Shock presents as a functional circulatory abnormality whereby inadequate organ perfusion and tissue oxygenation results in a disparity between oxygen consumption and oxygen delivery.\(^1,2\) The prompt recognition of hypoperfusion is fundamental in guiding appropriate stabilization and resuscitation strategies while limiting tissue damage, minimizing systemic organ impact, and ultimately reducing morbidity and mortality.\(^3,4\) Hypovolemic shock, manifested from a loss of intravascular blood volume or hemorrhage, is the most common form of shock presenting to the emergency room.\(^1\) In occult circumstances, it is one of the more difficult forms of shock to identify due to physiologic compensatory mechanisms that mask typical cardiovascular changes.\(^5,6\) If left untreated, compensatory mechanisms are exhausted and progression to a decompensated phase will ensue, resulting in impairment of core cardiovascular perfusion. Clinically, this is identified as hypotension and hyperlactemia.\(^7\)

Shock is reversible if identified early with appropriate stabilization and treatment specific to its underlying etiology; however, there is no single diagnostic test that can identify shock. Diagnostic tests that allow for the early, accurate, repeatable diagnosis of compensatory shock remains an area of interest in human medicine. A diagnosis of shock is currently based on perfusion parameter assessment.

**OBJECTIVE**
To determine whether shock index (SI) positively correlates with percentage blood loss and negatively correlates with cardiac output (CO) in a canine hemorrhagic shock model and whether SI and metabolic markers may be used as end point targets for resuscitation.

**ANIMALS**
8 healthy Beagles.

**PROCEDURES**
Between September and December 2021, dogs underwent general anesthesia for experimental induction of hypotensive shock, with the total volume of blood removed, CO, heart rate, systolic blood pressure, base excess, blood pH, and concentrations of hemoglobin, lactate, ionized calcium recorded, and SI calculated at 4 time points (TPs): after anesthetic induction when the dog had been stable for 10 minutes (TP\(_1\)), 10 minutes after the mean arterial pressure stabilized to a target of 40 mm Hg following jugular removal of up to 60% blood volume to induce hemorrhagic shock (TP\(_2\)), 10 minutes after autotransfusion of 50% of the removed blood (TP\(_3\)), and 10 minutes after autotransfusion of the remaining 50% of the removed blood (TP\(_4\)).

**RESULTS**
Mean SI increased between TP\(_1\) (1.08 ± 0.35) and TP\(_2\) (1.90 ± 0.73) and did not return to the prehemorrhage values for TP\(_3\) or TP\(_4\). SI correlated positively with percentage blood loss (r = 0.583) and negatively with CO (r = −0.543).

**CLINICAL RELEVANCE**
An increase in SI may support diagnosis of hemorrhagic shock; however, SI cannot be used as the sole end point of resuscitation. Significant differences in blood pH, base excess, and lactate concentration suggested they may be useful markers of hemorrhagic shock and need for blood transfusion.
(heart rate [HR], capillary refill time, mucous membrane pallor, pulse quality, and mentation), urine output, blood pressure (BP), base excess, and/or lactate measurement. Additionally, cardiac assessment using point of care ultrasonography has been shown to be beneficial in the assessment of shock by refining differential diagnoses and assessing patient responsiveness to treatment via evaluation of cardiac contractility and caudal vena cava collapsibility.

Shock index (SI), defined by the ratio of HR to systolic BP (SBP), has been evaluated as a parameter to identify moderate to severe shock in both human and veterinary emergency settings. In people, normal SI values are between 0.5 and 0.7, and those experiencing hemodynamic instability generally have an SI > 1.0. Recent veterinary studies have reported that a SI > 1.0 can identify patients in shock compared to healthy nonshock controls. Shock index is reported to be a useful measure of hemorrhagic shock in dogs and occult blood loss in people under controlled conditions. One small single-center veterinary study documented an SI > 0.9 for all dogs presenting in shock; however, presenting SI and resolution of elevated SI were not identified as predictors of mortality. To the authors’ knowledge, no veterinary study has utilized SI as a marker for successful resuscitation in hemorrhagic shock or its relationship to cardiac output (CO).

The purpose of this study was to determine whether SI was positively correlated with percent blood loss and negatively correlated with CO in a canine hemorrhagic shock model. Our second objective was to determine whether SI and select metabolic parameters (hemoglobin [Hb] concentration, blood pH, base excess, lactate concentration, and ionized calcium [iCa] concentration) could be used as end points of resuscitation. We hypothesized that SI would be positively correlated with percent blood loss and SI negatively correlated with CO. In addition, we hypothesized that SI would return to prehemorrhage values after administration of removed blood.

Materials and Methods

Animals

Eight purpose-bred, female spayed Beagles were used in this study. Each dog was determined to be healthy on the basis of results of physical examination, CBC, and serum biochemical panel. All procedures were approved by the IACUC at Colorado State University. This study was performed from September to December 2021.

Anesthesia and instrumentation

All dogs were premedicated with hydromorphone IM (0.1 mg/kg) and an IV catheter was placed in a cephalic vein. The dogs were preoxygenated with 100% fraction of inspired oxygen administered via face mask, and general anesthesia was induced with propofol (5 to 10 mg/kg, IV) to effect. Dogs were orotracheally intubated with a sterile cuffed endotracheal tube, and anesthesia was maintained using isoflurane vaporized in oxygen delivered via a circle system.

Dogs were instrumented for patient monitoring of ECG, pulse oximetry, esophageal temperature, and end-tidal partial pressure of carbon dioxide via sidestream sampling for the duration of general anesthesia. A forced-air warming device and heated water blankets were used to maintain normothermia.

After induction and placement of standard anesthetic monitoring, an arterial catheter was placed in the dorsal metatarsal artery and a left jugular venous catheter was placed. A Swan-Ganz catheter was placed using a flow-directed technique via the right jugular vein, and location in the pulmonary artery was confirmed via pressure waveform analysis. All catheters were placed using aseptic technique.

CO measurements

Measurement of CO via thermodilution (TD) was performed after hemodynamic stabilization for 10 minutes at each time point. In brief, a 5-ml bolus of a 4 °C saline solution was injected into the proximal port of the Swan-Ganz catheter and the temperature of the blood was continuously measured by a thermistor at the distal end of the catheter. All CO measurements were obtained in duplicate with 3 to 5 minutes between measurements. The CO was calculated by the software using a modified Stewart-Hamilton equation (HemoSphere Advanced Monitoring Platform; Edwards Lifesciences Corp).

Experimental design

After induction of anesthesia and instrumentation, the mean arterial pressure (MAP) was stabilized at 70 to 80 mm Hg for 10 minutes before CO measurements (TP1) were obtained via TD. Dobutamine (0.5 to 3 µg/kg/min, IV), phenylephrine (0.5 to 2 µg/kg/min, IV), and/or an IV bolus of isotonic crystalloids (3 to 20 mL/kg) were used to stabilize BP within the desired range when necessary.

A low CO state was induced by removing the dog’s blood to a target MAP of 40 mm Hg (fixed pressure hemorrhage model) with the total blood removed not exceeding 60% of the dog’s blood volume (blood volume = 90 mL/kg). The blood was collected from the jugular catheter over 20 minutes and stored in blood collection bags containing citrate phosphate dextrose adenine. Once the MAP was stable at 40 mm Hg for 10 minutes, CO measurements were obtained (TP2). After CO measurements were obtained, 50% of the removed blood was transfused back to the dog over 15 minutes. Ten minutes later, CO measurements were obtained (TP3). The remaining blood was transfused back to the dog over 15 minutes, and 10 minutes later, the final CO measurements were obtained (TP4). There were 4 sets of data time points (TP1–4) for each dog (Figure 1).

Arterial BP (systolic, diastolic, and mean), HR, esophageal temperature, peripheral oxygen saturation of Hb as measured by pulse oximetry, and end-tidal partial pressure of carbon dioxide were recorded at all TPs. An arterial blood gas was collected using a 1.5-mL syringe (safePICO Aspirator; Radiometer Medical Aps)
and performed at each time point (ABL800 Flex Blood Gas Analyzer; Radiometer Medical ApS).

**Statistical analysis**

Descriptive statistics were determined for each variable and time point. To investigate changes over time, a mixed model was fit separately for each response variable. Specifically, TP1-4 were included as a fixed effect. Dogs were included as a random effect to account for the repeated-measures design. SI was the primary response variable. The Dunnett method was used to compare downstream time points (TP2-4) versus initial values (TP1). Residual diagnostic plots were used to evaluate model assumptions of normality and equal variance. For CO-TD, log transformation was used to satisfy model assumptions. For variables normally distributed, the mean and SD were reported. For variables not normally distributed, the median and range were reported. Correlation between variables was calculated accounting for repeated measures on subjects.20 Statistical analyses were performed by commercial software (SAS Institute Inc). A value of \( P < .05 \) was considered a statistical difference.

**Results**

Eight healthy female spayed research Beagles were enrolled in this study. All continuous variables were evaluated for normality, with the majority of variables apart from CO being normally distributed. The mean age was 4.8 ± 1 years. The mean body weight was 8.8 ± 1.56 kg. All dogs recovered successfully from the procedure. A lactate measurement was not obtained from 1 patient at TP3 due to machine error and was therefore removed from statistical analysis for that TP.

The mean ± SD HR at TP1 was 102.75 ± 31.38 beats/min. The mean ± SD HR did not increase significantly at TP2 (121.38 ± 39.45 beats/min; \( P = .32 \)) or TP3 (118.25 ± 21.55 beats/min; \( P = .46 \); Table 1).

**Table 1**—Results for cardiovascular and hematologic variables for 8 healthy research Beagles undergoing general anesthesia for experimental induction of hypotensive shock and subsequent retransfusion between September and December 2021.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TP1</th>
<th>TP2</th>
<th>TP3</th>
<th>TP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood removed (% of total blood volume removed [90 mL/kg])</td>
<td>0 ± 0</td>
<td>40.31 ± 12.89</td>
<td>20.54 ± 6.63</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>102.75 ± 31.38</td>
<td>121.38 ± 39.45</td>
<td>118.25 ± 21.55</td>
<td>111.38 ± 11.98</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>96 ± 8.5</td>
<td>68.63 ± 20.83</td>
<td>90.75 ± 18.52</td>
<td>95.38 ± 21.19</td>
</tr>
<tr>
<td>Shock index</td>
<td>1.08 ± 0.35</td>
<td>1.9 ± 0.73</td>
<td>1.38 ± 0.52</td>
<td>1.21 ± 0.28</td>
</tr>
<tr>
<td>Cardiac output (L/min)</td>
<td>2.7 (1.2–3.8)</td>
<td>0.6 (0.5–1.5)</td>
<td>2.0 (1–2.6)</td>
<td>2.5 (1.8–5.3)</td>
</tr>
<tr>
<td>Hb (g/dL)</td>
<td>13.5 ± 0.4</td>
<td>13.61 ± 2.18</td>
<td>11.91 ± 1.75</td>
<td>11.1 ± 1.63</td>
</tr>
<tr>
<td>pH</td>
<td>7.24 ± 0.05</td>
<td>7.17 ± 0.09</td>
<td>7.22 ± 0.06</td>
<td>7.23 ± 0.06</td>
</tr>
<tr>
<td>Base excess (mmol/L)</td>
<td>−1.35 ± 2.44</td>
<td>−4.63 ± 3.16</td>
<td>−2.99 ± 2.78</td>
<td>−1.61 ± 3.04</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>1.03 ± 0.59</td>
<td>1.65 ± 0.84</td>
<td>1.5 ± 0.66</td>
<td>1.26 ± 0.48</td>
</tr>
<tr>
<td>Ionized calcium (mmol/L)</td>
<td>1.31 ± 0.09</td>
<td>1.31 ± 0.1</td>
<td>0.96 ± 0.17</td>
<td>0.91 ± 0.17</td>
</tr>
</tbody>
</table>

Time points (TPs): TP1 (mean arterial pressure stabilized at 70 to 80 mm Hg for 10 minutes after anesthetic induction), TP2 (mean arterial pressure stabilized at 40 mm Hg for 10 minutes after removal of up to 60% of the patient’s blood volume over 20 minutes), TP3 (stabilization for 10 minutes following retransfusion of 50% of the patient’s removed blood), and TP4 (stabilization for 10 minutes after retransfusion of the remaining 50% of the patient’s removed blood).

bpm = Beats per minute. Hb = Hemoglobin.
Once the total amount of blood removed was transfused, the mean ± SD HR at TP1 was 111.38 ± 11.98 beats/min. The mean ± SD percentage of blood volume removed was 40.31 ± 12.89. The mean ± SD SBP at TP1 was 96 ± 8.5 mm Hg. There was a significant decrease in mean SBP at TP2 (68.63 ± 20.83 mm Hg; P = .002; Tables 1 and 2), with an increase and plateau in SBP at TP3 (90.75 ± 18.52 mm Hg) and TP4 (95.38 ± 21.19 mm Hg).

Table 2—Results of ANOVA with the use of the Dunnett method for multiple comparisons to identify differences in variables at TP1 versus TP2, TP3, or TP4 in the study described in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>P value (TP1 vs TP2)</th>
<th>P value (TP1 vs TP3)</th>
<th>P value (TP1 vs TP4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood removed</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>.82</td>
</tr>
<tr>
<td>Heart rate</td>
<td>.52</td>
<td>.46</td>
<td>.79</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>.002</td>
<td>.79</td>
<td>.99</td>
</tr>
<tr>
<td>Shock index</td>
<td>.002</td>
<td>.39</td>
<td>.87</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>&lt;.001</td>
<td>.097</td>
<td>.71</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>.997</td>
<td>.127</td>
<td>.007</td>
</tr>
<tr>
<td>pH</td>
<td>.005</td>
<td>.582</td>
<td>.994</td>
</tr>
<tr>
<td>Base excess</td>
<td>&lt;.001</td>
<td>.06</td>
<td>.97</td>
</tr>
<tr>
<td>Lactate</td>
<td>&lt;.001</td>
<td>.03</td>
<td>.25</td>
</tr>
<tr>
<td>Ionized calcium</td>
<td>.99</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

The median CO at TP1 was 2.7 L/min (range, 1.2 to 3.8 L/min), which decreased significantly at TP2 to 0.6 L/min (range, 0.5 to 1.5 L/min; P < .001; Tables 1 and 2). The median CO increased at TP3 to 2.0 L/min (range, 1 to 2.6 L/min) and returned to prehemorrhage values at TP4 (median, 2.5 L/min; range, 1.8 to 5.3 L/min).

The mean ± SD lactate concentration at TP1 was 1.03 ± 0.59 mmol/L. Mean lactate concentration significantly increased at TP2 (1.65 ± 0.84 mmol/L; P < .001), then decreased to 1.5 ± 0.66 mmol/L at TP3. Lactate concentration remained significantly increased at TP3 compared to TP1 (P = .03; Tables 1 and 2).

The mean ± SD base excess at TP1 was −1.35 ± 2.44 mmol/L, which decreased significantly at TP2 (−4.63 ± 3.16 mmol/L; P < .001; Tables 1 and 2). Mean ± SD base excess increased to −2.99 ± 2.78 mmol/L at TP3 and −1.61 ± 3.04 mmol/L at TP4.

The mean ± SD iCa at TP1 was 1.31 ± 0.09 mmol/L. There were significant decreases at TP2 (0.96 ± 0.17 mmol/L; P < .001) and TP3 (0.91 ± 0.17 mmol/L; P < .001).

The mean ± SD pH at TP1 was 7.24 ± 0.05. It decreased significantly at TP2 (7.17 ± 0.09; P = .005) and increased at TP3 (7.22 ± 0.06) and TP4 (7.23 ± 0.06).

The mean ± SD Hb concentration at TP1 was 13.5 ± 2.04 g/dL, which increased to 13.61 ± 2.18 g/dL at TP2 and 11.91 ± 1.75 g/dL at TP3. Mean Hb concentration differed significantly (P = .007) between TP1 (13.5 ± 2.04 g/dL) and TP4 (11.1 ± 1.63 g/dL; Table 2).

The mean ± SD Si at TP1 (1.90 ± 0.73) was significantly (P = .002) higher than at TP1 (1.08 ± 0.35). The mean Si remained > 1.0 at TP1 and TP4 (Table 1) with no statistical difference when compared to TP1 (P = .39 and P = .87, respectively).5,10,11,18

Shock index had a moderate positive correlation with percentage of blood loss (r = .583; P = .002; Figure 2) and a moderate negative correlation with CO (r = −.543; P = .005; Figure 3).

**Discussion**

The current study found moderate correlations between Si and percent blood loss and between Si and CO in a canine model of induced hemorrhagic shock and whole blood transfusion. These findings supported our hypothesis that Si would be negatively correlated with CO and Si positively correlated with percent blood loss. There was also statistically significant differences in pH, base excess, lactate concentration, SBP, and iCa concentration over these same time periods.
In people, the use of SI to predict hemodynamic response to volume expansion has been investigated. A prospective study\textsuperscript{21} of patients with septic shock identified a 15% increase in cardiac index (CO) in relation to body size after volume expansion. Those with an SI of < 1.0 were unlikely to respond to volume expansion, whereas those with an SI of > 1.0 were most likely to be fluid responsive.\textsuperscript{23} Complimentary findings were identified in our model, with hypovolemic shock resulting in an increase in SI (TP\textsubscript{2}) and progressive decrease in SI toward normal with replacement of the removed blood volume (TP\textsubscript{3} and TP\textsubscript{4}).

In this study, the mean SI increased between TP\textsubscript{1} and TP\textsubscript{2}, with the total blood volume removed ranging between 21.0% and 51.2% to target an MAP of 40 mm Hg. Once 50% and 100% of the total blood removed was transfused back to the dog at TP\textsubscript{3} and TP\textsubscript{4}, there was a reduction in the SI. However, SI at both TPs remained above the reported cutoff values for shock (0.9 or 1.0), as previously defined in the veterinary literature.\textsuperscript{9,10,13,18} There was a significant increase in SI between TP\textsubscript{2} and TP\textsubscript{3}; however, the lack of normalization despite replacement of blood volume makes SI alone unreliable as an end point of resuscitation.\textsuperscript{22} The moderate correlation between SI and percent blood loss suggested that it is not appropriate to use SI as a sole marker for estimating percent blood loss, and thus need for transfusion, in dogs that present in hemorrhagic shock.

There was no difference in HR at any of the respective TPs (P > .05), with all mean values remaining within the reference interval. Isoflurane has been shown to cause a reflex tachycardia in an acute blood loss setting; however, propofol has been shown to decrease HR through inhibition of the baroreflex.\textsuperscript{23,24} The role of propofol and isoflurane in influencing HR in this study is not known. Although there were subtle changes in the HR consistent with cardiovascular compensation, it may not reflect the typical presentation in which a conscious veterinary patient may also exhibit signs of anxiety and pain, contributing to tachycardia. Similar minor changes in HR despite blood loss have been identified in previous hemorrhagic veterinary studies.\textsuperscript{25} Additionally, in military working dogs in traumatic hemorrhagic shock, the use of HR is not utilized as a resuscitative end point, with an increased importance placed on an improvement in SBP, decreased SI, improved mentation, and mucous membrane color.\textsuperscript{26}

As these dogs were under general anesthesia, their systolic pressures may have been iatrogenically decreased due to the vasodilatory effects of inhalant anesthesia, premedications, and induction agents.\textsuperscript{27} Due to the nature of this study as a fixed pressure hemorrhage model, the decrease in SBP between baseline (TP\textsubscript{1}) and blood removal (TP\textsubscript{2}) was significant and, to be expected, supportive of an acute decrease in intravascular volume. SBPs normalized and were not statistically different from baseline (TP\textsubscript{1}) when approximately 50% of the blood removed was transfused (TP\textsubscript{3}). This was to be expected, with whole blood resuscitation considered the optimal choice for treating hemorrhagic shock, and has shown to immediately improve hematologic and cardiovascular function, as well as reduce endothelial glycocalyx degradation, and the inflammatory response in rodent models.\textsuperscript{28–30}

The CO at all time points (TP\textsubscript{1–4}) was reflective of acute blood loss and replenishment during the resuscitative process, with results expected and similar to a previous veterinary study\textsuperscript{31} investigating CO and acute hemorrhage in dogs. Although it would be ideal to measure CO in our veterinary patients, placement of a pulmonary arterial catheter is required. This procedure is invasive, with increases in morbidity and mortality seen in both people and animals, so it is not used in clinical veterinary patients.\textsuperscript{12–25} Additional studies using CO in preclinical models can contextualize the utility of this parameter in a clinical setting.

In this study, the base excess decreased once blood was removed and remained outside standard reference intervals once blood was transfused. The cause of this decrease is likely secondary to a decrease in oxygen delivery, resulting in anaerobic metabolism and a subsequent metabolic acidosis.\textsuperscript{36}Previous veterinary studies have shown base excess to be an indicator for both blood transfusion and mortality in dogs presenting to the emergency room after blunt trauma.\textsuperscript{32} Additionally, base excess has been shown in people to be a highly sensitive indicator of blood loss, with multiple studies focusing on trauma patients utilizing base excess to predict both severity of hemorrhagic shock and blood transfusion requirements.\textsuperscript{37–39} Our study supported these findings, through both a decrease in oxygen delivery and need for blood transfusion secondary to blood removal.

An elevated plasma lactate indicates a lack of adequate oxygen delivery to organs and tissues and has been used to support the need for blood transfusion.\textsuperscript{40} In this study, the median plasma lactate at TP\textsubscript{1} was 0.86 mmol/L, which increased to 1.39 mmol/L after blood removal. This was statistically significant (P = .002); however, it is not a clinically significant difference. The lack of clinically significant change may be secondary to the general anesthetic, promoting a reduction in tissue metabolic demand. Similar hemorrhagic studies assessing routine blood donation in dogs have identified a decrease in lactate concentration after blood removal, and sedation has been hypothesized as one of the likely causes.\textsuperscript{41} Similarly, a study\textsuperscript{42} performed of 6 dogs identified a reduction in the oxygen extraction ratio associated with the induction of general anesthesia, resulting in a decrease in metabolic needs associated with a decrease in muscular activity, reduction in work of breathing, and a decrease in body temperature. Based on the results of this study, plasma lactate may be used as an indicator of blood loss; however, it is recommended to be used in conjunction with other clinical findings to support the need for blood transfusion and as a marker of response to resuscitative measures.

Ionized calcium has been shown to indicate critical illness in the emergency setting, with decreasing values consistent with a worsening outcome and poor prognosis.\textsuperscript{43} Additionally, an increase in mortality and need for blood product administration...
has been documented in trauma patients presenting with hypocalcemia. Ionized calcium decreased at each time point in this study. The decrease in iCa after hemorrhage (TP1) in our study supported the previous literature, which shows that iCa is an independent predictor for multiple blood transfusions. However, the blood bags used to store the removed blood contained citrate phosphate dextrose adenine, a calcium chelating agent, to limit the likelihood of clotting prior to the process of transfusion. The transfusion of the anticoagulated blood may have contributed to decreasing iCa concentrations after the transfusion (TP2 and TP3), which is a known phenomenon in the veterinary and human literature. This limited the ability to interpret the decrease in iCa at TP1 and TP2 in our study.

There was a significant decrease in pH values between TP1 and TP2; however, this did increase close to TP1 values after repeated transfusions. Acidemia has been identified in dogs in acute hemorrhagic shock in which large amounts of unmeasured anions—specifically citrate, fumarate, and α-ketoglutarate (intermediates of mitochondrial metabolism)—were generated after the induction of hemorrhage. These unmeasured anions may have contributed to the acidemia documented in this study.

Although mean Hb concentrations remained in the reference interval at all time points, the Hb declined at each time point despite blood transfusion, with a statistical difference only identified between TP1 and TP2. The typical response to acute blood loss in the dog is splenic contraction, accelerating erythrocyte release into circulation to maintain adequate oxygen delivery. Evidence of splenic involvement in hemorrhagic models has been previously tested in both splenectomized and nonsplenectomized dogs. Those that were splenectomized showed mean Hb concentrations that were significantly decreased after hemorrhage. The absence of change in Hb in the nonsplenectomized dogs was attributed to the translocation of extracellular fluid into the vascular space, which diluted the high concentration of RBCs from splenic contraction. This likely contributed to the Hb remaining within a normal reference interval at all time points in this study. The clinical relevance of the statistical difference in mean Hb between TP1 and TP2 is not clear.

Limitations of this study included the small sample size of 8 dogs, all of which were healthy prior to undergoing general anesthesia. All dogs were bled under controlled conditions, a scenario that is not fully reflective of a clinical presentation in the emergency room. As these dogs were under general anesthesia, a disruption to the cardiovascular system could have impacted the SI. Our study showed no significant change in HR over the 4 TPs; therefore, the increase in SI when the dogs were bled was likely secondary to changes in BP. Although the anesthetic agents could have contributed to a decrease in BP, the authors believe the induced blood loss was the more significant factor. In this study, 1 dog was administered dopamine and 1 dog was administered dobutamine to stabilize MAP at TP1. These drugs were discontinued prior to blood removal. The use of vaspressors will iatrogenically increase the SBP and therefore directly influence the SI. Finally, there was a single lactate measurement that was unable to be obtained due to machine error and therefore removed from statistical analysis for that TP.

In conclusion, this fixed pressure hemorrhage model in dogs identified a moderate positive correlation between SI and percent blood loss and a moderate negative correlation between SI and CO. An increase in SI may support a diagnosis of hemorrhagic shock; however, it cannot be used as the sole end point of resuscitation as SI did not return to prehemorrhage levels despite the complete transfusion of removed blood. There were significant differences identified in pH, base excess, and lactate concentration between TP1 and TP2 indicating they may be useful markers of hemorrhage and need for blood transfusion.

**Acknowledgments**

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**References**
