Cardiac output and other hemodynamic variables in anesthetized dogs undergoing laparotomy because of abdominal neoplasia

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In anesthetized patients, arterial blood pressure is often monitored as an indicator of circulatory status. Hypotension is reported to be the most common complication that occurs during general anesthesia in dogs,1-3 and maintaining an MAP ≥ 60 or 70 mm Hg during anesthesia has been recommended by various authors.4,5 However, because MAP depends on both CO and SVR, measurement of MAP alone does not provide complete information about circulatory status. For example, intense vasoconstriction may be associated with high MAP but low CO or CI (CO indexed to body surface area or body weight) and poor organ perfusion.5,6

Historically, methods for measuring CO have been too complicated to allow their routine use in anesthetized patients. However, the development of methods for measuring CO based on lithium dilution has made measurement of CO much simpler and less invasive. A number of studies7-15 have compared LiDCO with values obtained by means of traditional methods for measuring CO, such as thermodilution, and reported favorable results. We have previously reported LiDCO in healthy, young female dogs undergoing anesthesia for routine ovariohysterectomy.11 In that study, we found that changes in MAP did not necessarily reflect qualitatively similar changes in CI. Earlier studies of anesthetized dogs12 and horses13-15 have demonstrated a similar lack of qualitative agreement between MAP and CO or CI measured during surgery. However, to what degree specific disease processes such as abdominal neoplasia affect CO and CI and the relationship of MAP to CI are not known.

Therefore, the purpose of the study reported here was to measure CO and other hemodynamic variables in anesthetized dogs undergoing laparotomy because of abdominal neoplasia. Our hypotheses were that hemodynamic variables would change over time during anesthesia and surgery but that changes in MAP would not always be associated with qualitatively similar changes in CO.

Materials and Methods

The study protocol was approved by the Colorado State University Animal Care and Use Committee. Dogs weighing ≥ 20 kg (44 lb) that were examined at the
Colorado State University Veterinary Teaching Hospital because of any abdominal abnormality necessitating exploratory laparotomy were prospectively enrolled in the study. Individual dogs that met the inclusion criteria were enrolled only when convenient for the surgeon involved and only when the authors were available to perform measurements. Owners of dogs included in the study provided informed consent.

Dogs were anesthetized and monitored by senior veterinary students acting under the direct supervision of a faculty anesthesiologist. Anesthetic protocols were individualized according to each dog’s condition at the time of surgery in accordance with the hospital’s standard protocol. Dogs were premedicated with atropine (0.03 mg/kg [0.014 mg/lb], SC) or glycopyrrolate (0.01 mg/kg [0.0045 mg/lb], SC) in combination with hydromorphone (0.1 mg/kg [0.045 mg/lb], SC) or medetomidine (0.5 mg/kg [0.23 mg/lb], SC). An 18-gauge catheter was placed in a cephalic vein for administration of lactated Ringer’s solution and lithium chloride for measurement of CO. Lactated Ringer’s solution was administered at a rate of 10 mL/kg/h (4.5 mL/lb/h), IV, throughout the anesthetic period. Anesthesia was induced with midazolam (0.3 mg/kg [0.14 mg/lb], IV) in combination with propofol (0.4 to 4 mg/kg [0.18 to 1.8 mg/lb], IV) or ketamine (5 mg/kg [2.3 mg/lb], IV). An endotracheal tube was placed, and anesthesia was maintained with isoflurane delivered in oxygen (flow rate, 1 to 2 L/min) through a circle anesthetic system. In addition, fentanyl was administered as a continuous rate infusion (10 to 20 µg/kg/h [4.5 to 9.1 µg/lb/h], IV). All dogs were mechanically ventilated at a rate of 9 to 10 breaths/min with a time- and flow-cycled ventilator to maintain end-tidal partial pressure of carbon dioxide (PETCO2) between 35 and 45 mm Hg. A 20-gauge catheter was placed in a dorsal pedal or palmar digital artery for monitoring arterial blood pressure and collecting arterial blood samples for blood gas measurements and measurement of lithium concentration. Isoflurane vaporizer settings were adjusted on the basis of MAP and results of clinical assessments of anesthetic depth (including, but not limited to, jaw tone, eye position and reflexes, pedal withdrawal reflex, and spontaneous movement) in order to maintain a surgical plane of anesthesia. If MAP was < 70 mm Hg, efforts were made to increase MAP by decreasing the vaporizer setting, administering a bolus of lactated Ringer’s solution (5 to 10 mL/kg, IV) as quickly as possible by gravity flow (usually over a period of 3 to 5 minutes), and administering dobutamine (1 to 4 µg/kg/min [0.45 to 1.8 µg/lb/min], IV). End-tidal isoflurane concentration and PETCO2 were measured continuously with a multigas monitor; the sampling port was placed between the endotracheal tube and breathing circuit.

Hemodynamic variables were measured at 7 specific times during the anesthetic period as follows: after induction of anesthesia and clipping of the surgical site while the dog was in lateral recumbency (time point 1; baseline values), after surgical preparation and just prior to surgical incision while the dog was in dorsal recumbency (time point 2), 20 minutes after the beginning of surgery while the dog was in dorsal recumbency (time point 3), 40 minutes after the beginning of surgery while the dog was in dorsal recumbency (time point 4), 60 minutes after the beginning of surgery while the dog was in dorsal recumbency (time point 5), immediately after the end of surgery while the dog was in dorsal recumbency (time point 6), and after surgery after the dog had been repositioned in lateral recumbency (time point 7). At each of these times, heart rate; systolic, mean, and diastolic arterial blood pressures (measured directly); esophageal temperature; respiratory rate; PCV; plasma total protein concentration; end-tidal isoflurane concentration; PETCO2; and LiDCO were recorded. Plasma sodium concentration and hemoglobin concentration were measured as required for determination of LiDCO; LiDCO measurements were performed according to the manufacturer’s recommendations, as described.11 At time points 1, 2, 5, and 6, arterial blood samples were obtained, and arterial pH, arterial partial pressure of CO2 (Paco2), and arterial partial pressure of O2 (Pao2) were measured.6 Stroke volume, stroke volume index, CI, SVR, and SVR index were calculated with standard formulas. Mean right atrial pressure was not measured and was assumed to be 3 mm Hg on the basis of values previously reported for dogs anesthetized with isoflurane.16

Statistical analysis—Normality of data was assessed by examination of the scatterplots of residuals versus predicted values. Repeated-measures ANOVA followed by the Fisher protected least significant difference test was used to determine whether measured variables changed over time; variables for dog, time, and the dog-by-time interaction were included in the model. Standard software was used for computations with type 3 tests for fixed effects that incorporated restricted maximum likelihood estimation. Values of P < 0.05 were considered significant. Data are reported as mean ± SD.

Results Eight dogs were included in the study. Four underwent laparotomy because of a splenic tumor, and the other 4 underwent laparotomy because of a hepatic tumor. Mean ± SD body weight was 33.3 ± 0.8 kg (73.3 ± 1.8 lb), and mean age was 9.8 years (range, 3 to 15 years). Four dogs were classified as American Society of Anesthesiologists status II, and the other 4 were classified as status III. Six dogs were premedicated with atropine, and 2 were premedicated with glycopyrrolate. Five dogs were premedicated with hydromorphone, and 3 were premedicated with methadone. In 5 dogs, a combination of midazolam and propofol was used for anesthetic induction (mean ± SD propofol dose, 2.38 ± 1.34 mg/kg [1.08 ± 0.61 mg/lb]), and in 3 dogs, a combination of midazolam and ketamine was used for anesthetic induction.

Mean anesthesia time was 3.1 hours (range, 2.4 to 3.8 hours); mean surgery time was 1.6 hours (range, 1.2 to 2.1 hours). Mean time from induction of anesthesia to collection of the second set of hemodynamic measurements (ie, time point 1) was 31 minutes (range, 37 to 67 minutes); mean time from induction of anesthesia to collection of the second set of hemodynamic measurements (ie, time point 2) was 65 minutes (range, 50
to 79 minutes); and mean time from induction of anesthesia to collection of the third set of hemodynamic measurements (ie, time point 3; 20 minutes after the beginning of surgery) was 101 minutes (range, 82 to 115 minutes). Mean time from induction of anesthesia to collection of the final set of hemodynamic measurements (ie, time point 7) was 175 minutes (range, 125 to 219 minutes).

Mean rate at which lactated Ringer’s solution was administered was 9.6 mL/kg/h (4.4 mL/lb/h; range, 8.3 to 12.1 mL/kg/h [3.8 to 5.5 mL/lb/h]). Mean total amount of lactated Ringer’s solution administered was 28.8 mL/kg (13.1 mL/lb; range, 21.3 to 33.9 mL/kg [9.7 to 15.4 mL/lb]). Three dogs received a single IV bolus of lactated Ringer’s solution while anesthetized (5.5, 8.5, and 10 mL/kg [2.5, 3.9, and 4.5 mL/lb]). Three other dogs received continuous rate infusions of dobutamine (1 to 4 μg/kg/min, IV) for periods ranging from 120 to 165 minutes to help maintain MAP ≥ 70 mm Hg.

Compared with concentration measured at time point 1, end-tidal isoflurane concentration was significantly increased by time point 2 and remained significantly increased throughout the surgical period (ie, until time point 6; Table 1). Mean heart rate ranged from 99 to 137 beats/min, but significant differences among time points were not detected. Systolic, mean, and diastolic arterial blood pressures were significantly increased, compared with baseline (ie, time point 1) values, 20 minutes after the beginning of surgery (ie, time point 3). No significant differences in CI or stroke volume index over time were detected, except that values were significantly increased, compared with baseline values, at the time of the last measurement (ie, time point 7). Systemic vascular resistance index was significantly increased, compared with the baseline value, 20 minutes after the beginning of surgery but was not significantly different from the baseline value at the time of the last measurement.

Arterial pH was significantly lower during and after surgery (time points 5 and 6) than before surgery (time points 1 and 2; Table 2). Arterial partial pressure of CO₂ was unchanged throughout anesthesia and surgery until time point 6, when it was significantly increased, but no significant differences over time were detected for PaO₂. The PCV was significantly increased during surgery but had returned to the baseline value by the end of surgery. Plasma total protein concentration decreased significantly over time.

**Discussion**

As previously stated, hypotension is a common complication of inhalant anesthesia in animals. Hypotension is presumed to increase the risk of organ damage from inadequate blood flow and oxygen delivery. As many anesthetic drugs and other perianesthetic events or interventions (hemorrhage, IV fluid administration, or sympathomimetics) affect MAP through changes in vascular tone as well as changes in CI, ideal monitoring would include measurement of CI and calculation of...
SVR index. To fully use currently available technology such as LiDCO to evaluate clinical responses to various anesthetics and treatments, greater understanding of hemodynamic function in typical clinical veterinary patients managed according to current standards is needed.

Because dogs in the present study were clinical patients, it was not possible to standardize all aspects of their anesthetic management. However, all 8 dogs were premedicated with an anticholinergic and an opioid, and anesthesia was induced with midazolam in conjunction with a short-acting agent and maintained with isoflurane and fentanyl. In addition, all dogs were mechanically ventilated and received similar amounts of lactated Ringer’s solution.

In the present study, end-tidal isoflurane concentration was reported as a percentage of ambient barometric pressure, with mean values ranging from 0.95% to 1.21%. Given that ambient barometric pressure at the study location (Fort Collins, Colo) was approximately 640 mm Hg, these values would have been lower (0.8% to 1.02%) if reported as a percentage of barometric pressure at sea level (760 mm Hg). Minimum alveolar concentration of isoflurane at sea level has previously been reported to be approximately 1.28%\(^{17}\) to 1.46%,\(^{18}\) and surgical anesthesia generally requires a concentration 1.3 to 1.5 times the minimum alveolar concentration. However, minimum alveolar concentration is determined in dogs that have not received any drugs other than isoflurane. Use of a balanced anesthetic approach, as in the present study, reduces the amount of inhalant anesthetic needed to maintain anesthesia. In particular, IV administration of fentanyl (18 \(\mu\)g/kg/h) has been shown to reduce the minimum alveolar concentration of isoflurane in dogs by 33%.\(^{19}\) Therefore, it was not surprising that dogs in the present study were adequately maintained at isoflurane concentrations less than the minimum alveolar concentration. In the present study, the 2 periods when end-tidal isoflurane concentration was lowest were the very beginning of the anesthetic period, when uptake and distribution of isoflurane were still in the early stages, and the very end of the anesthetic period, when the anesthetist had begun to decrease delivery of isoflurane in anticipation of waking the dog up. All of the dogs appeared to be adequately anesthetized and tolerated surgery without moving.

Although heart rate varied considerably throughout the anesthetic period in the present study, no significant changes over time were identified, likely in part because of individual patient variation. Arterial blood pressures and SVR index were significantly increased 20 minutes after surgical incision, and similar responses have frequently been observed in animals during clinical anesthesia and surgery.\(^{11,13,14}\) It is presumed that surgical stimulation is associated with increased sympathetic tone, causing blood pressure to increase as a result of vasoconstriction.

In earlier studies\(^{1,13-15}\) of halothane-anesthetized horses, surgical stimulation was associated with significant decreases in CI, stroke volume index, or both, presumably as a result of increased afterload resulting from vasoconstriction. However, in a study\(^{11}\) of healthy young dogs that were undergoing ovariohysterectomy, CI and stroke volume index did not change during surgery. In the present study, we did not detect any significant difference in CI or stroke volume index over time during surgery. Whether these differences between halothane-anesthetized horses and isoflurane-anesthetized dogs represent differences between anesthetics, between species, or between surgical procedures is not known. However, in both situations, changes in MAP in anesthetized animals undergoing surgery were not associated with qualitatively similar changes in CI.

Although MAP was highest shortly after the beginning of surgical stimulation and again at the end of surgery in the present study, CI was highest before and after surgery (time periods 1 and 7), when the dogs were in lateral rather than dorsal recumbency. It is possible therefore that position affected CI. However, earlier studies\(^{20,21}\) of positioning in anesthetized dogs have produced variable results. A study\(^{20}\) of dogs during and after pregnancy found that pregnant dogs had lower systolic blood pressures than did nonpregnant dogs, but did not find that blood pressure changed when dogs were moved from lateral to dorsal recumbency. Unfortunately, CI was not measured in that study. In contrast, in a study\(^{21}\) of anesthetized Beagles, heart rate was significantly higher and MAP and peripheral vascular resistance were significantly lower when dogs were in dorsal recumbency, but CO was not different between positions. Our finding that MAP and SVR index were increased during some periods when dogs were in dorsal recumbency was different, but these values were likely affected by surgical stimulation. Because surgery was not performed in either of the previous studies, it is difficult to compare earlier results with results of the present study.

The significant decrease in arterial pH near the end of surgery in the present study was likely a result of an increase in base deficit associated with reduced tissue perfusion and increased lactate production during anesthesia and surgery. However, lactate concentration was not measured, and the alteration in pH (a mean decrease of 0.06 units) was not considered to be clinically important. Arterial partial pressure of CO\(_2\) was also significantly increased at the end of surgery, likely because mechanical ventilation was being decreased in anticipation of recovery, and increased hypercapnia would have contributed to the decrease in arterial pH. Again, the alteration in PaCO\(_2\) was not considered clinically important, although it could have contributed to the significant increase in CI that was seen during the final time period.

The PCV increased slightly during surgery in the present study but had decreased to baseline values by the end of surgery. Splenic reserves of RBCs are affected by anesthetics, which tend to enhance splenic sequestration and therefore reduce PCV, and by inotropic drugs and vasopressors, which may cause splenic contraction and increase PCV. Three of the dogs in the present study received dobutamine, which could have contributed to the increase in PCV.\(^{22}\) Additionally, increased sympathetic tone and vasoconstriction associated with the beginning of surgical stimulation may
have caused splenic contraction that increased PCV, and IV administration of fluids in conjunction with a gradual relaxation of vascular tone toward the end of surgery may have eventually caused PCV to decrease to baseline values. Plasma total protein concentration, which decreased gradually but steadily throughout the anesthetic period, was most likely influenced by IV fluid administration as well as some blood loss; however, blood loss during surgery was considered to be minimal in these dogs.

When hemodynamic data from clinically ill dogs in the present study were compared with previously published data for healthy, young, anesthetized dogs, arterial blood pressure appeared to be higher in the clinically ill patients, even though dobutamine was administered to 3 of the 8 clinically ill dogs. Apparently, the clinically ill dogs were able to maintain arterial blood pressures similar to those in the healthy dogs, despite lower CI, because SVR index was higher than that in the healthy dogs. Possible explanations for the differences between the 2 patient populations include differences in anesthetic protocols, health status, or age or a combination of these factors. Anesthetic protocols for the 10 healthy dogs in the earlier study were similar to those for dogs in the present study, except that some of the healthy dogs also received a low dose of acepromazine and none received fentanyl.11 End-tidal isoflurane concentration was similar in the 2 populations, meaning that differences in isoflurane concentration were unlikely to be the cause of the differences in hemodynamic measurements. By definition, the clinically ill dogs did have pathologic conditions affecting major, highly vascular abdominal organs, so it is likely that disease adversely affected CI, stroke volume index, and SVR index. However, it is entirely possible that the major factor responsible for the difference in hemodynamic measurements between the 2 populations was the difference in their ages. Mean age of dogs in the present study was 9.8 years. Although reference cardiopulmonary values for healthy young to middle-aged dogs have been published,23 values for specific ages are difficult to find. It has been reported that arterial blood pressures and SVR index increase and CI decreases as puppies grow from 1 to 9 months of age,24 and aging in humans has been associated with decreases in arterial compliance and CO.25 Therefore, age alone could explain the differences between clinically ill dogs in the present study and healthy dogs in the previous study. We present the comparison simply to assist in the qualitative evaluation of 2 diverse patient populations and in recognition of the fact that such measurements will likely be performed more often in clinical patients in the future. Further studies involving age-matched controls will be needed to separate and clarify the contributions of age and disease to hemodynamic measurements in clinical patients.

Results of the present study provide further evidence that MAP is not an accurate indicator of changes in CO or CI in anesthetized dogs undergoing surgery. Further studies are needed to understand the clinical utility of the values measured, to determine what is clinically acceptable for each variable, and to identify appropriate therapeutic interventions when abnormal values are obtained.

References

Selected abstract for JAVMA readers from the American Journal of Veterinary Research

Ultrasound biomicroscopy of the iridocorneal angle of the eye before and after phacoemulsification and intraocular lens implantation in dogs
Michelle D. Rose et al

Objective—To compare the iridocorneal angle (ICA) and angle opening distance (AOD) in dogs with cataractous and noncataractous lenses; evaluate cataractous eyes ultrasonographically for association of postoperative ocular hypertension (POH) with the ICA, AOD, and postoperative echogenic anterior chamber debris; and evaluate intraobserver reliability associated with ICA and AOD measurements.

Animals—56 dogs with 102 cataracts, and 23 clinically normal dogs.

Procedures—Ultrasound biomicroscopy was performed on 102 eyes of 56 dogs before and after cataract surgery and on 46 nondilated and dilated eyes of 23 clinically normal dogs. Cataract stage, ICA, AOD, and association with POH were assessed.

Results—Cataract stage and ICA or AOD were not significantly associated; however, ICA and AOD typically decreased with increasing cataract maturity. Before and after pupillary dilation, AODs were significantly smaller in cataractous eyes than in noncataractous eyes. Before surgery, ICA and AOD in eyes without pupillary dilation were significantly associated with POH. At > 13°, odds of developing POH increased by 11% for each degree increase in the ICA. Postoperative anterior chamber debris was not associated with POH. Coefficient of variation for repeated measurements was 10% for the ICA and 9.5% for the AOD, suggesting good intraobserver reliability.

Conclusions and Clinical Relevance—In this study, dogs with larger ICA and AOD measurements before surgery were at greater risk of developing POH. This information may be useful for future studies to determine whether preventative treatment for POH administered prior to surgery may be beneficial. (Am J Vet Res 2008;69:279–288)