Correlation of the ratio of caudal vena cava diameter and aorta diameter with systolic pressure variation in anesthetized dogs

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Received November 24, 2014.
Accepted April 21, 2015.

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OBJECTIVE
To evaluate the correlation coefficient of the ratio between diameter of the caudal vena cava (CVC) and diameter of the aorta (Ao) in dogs as determined ultrasonographically with systolic pressure variation (SPV).

ANIMALS
14 client-owned dogs (9 females and 5 males; mean ± SD age, 73 ± 40 months; mean body weight, 22 ± 7 kg) that underwent anesthesia for repair of skin wounds.

PROCEDURES
Anesthesia was induced. Controlled mechanical ventilation with a peak inspiratory pressure of 8 cm H2O was immediately started, and SPV was measured. During a brief period of suspension of ventilation, CVC-to-Ao ratio was measured on a transverse right-lateral intercostal ultrasonographic image obtained at the level of the porta hepatis. When the SPV was ≥ 4 mm Hg, at least 1 bolus (3 to 4 mL/kg) of Hartmann solution was administered IV during a 1-minute period. Bolus administration was stopped and the CVC-to-Ao ratio measured when SPV was < 4 mm Hg. Correlation coefficient analysis was performed.

RESULTS
28 measurements were obtained. The correlation coefficient was 0.86 (95% confidence interval, 0.72 to 0.93). Mean ± SD SPV and CVC-to-Ao ratio before bolus administration were 7 ± 2 mm Hg and 0.52 ± 0.16, respectively. Mean ± SD SPV and CVC-to-Ao ratio after bolus administration were 2 ± 0.6 mm Hg and 0.91 ± 0.13, respectively.

CONCLUSIONS AND CLINICAL RELEVANCE
In this study, the CVC-to-Ao ratio was a feasible, noninvasive ultrasonographically determined value that correlated well with SPV. (Am J Vet Res 2016;77:137–143)

ABBREVIATIONS
Ao  Aorta
CVC  Caudal vena cava
MAP  Mean arterial blood pressure
SAP  Systolic arterial blood pressure
SPV  Systolic pressure variation

Maintaining tissue perfusion is a crucial task for many clinicians involved in management of critically ill patients.1–3 Critically ill animals are often hypovolemic or hypervolemic, which can affect cardiac preload and, in turn, cardiac output. In humans, a protocol for fluid administration designed to optimize perioperative stroke volume and cardiac output has been found to reduce postoperative complications and duration of hospital stay for patients undergoing major surgery.1–5 Similarly, early aggressive resuscitation of critically ill patients may limit or reverse tissue hypoxia and the progression toward organ failure and improve outcome.3–5 However, an overload of fluids during resuscitation has been associated with an increase in complications, an increase in duration of stay in an intensive care unit and hospital, and an increase in mortality rate.5,6

Unfortunately, clinical examination and arterial blood pressure have not proven to be reliable methods for assessment of volemic status in humans.7,8 Traditionally, central venous pressure has been indicated in humans and dogs as an index to guide fluid administration during anesthesia and intensive care.9–11 However, there is a large body of evidence that proves a poor relationship between central venous pressure and blood volume and the inability to predict the hemodynamic response.12–14 In the past 2 decades, evidence has emerged of a strong correlation between cardiac preload and dynamic indices of volemia in anesthetized and mechanically ventilated subjects. Variations in systolic pressure, pulse pressure, and stroke volume are some of the most studied dynamic indices of volemia.5,13,15–17 Investigators who conducted a seminal study18 on dynamic indices of volemia confirmed that
SPV is a reliable indicator of hypovolemic status in mechanically ventilated dogs with physiologically normal cardiovascular function in an experimental setting.

During inspiration, venous return to the right atrium decreases as a result of 2 mechanisms: compression of the vena cava secondary to increases in pleural pressure and right atrial pressure and, concurrently, an increase in the right ventricular afterload attributable to an increase in alveolar pressure. These effects cause a reduction in right ventricular stroke volume as a result of the Frank-Starling myocardial mechanism. For the left ventricle, the initial effect is to facilitate both inflow and outflow of blood. Preload is increased as a result of blood contained within the lungs moving toward the left side of the heart, and afterload is reduced through a reduction in thoracic blood volume. These concomitant effects cause an increase in stroke volume and therefore in systolic pressure (maximum systolic pressure). After a few heartbeats, the inspiratory decrease in the right ventricular stroke volume causes a decrease in left heart refilling and, consequently, a reduction in stroke volume and systolic pressure (minimum systolic pressure). The SPV is the difference between maximum and minimum systolic pressure over a respiratory cycle.

It has recently been reported that a recorded SPV of > 4.52% in anesthetized (isoflurane in oxygen and air) mechanically ventilated (peak inspiratory pressure, 8 cm H2O) dogs with physiologically normal cardiovascular function most likely predicts a cardiovascular response (> 10% increase in MAP > 10% decrease in heart rate, or both) after a bolus (3 mL/kg) of crystalloids. Although SPV has been found to be a reliable index of fluid responsiveness in dogs, it can only be used in anesthetized, intubated, and mechanically ventilated patients. Consequently, its use is limited to operating rooms and a small minority of dogs in intensive care units.

Ultrasonography has become an integral part of human emergency medicine in clinical practice. It can be used to enhance a clinician’s ability to assess and manage patients with a variety of acute illnesses and injuries. Furthermore, it can be rapidly, painlessly, and noninvasively applied and can be used for repeated assessment. Ultrasonography provides a simple and generally reliable method for assessment of fluid status in conscious human patients. One ultrasonographic method frequently used to evaluate volemia in adult humans is measurement of the diameter of the inferior vena cava and comparison of that value with a reference range. In pediatric subjects, a new ultrasonographic variable has been introduced to overcome difficulties encountered when attempting to determine reliable ranges of the inferior vena cava diameter for subjects with various body sizes. This variable is the ratio between the inferior vena cava and diameter of the descending Ao; the ratio remains relatively constant, despite intravascular volume depletion.

Similar to human subjects, dogs are also highly variable in size, and for this reason the use of an index of volemia similar to the one described for pediatric humans may be effective. Moreover, an echographic window, which allows the diameters of the CVC and Ao to be rapidly measured, is commonly used by veterinary radiologists to detect portosystemic shunts in small animals. In healthy anesthetized dogs, the CVC increases in diameter to a greater extent than does the Ao after acute, large-volume, IV administration of fluids. Therefore, the objective of the study reported here was to evaluate the correlation of the ratio between the diameter of the CVC and diameter of the Ao versus the SPV as an index of preload in dogs anesthetized with isoflurane and mechanically ventilated with a peak inspiratory pressure of 8 cm H2O.

Materials and Methods

Animals

Dogs admitted to the Ospedale Veterinario Roma Sud for anesthesia and surgical repair of recent skin wounds were eligible for enrollment in the study. The study was approved by the Ethical Committee of the University of Padua, and all owners provided informed consent for participation of their dogs.

A preoperative physical examination was performed on each dog. Hematologic and biochemical tests (eg, PCV and plasma concentrations of total protein, urea, creatinine, and electrolytes) were performed on all dogs. Perioperative MAP was assessed by use of oscillometric measurement with a blood pressure device. When a dog had an MAP < 75 mm Hg, it received a bolus (5 mL/kg) of Hartmann solution administered at a rate of 999 mL/h by use of a volumetric pump. If the dog still had an MAP < 75 mm Hg, it received a second bolus (5 mL/kg) of Hartmann solution. Dogs with an MAP < 75 mm Hg after administration of 2 boluses (ie, 10 mL/kg) were excluded from the study. Dogs were also excluded because of owner refusal, clinical signs of profound hypovolemia, or a history or clinical signs of cardiovascular disease, arrhythmia, or other systemic disease or if they were < 1 year old, had recently been fed, or had a temperament that precluded use of a standard anesthetic technique.

Anesthesia

An over-the-needle catheter was aseptically inserted into a cephalic vein. Hair was clipped from the 9th to 12th intercostal space on the right thoracic area. Anesthesia was induced with propofol administered IV to effect. The trachea was intubated with a cuffed endotracheal tube, which was then connected to the anesthetic machine and controlled mechanical ventilation was initiated. Tidal volume of ventilation was set to maintain a peak inspiratory pressure of 8 cm H2O, and the respiratory rate was set to maintain the end-tidal partial pressure of CO2 between 4.6 and 6 kPa. Anesthesia was maintained with isoflurane (end-tidal isoflurane concentration, 1.0% to 1.4%) vaporized in oxygen and air (inspired oxygen concentration,
< 40%) and delivered via a circle system. Anesthetized dogs were positioned in left lateral recumbency.

Routine anesthetic monitoring<sup>2</sup> was performed for all dogs and consisted of capnography (side-stream system), measurement of inspired and end-tidal concentrations of oxygen and other gases, spirometry (pitot based), pulse oximetry (with an ear probe), electrocardiography (3 derivations), and measurement of rectal temperature. Arterial blood pressure was measured through an arterial catheter inserted into a dorsal pedal artery and connected to a transducer calibrated to 0 at the level of the right atrium. Cardiovascular and respiratory variables were recorded every 5 seconds on an electronic sheet throughout the study by use of commercial software<sup>6</sup>; data were downloaded onto a laptop computer connected to the anesthesia monitor by a serial port adaptor.<sup>h</sup>

Once a stable plane of anesthesia was achieved, SPV was measured as described elsewhere.<sup>29</sup> Three consecutive SPV measurements were obtained, and the median value was recorded. All SPV measurements were recorded by the same investigator (CM). Dogs with an SPV < 4 mm Hg were excluded from the study.

Ultrasonographic recordings<sup>5</sup> were obtained with an electronic microconvex/curvilinear (8- to 10-MHz) or linear<sup>4</sup> (3.1- to 10-MHz) probe. To locate the porta hepatis, the transducer was placed in a transverse position in the 10th to 12th intercostal spaces at a point approximately 5 to 10 cm ventral to the vertebral column.<sup>27</sup> When an aerated lung was encountered, the transducer was angled caudally or moved caudally 1 intercostal space. When the right kidney was seen, the transducer was angled cranially or moved cranially 1 intercostal space.

A transverse ultrasonographic image of the porta hepatis was obtained, optimized by suspending mechanical ventilation, and stored (Figure 1). All images were obtained by the same investigator (RR). The amount of time needed to obtain a satisfactory image of the porta hepatis was recorded. Care was taken so that unnecessary pressure was not applied with the probe to each dog to avoid artifacts of the CVC and measurement of its lumen. Measurement of SPV was suspended when a dog retained some degree of spontaneous respiratory activity, there was detectable variability in the heart rate, or the MAP was < 50 mm Hg. When abnormalities in the ventilatory pattern were attributed to inadequate depth of anesthesia, a bolus (1 mg/kg) of propofol was administered IV, and SPV measurement began 5 minutes later. When MAP was < 50 mm Hg, the end-tidal isoflurane concentration was decreased, if deemed appropriate, by use of clinical signs of depth of anesthesia. When the aforementioned abnormalities were not treated by relevant interventions or a dog required use of a vasopressor, the subject was excluded from the study.

**Experimental procedures**

A bolus (3 to 4 mL/kg) of Hartmann solution<sup>1b</sup> was administered IV during a 1-minute period by use of preloaded 50-mL syringes. When the measured SPV reached what is considered a fluid unresponsive value (< 4 mm Hg), bolus administration was stopped and the image of the porta hepatitis was recorded and stored.<sup>25</sup> Cardiovascular and respiratory variables were recorded<sup>4</sup> continuously during fluid administration and until 5 minutes after injection of the last bolus of Hartmann solution.

After the ultrasonographic images were recorded, the same investigator who performed the ultrasonographic examination and recorded the images (RR) obtained measurements for the calculations. That investigator was not aware of SPV values for each dog. The CVC has an elliptical shape on the transversal scanning plane. Measurements were obtained on the short-axis for both hypovolemic and normovolemic dogs (Figure 2). The CVC-to-Ao ratio was derived by measuring the diameters of the CVC and the Ao. Three consecutive measurements were obtained, and the median value was recorded and used for calculation of the CVC-to-Ao ratio. The fractional increment in the CVC-to-Ao ratio evaluated at 1 minute after bolus administration was calculated as the difference between the CVC-to-Ao ratio before and after bolus administration.

**Statistical analysis**

Continuous variables were assessed for a normal distribution by visual inspection of the frequency distribution and with a Shapiro-Wilk normality test. Variables that were normally distributed were reported as mean and SD, whereas nonnormally distributed variables were expressed as median and range. A dependent t test for paired samples was used to analyze differences in Ao diameter before and after bolus administration.

Pearson parametric correlation analysis was used to evaluate the correlation between SPV and the CVC-to-Ao ratio.

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**Figure 1**—Transverse ultrasonographic image of the liver at the level of the porta hepatitis through a right intercostal space of a representative dog. A suitable image was obtained when there was no artifact from air in the lungs or gas in the gastrointestinal tract and the Ao, CVC, and portal vein (PV) were visible. The Ao is the most dorsal structure in the region of the porta hepatitis and is located on the midline. The CVC is ventral and slightly to the right of the Ao, and the PV is ventral and slightly to the right of the CVC.
Linear regression analysis was also performed with the CVC-to-Ao ratio as the predictor variable and the total bolus dose as the dependent variable. The $R^2$ was an estimate of the variance required in the bolus dose to obtain an SPV $< 4$ mm Hg. Values were considered significant at $P < 0.05$. Data were analyzed by use of a commercial statistical software package.

Results

A total of 19 dogs were enrolled in the study. Measurements could not be obtained for 5 dogs because of abnormalities in the ventilatory pattern during fluid administration ($n = 2$), an unstable plane of anesthesia during fluid administration ($2$), or difficulties in obtaining good-quality transverse images of the vessels ($1$). Thus, data for 14 dogs (9 females and 5 males; mean ± SD age, 73 ± 40 months; and mean body weight, 22 ± 7 kg) were available for analysis.

Mean ± SD total bolus volume administered was 14 ± 7 mL/kg. Median number of boluses administered to each dog was 3 (range, 2 to 6).

Twenty-eight paired CVC-to-Ao ratios (14 before bolus administration and 14 after bolus administration) were analyzed. All variables were normally distributed, except for SAP, which had a nonnormal distribution.

Median amount of time to obtain a satisfactory image of the porta hepatis was 60 seconds (range, 25 to 120 seconds). Before bolus administration, mean ± SD heart rate was 104 ± 23 beats/min and median SAP was 97 mm Hg (range, 86 to 138 mm Hg). Mean ± SD SPV and CVC-to-Ao ratio before bolus administration was 7 ± 2 mm Hg and 0.52 ± 0.16, respectively. After bolus administration, mean ± SD heart rate, SPV, and CVC-to-Ao ratio was 83 ± 22 beats/min, 2 ± 0.6 mm Hg, and 0.91 ± 0.13, respectively, and median SAP was 108 mm Hg (range, 89 to 140 mm Hg). Mean diameter of the CVC and Ao before bolus administration was 0.50 ± 0.20 cm and 0.95 ± 0.16 cm, respectively, whereas mean diameter of the CVC and Ao after bolus administration was 0.89 ± 0.15 cm and 0.97 ± 0.16 cm, respectively. The CVC-to-Ao ratio before and after bolus administration differed significantly ($P < 0.001$), but Ao diameter before and after bolus administration did not ($P = 0.2$).

The Pearson correlation coefficient was 0.86 (95% confidence interval, 0.72 to 0.93; $P < 0.001$). A scatterplot was created (Figure 3).

Linear regression analysis between the dependent variable, defined as the total volume of bolus administered, and independent variable, defined as the difference in the CVC-to-Ao ratio before and after bolus administration (increment CVC-to-Ao ratio), yielded an $R^2$ of 0.513 ($P = 0.004$). A scatterplot of the regression analysis was created (Figure 4). The equation for the
Blood pressure, pulse rate, and Ao diameter. Variables that are based on the arterial system, such as Ao, reflect volume status more closely than do other variables. The diameter of the inferior vena cava (CVC) in humans is commonly used as an echographic indicator of volemia.26 The CVC to Ao ratio can be used in practice settings to overcome some of the limitations of the use of SPV for the assessment of volemic status. The SPV cannot provide reliable information about volemia when the R-R interval is variable and when severe lung dis...

**Discussion**

Cardiac output increases substantially after administration of a bolus of fluid only if the ventricles operate on the ascending part of the cardiac function curve (ascending part of the Frank-Starling relationship curve). The use of practical indices of cardiac preload has been proposed to guide fluid administration in the perioperative period and during intensive care.5,15,19-21 The use of such indices has resulted in so-called individualized goal-directed fluid therapy, which can have a beneficial effect on patient outcome in humans.5,17

Central venous pressure is still commonly suggested as a useful index on which to base fluid administration in veterinary practice.10 However, there is a large body of evidence that suggests central venous pressure is not a reliable index to guide clinical decisions regarding fluid administration.12-14,16

Evaluation of volemia by measurement of inferior vena cava diameter is common practice in humans, and there is an abundance of literature to support the validity of this technique.3,24-26 Ultrasonographic evaluation of the inferior vena cava diameter in humans reflects volume status more closely than do other variables that are based on the arterial system, such as blood pressure, pulse rate, and Ao diameter.26

Although CVC to Ao ratio has been proposed for the evaluation of volemia in human pediatric subjects,24 the study reported here provided evidence in dogs that the CVC to Ao ratio was highly correlated with SPV; therefore, the CVC to Ao ratio can be used to estimate cardiac preload in dogs. Findings of the present study also supported the theory that the CVC to Ao ratio can be a significant predictor of the volume of fluids needed to restore cardiac preload in dogs with high SPV.

The inferior vena cava in humans is commonly scanned in a right paramedian substernal view, and the diameter is determined on a long-axis view of the vessel.3,25,26 Even though CVC assessment in dogs could theoretically be obtained in the same manner, evaluation of the CVC to Ao ratio may have some practical advantages. To obtain ultrasonographic images of the CVC in dogs by use of the same approach that is used for humans can be frustrating because of anatomic differences (ie, a dog’s thorax and abdomen are deeper and narrower). Investigators of the study reported here found that the best way to obtain ultrasonographic images of the CVC in dogs was to use a right lateral transverse intercostal approach at the level of the porta hepatis (11th or 12th intercostal space). This echographic window is commonly used by veterinary radiologists for detecting portosystemic shunts in small animals.27 This approach provides, on the same image, the transverse ultrasonographic view of the Ao on the left side, CVC in the middle, and portal vein on the right side. By use of this view of the vessels, measurement error attributable to movement of the CVC during the respiratory cycle is minimized. Good-quality images can easily be obtained with this approach, and the technique is easy to master.

Diameter of the inferior vena cava is used to evaluate volemia by comparing the measured value with a reference range in adult humans.26 In dogs as well as in pediatric subjects, the variability in body size makes it extremely difficult to establish a reference range; however, the CVC to Ao ratio is a dimensionless index and therefore is independent of body size.24 Measurements are obtained noninvasively, and the vessels can be measured during spontaneous breathing in conscious subjects. Further studies are needed to test the usefulness of this index in conscious dogs.

In the present study, dogs considered normovolemic on the basis of the SPV had a CVC to Ao ratio of approximately 1. This and the appearance of the CVC and Ao on the same ultrasonographic image made it easy for us to rapidly visually assess preload, which may be potentially useful in an emergency setting. The CVC diameter and shape in a transverse echographic view can change dramatically on the basis of the volemic status. Appearance of the CVC can vary from a curved narrow strip (elliptical) to a circle that has a diameter far larger than that of the Ao (Figure 2). According to results of 1 study,28 the Ao diameter is independent of mild to moderate volemia and does not change substantially during fluid administration. The CVC to Ao ratio can be used in practice settings to overcome some of the limitations of the use of SPV for the assessment of volemic status. The SPV cannot provide reliable information about volemia when the R-R interval is variable and when severe lung dis-
ease substantially alters lung compliance. In all such subjects, the CVC-to-Ao ratio can be a useful option because it is not affected by these factors.

Nevertheless, the CVC-to-Ao ratio also has limitations. It cannot be reliably used in patients affected by intrathoracic disease (eg, right heart failure, cardiac tamponade, pneumothorax, pleural effusion, or pulmonary thromboembolism) or patients with increased abdominal pressure (presence of fluids or masses), both of which cause CVC dimensions to be partially or totally unrelated to volemic status. The CVC-to-Ao ratio should be used as part of a more comprehensive physical examination, including an echographic examination, and not as the sole variable used to assess volemic status in an animal. Large, deep-chested, polyneic dogs as well as the presence of free fluid or a mass in the abdomen can pose additional difficulties in obtaining good-quality images by use of the aforementioned ultrasonographic window.

Lack of sensitivity and specificity of clinical variables, including arterial blood pressure, for the detection of hypovolemia in humans has been reported. In a seminal study on the dynamic indices of volemia, neither heart rate nor MAP was correlated with volemia and cardiac output in anesthetized dogs with various degrees of volemia achieved by exsanguination. Investigators of that study found that even though cardiac output at the end of exsanguination was approximately half the output at the beginning of exsanguination, heart rate and mean MAP did not change throughout the study. On the contrary, the dynamic voleric indices were found to increase each time cardiac output decreased.

In the study reported here, each dog received a thorough physical examination. An experienced investigator evaluated cardiovascular function, including heart rate, metatarsal arterial pulse, mucous membrane color, and capillary refill time, and none of the dogs were hypotensive. However, after induction of anesthesia, some dogs required rapid administration of fluid. This can increase cardiac preload as a result of an increase in the administration flow rate rather than as a result of the total volume of fluid administered.

Fluid administration used in the present study has been defined as a mini-fluid bolus, which was similar to the mini-fluid challenge used in another study. A mini-fluid bolus, similar to a mini-fluid challenge, can be described as IV administration of a small volume of fluid during a short period. This can increase cardiac preloading as a result of an increase in the administration flow rate rather than as a result of the total volume of fluid administered.

A mini-fluid bolus typically causes a transient increase in preload, and a variable number of boluses may be required for treatment of hypovolemia. In the study reported here, fluid administration was stopped when the SPV was normalized (≤ 4 mm Hg). The use of mini-fluid boluses and assessment of SPV can provide an easy manner in which to obtain information about the amount of fluid required for administration. In addition, this fluid administration modality can be used to avoid administration of excessive amounts of fluid (overload).

In the study reported here, we investigated use of the CVC-to-Ao ratio in anesthetized dogs as a marker of cardiac preload. Further studies should be performed to investigate the dynamic components (collapsibility and distensibility indices) of the CVC-to-Ao ratio and to examine whether cutoff values can be obtained that would be useful in the assessment of the response to fluid administration. The ultrasonographically obtained CVC-to-Ao ratio provided a simple, quick, noninvasive method for estimation of volume status and may be useful in guiding fluid administration for anesthetized hypovolemic dogs.

Acknowledgments
This manuscript represents a portion of a thesis submitted by Dr. Meneghini to the University of Padua Department of Animal Medicine, Production and Health as partial fulfillment of the requirements for a Master of Science degree.

Presented in part at the Association of Veterinary Anaesthetists Spring Meeting, London, April 2013; and at the European Veterinary Emergency and Critical Care Society Congress, Copenhagen, June 2015.

Footnotes
a. AS/5, Datex-Ohmeda, Bromma, Sweden.
b. Baxter Healthcare Corp, Deerfield, IL.
c. Alaris volumetric infusion pump, signature edition 7200, Care Fusion, San Diego, Calif.
e. Cato, Draeger Medical GmbH, Lubeck, Germany.
g. Monitor program for PC, version 5.0A, The Chinese University of Hong Kong, Hong Kong, People’s Republic of China.
h. USB 2.0/serial port adaptor, SerialGear, Clearwater, Fla.
i. GE, Logiq s7pro, GE Healthcare, Milwaukee, Wis.
j. 8C microconvex probe, GE Healthcare, Milwaukee, Wis.
k. 9L-D linear probe, GE Healthcare, Milwaukee, Wis.
l. MedCalc software, version 12.7.7, MedCalc Software, Ostend, Belgium.

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7. Wilson M, Davis DP, Coimbra R. Diagnosis and monitoring of