellules.** Cette étude signale les perturbations électrolytiques et acido-basiques observées dans des cas cliniques recevant une transfusion de sang autologue traitée à l'aide d'un dispositif de récupération des cellules. On a évalué les dossiers de 12 chiens, appartenant à des propriétaires, qui avaient reçu une transfusion autologue à l'aide d'un dispositif de récupération des cellules et avaient subi des analyses sanguines avant et après la transfusion autologue. Les analyses sanguines des 12 chiens ont été comparées aux analyses de 12 chiens témoins atteints de maladies semblables. Les chiens témoins ont reçu des traitements chirurgicaux semblables et un volume semblable par kg de concentré de globules rouges que les chiens du cas, mais n'ont pas subi la transfusion autologue. Il était significativement plus probable que les chiens du cas qui avaient reçu une transfusion autologue à l'aide d'un dispositif de récupération des cellules subissent une baisse du niveau de calcium ionisé et de magnésium après la transfusion que les chiens témoins. Le niveau de calcium et de magnésium devrait être étroitement surveillé durant et après la transfusion autologue. Des suppléments de calcium et/ou de magnésium pourront être requis.

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Introduction

In human medicine, autologous red blood cell (RBC) transfusion, whether by preoperative RBC donation, perioperative isovolemic hemodilution, or intraoperative RBC salvage, is a good option for eligible patients requiring perioperative RBC transfusion (1). When utilizing cell salvage in surgical patients with ongoing blood loss, whole blood is suctioned

from the surgical field. The whole blood, lavage solution, and debris present in the surgical field are delivered to the cell salvage machine. Inside the machine, the RBCs are separated from plasma proteins and lighter cellular elements by centrifugation and are washed (C.A.T.S. Operating Instructions, Fresenius HemoCare GmbH, Bad Homburg, Germany, August 2000) (2). The RBCs can be washed with a variety of solutions including 0.9% saline, Isolyte S, and bicarbonate-buffered hemofiltration solution (3,4). The washed RBCs are suspended in 0.9% saline and returned to the animal (C.A.T.S. Operating Instructions) (2).

The conceivable benefits of autologous blood transfusion over allogenic transfusion have been described in human and veterinary medicine (1,2,5–8). These benefits include RBC antigenic compatibility, the absence of costs and time delays associated with blood typing and/or crossmatching, and absence of risk for transmission of systemic infectious disease and blood borne pathogens (2). Although the risk of blood-borne pathogen transmission is low in veterinary patients, the risk is present as evidenced by reports of transmission of *Leishmania* spp. and *Babesia* spp. by blood transfusion in dogs (9,10).

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When utilizing autologous blood processed by a cell salvage device, the potential reservoir of autologous RBCs requires little time for preparation, does not contain preservative, and contains very little anticoagulant (6,11). In contrast, stored packed RBCs undergo cellular changes that affect red cell viability and function, potentially resulting in diminished cell survival following transfusion (12). The changes induced by storage include reduction in pH and glucose, depletion of 2,3 diphosphoglycerate and ATP, and increase in sodium and potassium concentrations (13). Other benefits of using a cell salvage device to process and return RBCs rather than administering unprocessed salvaged whole blood include return of blood with a higher hematocrit and hemoglobin and removal of thromboplastic substances and other components of the coagulation system (fibrin degradation products) that may lead to coagulation abnormalities (14).

The deleterious effects of autologous transfusion by cell salvage have been explored in human medicine, but there is limited information on this topic in veterinary medicine (15). Electrolyte changes induced by washing RBCs from healthy dogs in an experimental setting with iatrogenic induced hemorrhage have been reported (16). Statistically significant changes in systemic pH, total CO₂, chloride, phosphorous, hemoglobin, hematocrit, total and ionized calcium, magnesium, total protein, and albumin were found when comparing baseline values to study end blood values (16).

Calcium, electrolyte, and acid/base changes have not been reported in association with the clinical use of a cell salvage machine in veterinary medicine. The purpose of this study was to report calcium, electrolyte, and acid/base disturbances observed in clinical cases receiving autologous transfusion of blood processed by a cell salvage machine compared to control cases. Identifying whether predictable clinically important electrolyte and acid/base disturbances occur after cell salvage will help prompt early intervention for potentially life threatening complications.

Materials and methods

Case dogs were retrospectively identified by searching records for animals undergoing autologous transfusion at our institution between January 1, 2002 and July 1, 2013. The records were reviewed to verify that the cell salvage device (C.A.T.S AT1 Autotransfusion Set; Fresenius HemoCare GmbH) was used for autologous blood transfusion in each case. Study inclusion criteria required that each case dog have pre- and post-autologous blood transfusion blood gas and/or electrolyte data available for comparison. Data retrieved from the medical records included signalment, underlying disease or injury, clinical laboratory analyses, volume of autologous blood administered from the cell salvage device, and the volume and type of additional blood products administered (when available).

Control dogs were selected from hospital records at our institution. Control dogs were dogs that had a similar disease process to each case dog and underwent a similar surgical intervention. Control dogs did not receive an autologous transfusion but received a volume per kg of packed red blood cells (pRBCs) that was similar to that administered to the case dogs. Study inclusion criteria required that each control dog have pre- and

post-allogenic blood transfusion blood gas and/or electrolyte data available for comparison. Data retrieved from the medical records included signalment, underlying disease or injury, clinical laboratory analyses, and volume and type of blood products administered.

In all case dogs, hemorrhagic fluid present in a body cavity was removed with a Yankauer suction tip by the surgical team upon entry into the cavity or from the surgical field during active hemorrhage. The retrieved fluid in the suction line (ATS Suction Line; Fresenius Kabi AG, Bad Homburg, Germany) was anticoagulated using heparin (Heparin Sodium Injection, 5000 USP units/mL; APP Pharmaceuticals, Schaumburg, Illinois, USA) at a concentration of 30 000 IU/L of 0.9% NaCl (0.9% NaCl; Abbott Laboratories, North Chicago, Illinois, USA). The heparin and retrieved fluid were stored in the cardiotomy reservoir (Autotransfusion Reservoir; Fresenius Kabi AG) of the cell salvage device. Once sufficient blood was present in the cardiotomy reservoir, or at the discretion of the cell salvage device operator, the retrieved fluid and heparin were pumped from the cardiotomy reservoir to the centrifugation bowl (Autotransfusion Set; Fresenius Kabi AG). The heparin and RBCs were separated in the centrifugation bowl. The centrifuged RBCs were subsequently washed with 0.9% NaCl and the RBCs were pumped into a reinfusion bag. The RBCs were moved to a transfer bag (Terumo transfer bag; Terumo Corporation, Tokyo, Japan) where they were filtered with a high blood flow filter (Pall SQ40 High Blood Flow Filter; Terumo Cardiovascular Systems Corporation, Ann Arbor, Michigan, USA) before being administered to the dog.

The cause of the body cavity hemorrhage was defined as traumatic if there was a known traumatic event, iatrogenic if excessive hemorrhage developed intraoperatively, spontaneous if there was no reported source of trauma or identifiable neoplasia, and neoplastic if there was hemorrhage from a neoplasm.

For all dogs, the medical records were reviewed for changes detected in electrolyte and blood gas measurements before and after the autologous or allogenic transfusion, specifically ionized calcium (iCa²⁺), ionized magnesium (Mg²⁺), potassium (K⁺), sodium (Na⁺), chloride (Cl), and pH. Electrolyte and pH concentrations were determined with a point-of-care testing instrument (Nova analyzer; Nova Biomedical, Waltham, Massachusetts, USA and IRMA TruPoint blood analysis system; International Technidyne Corporation, Edison, New Jersey, USA). Any intervention to address clinically relevant changes in blood work variables was noted. The amount of additional blood products (fresh frozen plasma, allogenic packed RBCs, and whole blood) administered was noted when available. The amount of intraoperative isotonic crystalloids and colloids was noted.

Outcome was defined as death or euthanasia intraoperatively, death or euthanasia within 12 h after surgery, death or euthanasia occurring after 12 h following the surgery but prior to discharge from the hospital, or survival to discharge from the hospital.

A Bayesian approach was implemented to estimate and compare the distributions of 6 blood parameters before and after treatment for case dogs and control dogs and to compare

Table 1. Pre- and post-transfusion blood gas and electrolyte data for case and control dogs with relevant reference ranges. Median values and ranges are reported for the dogs with available data

	Electrolyte or blood gas reference ranges	Number of dogs with data available (pre)	Number of dogs with data available (post)	Median (pre)	Range (pre)	Median (post)	Range (post)
Case	K ⁺ 3.91 to 4.40 mmol/L	11	12	3.9	2.93 to 5.2	3.72	3.39 to 5.1
Control	K ⁺ 3.91 to 4.40 mmol/L	12	11	3.96	3.4 to 4.76	3.75	3.2 to 4.52
Case	Cl ⁻ 110.6 to 115.5 mmol/L	9	9	115.6	106.8 to 125.2	117.1	111.4 to 125.5
Control	Cl ⁻ 110.6 to 115.5 mmol/L	10	10	116	108.2 to 122.1	117.9	103.2 to 123.7
Case	Na ⁺ 146.8 to 153.1 mmol/L	11	11	143	133.8 to 154.2	144.1	140.6 to 150.9
Control	Na ⁺ 146.8 to 153.1 mmol/L	12	12	144.9	130.2 to 151.6	145.3	130.8 to 151
Case	iCa ²⁺ 1.23 to 1.35 mmol/L	10	12	1.17	0.94 to 1.44	1.10	0.56 to 1.26
Control	iCa ²⁺ 1.23 to 1.35 mmol/L	12	12	1.22	1.12 to 1.34	1.23	0.66 to 1.34
Case	Mg ²⁺ 0.38 to 0.52 mmol/L	9	11	0.44	0.31 to 0.86	0.37	0.29 to 0.52
Control	Mg ²⁺ 0.38 to 0.52 mmol/L	10	11	0.48	0.32 to 0.52	0.44	0.28 to 0.55
Case	pH 7.350 to 7.490	11	11	7.31	7.143 to 7.432	7.337	7.141 to 7.487
Control	pH 7.350 to 7.490	11	12	7.432	7.179 to 7.557	7.385	7.172 to 7.453

the changes in blood parameters controlling for patient effects. Means for values are reported but because the full distribution of the parameters was estimated, the mean difference between treatment groups does not necessarily equal the difference of the group means. All means were given a relatively uninformative normal prior, namely a mean of 0 and a precision of 0.0001. With respect to the comparison of blood volumes, administered blood volumes were assigned an imprecise normal prior. The mean of the prior was given a gamma (epsilon, epsilon) prior to provide adequate prior support for a zero amount administered and to allow for only positive numbers. The precision of the prior was also assigned a gamma (epsilon, epsilon) prior. After allowing for convergence, each 100th of the next 1 000 000 iterations were saved for the posterior distribution. The analysis was implemented in OpenBUGS version 3.2.1, a readily available software program (17). The *P*-values reported were Bayesian and specifically were the sampled posterior *P*-values (18). *P*-values were defined as significant if ≤ 0.05 .

Results

During the study period, the cell salvage machine was prepared for use in 23 cases (22 dogs and 1 lion). The cell salvage machine was subsequently used to collect blood utilized for an autologous transfusion in 14 cases (all dogs). Twelve dogs met the criteria for inclusion in the study. Two cases were excluded due to lack of post-autologous transfusion blood gas and electrolyte data. The median age of the case dogs was 6.7 y (range: 9 mo to 10.3 y). Six dogs were female (2 intact, 4 spayed) and 6 were male (2 intact, 4 neutered). Median weight was 35.5 kg (range: 9.4 to 60 kg). Twelve dogs were identified for the control group. The median age of the control dogs was 8.6 y (range: 1 y to 11.2 y). Five dogs were spayed females and 7 were male (2 intact, 5 neutered). Median weight was 27 kg (range: 3.5 to 49 kg). There was no statistically significant difference in age or weight between control and case dogs.

When changes in calcium, electrolyte, and acid/base variables were compared between case and control dogs, differences were detected. For case dogs, statistically significant decreases in both iCa²⁺ and ionized magnesium were detected post-autologous transfusion ($P < 0.05$). For control dogs, neither iCa²⁺ nor

ionized magnesium was significantly decreased after allogenic blood transfusion ($P = 0.17$ and $P = 0.08$, respectively). Pre- and post-transfusion potassium, chloride, sodium, and pH were not significantly different between case and control dogs.

The median values measured for electrolyte and acid-base variables for pre- and post-autologous transfusion (case dogs) or pre- and post-allogenic blood product transfusion (control dogs) are shown in Table 1. No specific protocol was in place for standardized blood sampling in these dogs.

Five case dogs and 1 control dog received calcium supplementation; the median iCa²⁺ post-transfusion for all dogs receiving calcium supplementation was 0.82 mmol/L (range: 0.56 to 1.1 mmol/L). Four of the 5 case dogs and the 1 control dog receiving calcium supplementation were still under anesthesia on continuous ECG and blood pressure monitoring when they were supplemented with calcium. None of the dogs had clinical signs of hypocalcemia (19,20). Calcium was supplemented with calcium gluconate (Calcium Gluconate; APP Pharmaceuticals) intravenously in 3 case dogs and 1 control dog and calcium chloride (Calcium Chloride; American Regent, Shirley, New York, USA) intravenously in 2 case dogs. Of the 11 case dogs that were hypocalcemic post-autologous transfusion, 6 were also hypomagnesemic post-autologous transfusion. Four of the other dogs were normomagnesemic post-autologous transfusion and 1 dog did not have a post-autologous transfusion magnesium measurement available. None of the records documented any drug intervention administered to address acidosis, alkalosis, or any electrolyte abnormalities other than the mentioned hypocalcemia.

The types of hemorrhage-inducing injury in the case dogs included neoplastic ($n = 3$), spontaneous ($n = 2$), traumatic ($n = 1$), and iatrogenic ($n = 6$). The types of hemorrhage-inducing injury in the control dogs included neoplastic ($n = 3$), spontaneous ($n = 0$), traumatic ($n = 2$), and iatrogenic ($n = 7$).

Three of the 12 case dogs died or were euthanized during the surgery (1 died and 2 were euthanized). Two additional case dogs were euthanized due to continued hemorrhage and poor prognosis within the first 12 h after surgery. One case dog was euthanized approximately 48 h after surgery for financial concerns as well as a poor long-term prognosis, and another case

dog was euthanized approximately 96 h after surgery because portal hypertension developed after surgery due to a portal vein thrombus. Most of the case dogs (9/12; 75%) survived the autologous transfusion and surgery and 5 of 12 case dogs (41.7%) survived to discharge. Of the 7 case dogs that did not survive to discharge, 6 were euthanized at the owner's request. All 12 control dogs survived surgery. One control dog was euthanized within the first 12 h after surgery due to a poor prognosis. The remaining 11 of 12 control dogs (91.7%) survived to discharge. The case dogs were significantly less likely than control dogs to survive to discharge ($P = 0.002$).

Ten of 12 case dogs and 9 of 12 control dogs received fresh frozen plasma (FFP). The median volume of plasma administered to case dogs was 18.46 mL/kg (range: 11.9 to 52.2 mL/kg). The median volume of plasma administered to control dogs was 10 mL/kg (range: 5.8 to 26.1 mL/kg). Three case dogs and no control dogs received fresh allogenic whole blood transfusions. The median volume of whole blood administered to the 3 case dogs was 12.8 mL/kg (range: 8.3 to 78.1 mL/kg). Seven case dogs and 12 control dogs received allogenic pRBCs. The median volume of allogenic pRBCs administered to case dogs was 9.85 mL/kg (range: 6.4 to 36.2 mL/kg). The median volume of allogenic pRBCs administered to control dogs was 13.95 mL/kg (range: 5.1 to 36.1 mL/kg). Considering all 12 case dogs, the median volume of autologous blood returned to the dogs was 28.1 mL/kg (range: 2.2 to 67.2 mL/kg). There was no statistically significant difference in the total volume (mL/kg) of pRBCs administered between the case and control dogs ($P = 0.64$). Additionally, there was no significant difference in the total volume (mL/kg) of allogenic fresh frozen plasma combined with allogenic pRBCs administered between the case and control dogs ($P = 0.36$). All case and control dogs received intraoperative crystalloid fluid therapy. The exact volume was noted in 11 case dogs and 12 control dogs. The median volume of isotonic crystalloids administered intraoperatively in case dogs was 31.9 mL/kg (range: 3.79 to 89.2 mL/kg). The median volume of isotonic crystalloids administered intraoperatively in control dogs was 55.8 mL/kg (range: 12.3 to 114.5 mL/kg). Eleven case dogs and 11 control dogs received intraoperative hydroxyethyl starch (HESPERAN; B. Braun Medical, Irvine, California, USA) (6% hetastarch in 0.9% sodium chloride). The volume of hydroxyethyl starch administered was recorded in 10 of 12 case dogs and the median volume of hydroxyethyl starch administered to these 10 dogs was 5.32 mL/kg (range: 0 to 10.6 mL/kg). The median volume of hydroxyethyl starch administered to the control dogs was 14.4 mL/kg (range: 0 to 24 mL/kg).

Case dogs that received a higher dose of autologous pRBCs were significantly more likely to have a post-autologous transfusion $iCa^{2+} < 1$ mmol/L ($P = 0.05$). Additionally, when comparing the volume of autologous blood administered to all 12 case dogs (median: 28.1 mL/kg) and to the 5 case dogs requiring calcium supplementation (median: 39.1 mL/kg), those requiring calcium supplementation were administered a larger volume of autologous blood. The 1 control dog that required calcium supplementation received a slightly higher dose of pRBCs (16.3 mL/kg) compared to the median volume

of pRBCs administered to all 12 control dogs (13.95 mL/kg). This was the only control dog with a post-allogenic transfusion $iCa^{2+} < 1$ mmol/L.

Three case dogs were considered to have received a massive transfusion of blood products, defined as transfusion of a volume of blood products in excess of the patient's blood volume of 85 mL/kg in a 24-hour period (21,22). The median volume of total blood products for these 3 dogs was 134.75 mL/kg (range: 107.1 to 155.6 mL/kg). Only 1 of the dogs receiving a massive transfusion required calcium supplementation. No control dogs were considered to have received a massive transfusion.

Discussion

The blood gas and electrolyte changes that are likely to develop in conjunction with use of a cell salvage machine require awareness of the veterinary team to allow early intervention and treatment. The current study identifies a larger population of dogs undergoing autologous blood transfusion by cell salvage than has previously been reported and compares changes in blood gas and electrolyte variables between these dogs and a group of dogs undergoing similar procedures but not receiving autologous transfusion.

Dogs undergoing autologous transfusion were significantly more likely to experience a decrease in iCa^{2+} than were control dogs. Several mechanisms may be responsible for the decrease in iCa^{2+} in case dogs. Electrolyte abnormalities induced by cell salvage in dogs has been reported previously in the experimental setting in a study by Halpern et al (16). Halpern's study found blood concentrations of ionized calcium, magnesium, and total protein as well as pH decreased following autologous transfusion (16). Halpern et al (16) demonstrate that iCa^{2+} is removed from the blood during the cell salvage process by comparing iCa^{2+} of salvaged blood that had been washed by the cell salvage device and was ready for readministration to systemic concentrations of iCa^{2+} prior to removal and readministration of blood. The iCa^{2+} concentration in washed blood (0.58 mg/dL) was significantly decreased compared to the mean baseline iCa^{2+} concentration of the systemic blood (1.44 mg/dL) (16). Another mechanism leading to a decrease in iCa^{2+} among case dogs may be binding of calcium to the heparin utilized in the suction line (23). Additional causes of hypocalcemia in this critically ill group of dogs include impaired PTH secretion or action, impaired vitamin D synthesis or action, hypomagnesemia, chelation of calcium, primary hypoparathyroidism, or the effect of heparin used during whole blood collection for analysis (19,23–26). In the present study, multiple mechanisms are likely contributing to hypocalcemia. There are many possible causes of hypocalcemia in the dogs in this study, and the true mechanism of decreased iCa^{2+} values cannot be elucidated. We suspect that the collection and washing of autologous blood for cell salvage contributes to the decreased iCa^{2+} levels in case dogs. Because of the high likelihood of a decrease in iCa^{2+} post-autologous transfusion in the case dogs compared to the control group, the authors recommend that ionized calcium concentrations be monitored during autologous transfusion and at the completion of the transfusion. Calcium plays a major role in maintaining the stability and structure of fibrinogen and platelet activation

(27). Monitoring ionized calcium concentrations and administration of calcium as needed may prevent further disruption of the coagulation cascade as well as prevent clinical signs of hypocalcemia.

In the present study, a decrease in ionized magnesium after transfusion was significantly more likely to be detected in case dogs than in control dogs. Halpern et al (16) demonstrated that magnesium was removed from blood during the cell salvage process. We expect that the collection and processing of autologous blood led to the decrease in magnesium in the case dogs as the control dogs were less likely to experience a decreased magnesium. Additional contributing causes of hypomagnesemia include trauma or hypothermia leading to an intracellular shift of magnesium or chelation of magnesium (20). Previous veterinary studies indicate 54% of critically ill dogs are hypomagnesemic due to increased loss, redistribution or chelation of magnesium, and transcellular shifts of magnesium (28); therefore, multiple factors likely play a role in the development of hypomagnesemia in case dogs. Clinical sequelae of hypomagnesemia in humans and veterinary patients include cardiac arrhythmias, general muscular weakness, seizures, refractory hypokalemia, and hypocalcemia (20,26,29–31). These reported sequelae were not detected in the case dogs that underwent a decrease in ionized magnesium in the present study; however, case dogs did have an increased likelihood that iCa^{2+} would decrease. Because hypomagnesemia can lead to refractory hypocalcemia, the ionized magnesium should be monitored along with the ionized calcium and supplemented if clinically indicated.

The survival rate in the present study was significantly higher among the control dogs compared to the case dogs. This finding should be interpreted with caution. Decreased survival rate in the case dogs may also represent poor control dog selection or increased severity of disease among the case dogs. Although we attempted to match case and control dogs by similar or identical disease processes and similar surgical procedures, it was impossible to perfectly select control dogs. The cell salvage machine is often used in cases where a large volume of hemorrhage is expected during surgery. Therefore, the cell salvage device is often selected for the most critically ill animals, biasing our results. The survival rate among case dogs (41.6%) was lower than in other studies of dogs undergoing allogenic pRBC or whole blood transfusions (47% to 61%) (32,33). This finding is likely due to the disease process and subjective severity of illness and injury triggering the need for transfusion in our case population (32,33). Elective euthanasia may also skew the results to show a lower survival to discharge rate among dogs undergoing autologous transfusion.

Different wash solutions have been evaluated to avoid metabolic acidosis and progressive systemic hyperchloremia induced by washing RBCs with 0.9% NaCl (16,34). In the present study, 0.9% NaCl was used as the wash solution in every case undergoing autologous transfusion. By using Isolyte S or a bicarbonate-buffered hemofiltration fluid as a wash solution in place of 0.9% NaCl, metabolic acidosis may be avoided because the pH and electrolyte content of both of these solutions approximate plasma values (3,4). A previous study looking at Isolyte S as a wash solution concluded that when using high-volume autologous cell

salvage blood processing, Isolyte S should be considered instead of 0.9% NaCl for the wash solution to maintain more normal chloride and pH (3). When using Isolyte-S as the wash solution rather than 0.9% NaCl, systemic total magnesium is significantly higher at study end compared with baseline (3). The population of case dogs in our study trended toward hypomagnesemia, and using Isolyte-S as a wash solution may have prevented this change. Washing of pRBCs with bicarbonate-buffered hemofiltration in an *in vitro* cell salvage setting has been shown to cause less elevation in chloride and less acid base disturbance than washing blood with 0.9% NaCl (4). Interestingly, we did not notice a statistically significant increase in chloride or decrease in pH as has been observed in previous studies using 0.9% NaCl as the wash solution (3,16). This finding could be caused by a disparity in the volume of autologous blood transfused to our patients compared to those in the previous studies. All of the dogs in Halpern's study had 120% of their circulating blood volume exchanged in the cell salvage machine by study end (16). In that study, when 96% of the circulating blood volume was processed through the cell salvage machine and returned to the dog, a systemic acidosis developed (16). The chloride increased significantly when 48% of the blood volume was processed through the cell salvage machine and returned to the dog (16). In the present study, only 3 case dogs received > 48% of their circulating blood volume via autologous transfusion. One additional explanation for lack of a significant change in pH in our dogs undergoing autologous transfusion compared to those in Halpern's study is that in Halpern's study, 0.45% NaCl was used for intraoperative fluid therapy throughout the experiment (16). The pH of this product is 5.0. All of the dogs in our study received intraoperative fluid therapy of LRS (Veterinary Lactated Ringer's Injection, USP; Abbott Laboratories) with a pH of 6.5 or Normosol-R (Normosol-R; Hospira, Lake Forest, Illinois, USA) with a pH of 6.6. Based on our study of clinical cases undergoing autologous transfusion receiving intraoperative isotonic crystalloid therapy, it appears that using 0.9% NaCl as the wash solution does not cause a significant metabolic acidosis or hyperchloremia; however, it is possible that use of Isolyte-S as the wash solution may have prevented a significant decrease in magnesium in case dogs. Results should be interpreted with caution as changes in pH and chloride may have been detected if a higher percentage of the dogs' blood volume had been processed through the cell salvage device.

Limitations of the current study are primarily attributable to its retrospective nature and small sample size. Some dogs had missing data points that could not be retrieved. The control dogs were selected because they had similar disease processes, received a similar dose of pRBCs, and underwent a similar surgical intervention, but perfectly matched control dogs with identical disease processes and doses of pRBCs were not possible. Given the retrospective design of the study and non-standardized treatment, the effect of pre-, intra-, and post-operative crystalloids, colloids, and allogenic blood products on electrolyte and acid-base variables cannot be elucidated because of the inconsistent amounts and types of fluid and blood products each dog was administered. Inconsistent methods in blood collection were present which could affect the direct comparison of blood work.

Some samples were collected in heparinized tubes or syringes and some samples were collected in non-heparinized syringes. Also, some samples were run immediately whereas others may have had a time delay between collection and analysis. The timing of pre- and post-transfusion blood collection was not standardized and could have a significant effect on the results reported. No specific criteria were used to direct intervention to address electrolyte abnormalities, so intervention points may have been variable between clinicians. Finally, there was no certain formula for the volume of blood products administered to each dog. Blood product administration was based on individual response to treatment and at the discretion of the managing clinician. Because of the large number of limitations, conclusions drawn from this paper should be interpreted with caution.

Use of the cell salvage device for autologous transfusion, in combination with allogenic blood product administration, may lead to clinically important changes in electrolyte and acid/base variables; therefore, the surgical and anesthetic team should monitor for abnormalities when utilizing the cell salvage device and treat appropriately. The most clinically significant variables to monitor are ionized calcium and magnesium. The use of intravenous calcium and/or magnesium supplementation may be necessary during or after autologous transfusion. Future prospective studies with complete data sets including specific timing and handling of pre- and post-transfusion blood work will be beneficial to elucidate the exact effect of autologous transfusion using a cell salvage device on clinical cases. CVJ

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