Cardiac output (CO) is the quantity of blood pumped into systemic circulation by the heart and is generally quantified in milliliters or liters per minute. It is a primary determinant of oxygen delivery to tissues and is therefore extremely valuable to measure in many patients, especially those considered cardiovascularly unstable or critically ill. Currently in veterinary medicine, noninvasive methods including blood pressure, pulse oximetry, and central venous pressure are used to assess and monitor the cardiovascular status of critical patients. Dynamic parameters including pulse pressure variation, systolic pressure variation, and stroke volume variation can be used in mechanically ventilated patients. However, these parameters are not substitutes for CO measurement, which is the only way to provide a global assessment of the cardiovascular system. CO measurement is indicated in any critically ill veterinary patient, but especially those with conditions such as systemic inflammatory response syndrome, sepsis, and multiple organ dysfunction. By evaluating CO, medical therapy, including the administration of vasopressors, inotropes, and IV fluids, can be specifically and immediately tailored to the needs of the patient. This individualized therapy has

The Edwards Acumen IQ system using peripheral arterial catheter-based waveforms to estimate cardiac output is not accurate as compared to thermodilution in dogs

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OBJECTIVE
To assess the agreement between cardiac output (CO) estimated via evaluation of the arterial pressure waveform by a novel monitoring system (Edwards Acumen IQ sensor and HemoSphere Advanced Monitor Platform [HS-IQ]; Edwards LifeSciences) and measured by thermodilution (TD) in anesthetized, normovolemic, and hypovolemic dogs. To assess the agreement between the HS-IQ CO measurements in the radial artery and dorsal metatarsal artery.

ANIMALS
8 purpose-bred Beagles.

METHODS
Dogs were placed under general anesthesia. CO was measured via TD and via the HS-IQ at radial and dorsal metatarsal arterial catheters. CO measurements were obtained at 4 time points including normovolemic and multiple hypovolemic states. Paired measurements of CO were evaluated via the method of Bland and Altman with acceptable limits of agreement (LOA) defined as < 30%.

RESULTS
A total of 24 (dorsal metatarsal) and 21 (radial) paired measurements were collected in 8 dogs. The overall bias (CI) for comparison of TD to radial arterial HS-IQ CO measurements was −0.09 L/min. LOA and proportional LOA were −2.66 to 2.49 L/min and −140.72% to 104.94%. The overall bias (CI) for comparison of TD to dorsal metatarsal arterial HS-IQ CO measurements was −0.26 L/min. LOA and proportional LOA were −2.76 to 2.24 L/min and −135.96% to 93.25%. The overall proportional error for radial arterial was −17.9% and for dorsal metatarsal was −21.4%.

CLINICAL RELEVANCE
CO measurements with the HS-IQ were easy to obtain but did not produce results within a clinically acceptable range for either measurement site, with a very wide LOA. The CO estimations from the HS-IQ are not appropriate for clinical use at this time.

Keywords: cardiac output, thermodilution, arterial catheter, hypovolemia, normovolemia

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the potential to vastly improve patient care in many of the sickest and most vulnerable patients.

While there are multiple ways to measure CO in veterinary species including thermodilution (TD), lithium dilution, and transpulmonary pulse contour analysis, it is rarely performed because the techniques are either invasive, have significant risks, or require specialized expertise for placement of catheters and to perform the technique. In addition, most of these techniques are used for the single purpose of measuring CO, further increasing its cost per use. The TD technique for CO measurement requires the placement of a pulmonary arterial catheter, which can be difficult to place and is rarely used in human or veterinary medicine because of an increased risk for morbidity and mortality that has been previously reported in humans. However, TD remains the gold standard for measuring CO, as it has been validated in a variety of experimental models.

A new monitoring platform has been introduced into the human medical market (HemoSphere Advanced Monitoring Platform [HS]; Edwards Lifesciences) that can estimate CO, stroke volume, systemic vascular resistance, and cardiac index using the arterial blood pressure waveform obtained from a proprietary pressure sensor (Acumen IQ Sensor [IQ]; Edwards Lifesciences) connected to a peripheral arterial catheter placed in the radial artery in humans. This system (HS-IQ) does not require specialized expertise and does not require invasive catheter placement beyond a peripheral arterial catheter, something that is placed on a regular basis in specialty veterinary practice, especially in unstable patients undergoing general anesthesia and in critically ill patients. Arterial catheters are generally considered to carry only a moderate risk of complications in dogs, and although the frequency of complications is high (approx 20%), these are generally considered mild and no long-term complications have been reported in this species.

To the authors’ knowledge, there have been no reports using the HS-IQ to estimate CO in veterinary patients, although other similar proprietary monitoring technologies have shown promise in dogs. Therefore, the objective of this study was to assess the agreement between CO measured by the HS-IQ and measured via TD in anesthetized, normovolemic, and hypovolemic dogs and to assess the agreement between the HS-IQ CO measurements in the radial artery and dorsal metatarsal artery. We hypothesized that the limits of LOA between the HS-IQ and TD CO measurements would be < 30% and that there would be similarly good agreement between radial and dorsal metatarsal HS-IQ CO measurements.

Methods

Animals

Eight purpose-bred Beagles were used in this study. Each dog was determined to be healthy based on physical examination, CBC, and serum biochemistry panel. After completion of the study, all dogs returned to participation in ongoing research for a finite period of time before being adopted. All procedures were approved by the IACUC at Colorado State University (protocol No. 2237).

Anesthesia and instrumentation

All dogs were premedicated with hydromorphone (0.1 mg/kg, IM), and an IV catheter was placed in a forelimb. The dogs were preoxygenated with 100% oxygen, and general anesthesia was induced with propofol (5 to 10 mg/kg, IV) to effect. Dogs were orotracheally intubated, and anesthesia was maintained using isoflurane vaporized in 100% oxygen and delivered via a circle system. Dogs were allowed to spontaneously breathe throughout the protocol.

Dogs were instrumented with ECG, pulse oximetry, invasive blood pressure monitoring, esophageal temperature probe, and end-tidal carbon dioxide (ETCO2) via sidestream sampling for the duration of general anesthesia. A forced air warming device and heated water blankets were used as needed to maintain normothermia.

After induction and placement of anesthetic monitoring, 20-gauge IV catheters were placed in both the dorsal metatarsal and radial arteries. When needed, ultrasound guidance was used to assist in placement. A 16-gauge catheter was placed in a jugular vein for blood collection, and an introducer catheter was placed in the opposite jugular vein to facilitate the placement of a Swan-Ganz catheter for TD CO measurement. The Swan-Ganz catheter was placed using a flow-directed technique via the jugular vein, and the location in the pulmonary artery was confirmed via pressure waveform analysis. All catheters were placed using an aseptic technique.

CO measurements

Dogs were allowed to equilibrate at each CO state for 10 minutes before measurement of CO via TD and HS-IQ. TD measurements of CO were performed using the HS monitoring platform according to the manufacturer’s guidelines. In brief, the temperature probe was placed in an ice bath with syringes of 0.9% NaCl. A 5-mL bolus of 0.9% NaCl from the ice bath was injected into the proximal port of the Swan-Ganz catheter. The CO was calculated by system software. All CO measurements were obtained in duplicate, and the average of these duplicate measurements was used for statistical analysis.

Measurement of CO via HS-IQ was performed according to manufacturer guidelines. In brief, the IQ sensor was attached to the dog’s radial or dorsal metatarsal arterial catheter and to the HS monitoring platform. The IQ sensor was allowed to equilibrate for 3 minutes before the measurement was recorded. The IQ sensor was then connected to the second arterial catheter and again allowed to equilibrate for 3 minutes before the measurement was recorded. All measurements were obtained in duplicate, and the average of the duplicate measurements was used for statistical analysis. A flush test was performed each day at the beginning of the anesthetic events to evaluate the performance of the pressure transducer and system.
Experimental design

CO measurements were obtained at 4 time points: (1) baseline after induction of anesthesia; (2) after induction of hypovolemia, targeting a mean arterial pressure (MAP) of 40 mm Hg; (3) after 50% of the withdrawn blood was transfused back to the dog; and (4) after 100% of the withdrawn blood was transfused back to the dog. The dogs were maintained at each time point for 10 minutes before the collection of CO measurements via TD and the HS-IQ at the radial and dorsal metatarsal arterial catheters. All CO measurements were obtained in duplicate with 3 to 5 minutes between measurements. Arterial blood pressure, body temperature, heart rate, pulse oximetry (SpO2), and ETCO2 were recorded at all time points.

After the dog was placed under general anesthesia and instrumented, the MAP was stabilized at 70 to 80 mm Hg for 10 minutes before time point 1 CO measurements were obtained. If necessary, the anesthesiologist administered dobutamine (0.5 to 3 μg/kg/min, IV), phenylephrine (0.5 to 2 μg/kg/min, IV), and/or an IV bolus of lactated Ringer solution (3 to 20 mL/kg) to stabilize the blood pressure within the desired range. After the target MAP was reached, the dog was maintained for 10 minutes before time point 1 CO measurements were collected.

A low CO state was then induced by withdrawing up to 60% of the dog’s blood volume [calculated as body weight (kg) X 90 mL], targeting a MAP of 40mm Hg. The blood was collected from the jugular catheter over 20 minutes and stored in blood collection bags containing citrate phosphate dextrose adenine. After 10 minutes, time point 2 CO measurements were obtained. Time point 3 CO measurements were obtained 10 minutes after 50% of the withdrawn blood was transfused back to the dog over 15 minutes. Time point 4 CO measurements were obtained 10 minutes after the remaining 50% of the withdrawn blood was transfused back over an additional 15 minutes.

Statistics

Differences between paired measurements were analyzed for normality via visual observation of histograms and qqplots. Correlation between HS-IQ measurements was evaluated using a paired t test (t.test) and Kendall rank correlation τ (cor.test) from the base R stats package (The R Foundation). Evaluation of agreement between TD and HS-IQ measurements was carried out using the method of Bland and Altman via the R package blandr with some modifications currently under design by one of the authors (GMG; R code available upon request). LOA of 30% were decided on a priori as the maximum acceptable deviation from the TD standard. All analyses were carried out using R version 4.1.2 (“Bird Hippie”), and the code and data used for analysis are available at https://github.com/gregg-g/CO_analysis/tree/main. Data are reported as range (mean, SD) unless otherwise noted.

Results

Eight spayed female Beagle dogs were used in this study. Dogs were 2.5 to 5.5 years old (4.8 ± 1.0) and weighed 6.6 to 11.5 kg (8.8 ± 1.6). All dogs recovered from this study without complication. A total of 24 (dorsal metatarsal) and 21 (radial) paired measurements were collected in 8 dogs. Two dogs received dobutamine after induction of anesthesia and during the T1 data collection, but dobutamine was discontinued during the remaining time points, and no other therapies for blood pressure management were administered. One dog was excluded from analyses at time points 2, 3, and 4 because it never became hypotensive after removal of the maximum blood volume allowable in the protocol. A radial arterial catheter was unable to be placed in 2 dogs, so 6 sets of data were used for the CO via HS-IQ via radial arterial catheter analysis.

CO via TD was 1.2 to 3.8 L/min (2.7 ± 1.01) at time point 1, 0.5 to 1.6 L/min (0.8 ± 0.36) at time

Table 1—Selected cardiovascular parameters in 8 anesthetized dogs that were instrumented and had cardiac output (CO) measured via thermodilution (TD) and via evaluation of the arterial pressure waveform by a novel monitoring system (Edwards Acumen IQ sensor and HemoSphere monitor system [HS-IQ]; Edwards LifeSciences) using 2 different arterial catheter locations.

<table>
<thead>
<tr>
<th>Time point</th>
<th>HR (bpm)</th>
<th>MAP (mm Hg)</th>
<th>CO via TD (L/min)</th>
<th>CO via HS-IQ radial artery (L/min)</th>
<th>CO via HS-IQ dorsal metatarsal artery (L/min)</th>
<th>Blood volume removed/transfused (mL/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 (baseline)</td>
<td>102.8 ± 31.5 (8)</td>
<td>74.3 ± 7.2 (8)</td>
<td>2.7 ± 1.01 (8)</td>
<td>1.9 ± 0.55 (6)</td>
<td>2.4 ± 1.23 (8)</td>
<td>NA</td>
</tr>
<tr>
<td>T2 (after blood loss)</td>
<td>110.4 ± 26.4 (7)</td>
<td>45.1 ± 6.6 (7)</td>
<td>0.8 ± 0.36 (7)</td>
<td>2.1 ± 0.77 (5)</td>
<td>2.4 ± 0.77 (7)</td>
<td>36.3 ± 11.6 (7)</td>
</tr>
<tr>
<td>T3 (after 50% transfusion)</td>
<td>116.6 ± 22.7 (7)</td>
<td>60.6 ± 11.2 (7)</td>
<td>1.8 ± 0.57 (7)</td>
<td>2.0 ± 0.32 (5)</td>
<td>2.4 ± 0.44 (7)</td>
<td>17.9 ± 6.2 (7)</td>
</tr>
<tr>
<td>T4 (after complete transfusion)</td>
<td>110.3 ± 12.5 (7)</td>
<td>73.0 ± 8.1 (7)</td>
<td>2.9 ± 1.22 (7)</td>
<td>1.9 ± 0.53 (5)</td>
<td>2.2 ± 0.37 (7)</td>
<td>17.1 ± 5.8 (7)</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD (number of observations). Each CO measurement was obtained in duplicate and the results averaged for analysis. All measurements were obtained after a 10-minute equilibration period with the specified time points as at baseline prior to inducing a hypotensive state (T1), after exsanguination of 40% to 60% of blood volume to target a mean arterial pressure (MAP) of 40 mm Hg (T2), after transfusion of 50% of the exsanguinated blood (T3), and after complete transfusion of the entire blood volume removed (T4). Results are presented as mean ± SD (number of observations). One dog was removed from analysis after T1 as it did not meet the criteria for hypotension at T2.

HR = Heart rate.
point 2, 1 to 2.6 L/min (1.8 ± 0.57) at time point 3, and 1.9 to 5.3 L/min (2.9 ± 1.22) at time point 4. Heart rate, MAP, CO, and blood volume removed/transfused at each time point are reported (Table 1). HS-IQ estimations of CO demonstrated significant variation from TD when calculated at both the radial and dorsal metatarsal arteries as well as from each other (Figure 1). The estimations of CO via HS-IQ at the radial and dorsal metatarsal arteries were not significantly different from one another ($P = .055$) but only showed moderate correlation ($\tau = 0.499$).

Overall mean (lower CI, upper CI) bias for comparison of TD to radial arterial HS-IQ CO measurements was −0.09 L/min (−0.69, 0.51), with LOA of −2.66 to 2.49 L/min. Overall mean (lower CI, upper CI) bias for comparison of TD to dorsal metatarsal arterial HS-IQ CO measurements was −0.26 L/min (−0.75 to 0.23 L/min), with LOA of −2.76 to 2.24 L/min. Bias and LOA overall and at individual time points are listed (Table 2). Time point 3 was not included as it was not found to be significantly or clinically different from time point 4. The overall proportional error (lower CI, upper CI) and proportional LOA (pLOA, lower, upper) for radial artery CO was −17.9% (−46.2, 10.6) and pLOA (−140.72%, 104.94%) and for dorsal metatarsal CO was −21.4% (−43.6, 0.9) and pLOA (−135.96%, 93.25%) (Figures 2–4).

Figure 1—A comparison of cardiac output (CO) measurements obtained via thermodilution (TD) and via evaluation of the arterial pressure waveform by a novel monitoring system (Edwards Acumen IQ sensor and HemoSphere monitor system [HS-IQ]; Edwards LifeSciences) when evaluated at either the radial (A) or dorsal metatarsal (B) artery and via the HS-IQ (C) at either the radial or dorsal metatarsal artery in 8 anesthetized dogs. All measurements were obtained in duplicate and averaged for the final value. Measurements were obtained from each location and via TD while normotensive (mean arterial pressure [MAP], approx 80 mm Hg), hypotensive (MAP, approx 40 mm Hg, induced through blood loss of up to 60% of total blood volume), after return of 50% of the exsanguinated blood, and after completion of retransfusion. Two dogs could not have a radial artery catheter placed, and 1 dog was removed from analysis at all time points except baseline as it never became hypotensive after removing the maximum allowable volume of blood. The solid line represents the line of unity (the 2 measurements were equal), and the dashed lines (A and B) represent a ± 30% deviation from unity, while the dotted-dashed line (C) indicates the best-fit regression line with regression SE shown in gray shading. Closed circles represent measurements from individual dogs that are within the ± 30% area selected a priori as an acceptable clinical deviation from the TD standard measurement, while open circles represent measurements from dogs that are outside of this limit.

Table 2—Bias and limits of agreement (LOA) at each time point in 8 anesthetized dogs that were instrumented and had CO measured via TD and HS-IQ using 2 different arterial catheter locations.

<table>
<thead>
<tr>
<th>Time point/location</th>
<th>Bias (L/min)</th>
<th>LOA (L/min)</th>
<th>Proportional bias (%)</th>
<th>LOA (%)</th>
<th>No. of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Radial</td>
<td>−0.088 (−0.686 to 0.51)</td>
<td>−2.664 to 2.487</td>
<td>−17.89 (−46.42 to 10.63)</td>
<td>−140.72 to 104.94</td>
<td>21</td>
</tr>
<tr>
<td>Metatarsal</td>
<td>−0.26 (−0.746 to 0.225)</td>
<td>−2.762 to 2.241</td>
<td>−21.357 (−43.60 to 0.86)</td>
<td>−135.96 to 93.25</td>
<td>29</td>
</tr>
<tr>
<td>T1 (baseline)  Radial</td>
<td>0.533 (−0.480 to 1.547)</td>
<td>−1.36 to 2.426</td>
<td>17.83 (−24.44 to 60.10)</td>
<td>−61.12 to 96.78</td>
<td>6</td>
</tr>
<tr>
<td>Metatarsal</td>
<td>0.138 (−0.685 to 0.960)</td>
<td>−1.791 to 2.066</td>
<td>6.47 (−22.55 to 35.50)</td>
<td>−61.58 to 74.53</td>
<td>7</td>
</tr>
<tr>
<td>T2 (after blood loss) Radial</td>
<td>−1.46 (−2.535 to −0.385)</td>
<td>−3.157 to 0.237</td>
<td>−99.71 (−147.12 to −52.30)</td>
<td>−174.55 to −24.87</td>
<td>5</td>
</tr>
<tr>
<td>Metatarsal</td>
<td>−1.586 (−2.280 to −0.892)</td>
<td>−3.056 to −0.115</td>
<td>−96.20 (−126.32 to −66.08)</td>
<td>−160.04 to −32.36</td>
<td>6</td>
</tr>
<tr>
<td>T4 (after return of volume) Radial</td>
<td>0.870 (−0.933 to 2.673)</td>
<td>−1.976 to 3.716</td>
<td>29.30 (−18.67 to 77.27)</td>
<td>−46.42 to 105.02</td>
<td>5</td>
</tr>
<tr>
<td>Metatarsal</td>
<td>0.914 (−0.109 to 1.938)</td>
<td>−1.255 to 3.083</td>
<td>29.01 (1.76 to 56.27)</td>
<td>−28.75 to 86.77</td>
<td>7</td>
</tr>
</tbody>
</table>

Bias is reported as absolute (CI). Each CO measurement was obtained in duplicate and the results averaged for analysis. One dog was removed from analysis after T1 as it did not meet the criteria for hypotension at T2, and 2 dogs failed to have radial artery catheters placed.
Figure 2—Absolute Bland-Altman plots for comparison of TD reference measurement of CO versus HS-IQ calculated CO at the radial (A) and dorsal metatarsal (B) arteries in 8 anesthetized dogs. Measurements and groups are as noted in Figure 1. Dashed lines represent the bias and limits of agreement (LOA), the shaded area represents the bias CI, and the dotted-dashed line indicates the best-fit regression line for the differences between the measurements. The HS-IQ underestimated CO at low output states, while overestimating CO at higher output states, even when dogs were normotensive.

Figure 3—Proportional Bland-Altman plots for comparison of TD reference measurement of CO versus HS-IQ calculated CO at the radial (A) and dorsal metatarsal (B) arteries in 8 anesthetized dogs. Measurements and groups are as noted in Figure 1. Dashed lines represent the proportional bias and proportional LOA, the shaded area represents the proportional bias CI, and the double-dashed lines indicate the a priori ± 30% limits for proportional LOA that would indicate good agreement between TD and HS-IQ CO values.
Discussion

CO measurements within 0.5 L/min have been suggested to be a clinically acceptable difference when comparing 2 methods of CO measurement in older human patients undergoing coronary artery bypass grafting, a value that represents approximately 8% to 17% of the expected CO in that age group. However, LOA of up to 30% have been recommended elsewhere in the human literature, mainly because the reference standard TD has an inherent inaccuracy of 10% to 20%. The same authors also recommended that measurement methods be compared at each level of CO in addition to overall across all output states, as there is generally a non-linear relationship in the calculated errors. In our study, none of the LOA fell within this 30% benchmark, indicating that the HS-IQ cannot be used interchangeably with TD for CO measurement. It is also interesting to note that the HS-IQ measurements significantly underestimated CO in hypovolemic, hypotensive patients and then significantly underestimated CO after transfusion and return to normotension. This is significant because clinicians are more likely to use CO measurements in critically ill or hypovolemic patients, and the HS-IQ measurements indicated the patients’ CO was higher than it was when they were in a low CO state, which may lead to cessation of treatment too early. Additionally, the HS-IQ measurements underestimated CO when the patients were returned to a euclidean state, which may lead to continuation of treatment past the return of a normal CO.

The choice to evaluate the ability of the HS-IQ to estimate CO based on both radial and dorsal metatarsal arterial pressure waveforms was made for a number of reasons. The radial artery is the most commonly used site for arterial pressure measurements in human patients, while the dorsal metatarsal artery is generally the site accessed in canine and feline patients. Because the arterial pressure waveform is altered as it travels further down the arterial tree, there are differences in the pressure trace when evaluated at these 2 locations. The literature for the HS-IQ monitoring platform specifies the radial artery as the measurement location, and it would therefore be valuable to know if this site also represented a more appropriate location for placement of an arterial catheter in veterinary patients for CO measurements via HS-IQ. As can be seen (Figure 2), the estimations at the 2 sites were not the same, and although there was a fair correlation in the measurements as noted by the regression line, there were significant errors in individual measurements.

There are multiple CO measurement techniques available in veterinary medicine; however, it is not performed clinically because the techniques are either invasive, have significant risks, or require specialized expertise. Lithium dilution is a less invasive technique for measuring CO, which has been validated in dogs.

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Figure 4—Absolute Bland-Altman plots for comparison of TD reference measurement of CO versus HS-IQ calculated CO at the radial and dorsal metatarsal arteries in 8 anesthetized dogs. Measurements and groups are as noted in Figure 1. The time points are at baseline normotensive (MAP, approx 80 mm Hg), prior to exsanguination (T1); after hypotension was induced by exsanguination of 40% to 60% of total blood volume to target a MAP of 40 mm Hg (T2); and after return of all blood volume that was removed (T4). Dashed lines represent the bias and LOA, and the shaded area represents the bias CI. A negative bias was noted at low CO (hypotensive) states, while a positive bias was seen after return of exsanguinated blood despite no differences in blood pressure or CO between time points 1 and 4.
It uses the dilution of lithium, which is administered to the patient, to calculate CO. It requires a large volume of blood to be aspirated from the patient, which can be detrimental in an already hypovolemic or cardiovascularly compromised patient, and it requires administration of lithium, which can accumulate over time causing toxicity. The use of transpulmonary pulse contour analysis for measurement of CO has also been published in dogs; however, this technique requires placement of a femoral arterial catheter in anesthetized dogs, which is not feasible in most clinical patients. The use of noninvasive techniques, including transesophageal echocardiography (TEE) and thoracic electrical bioimpedance, have been very limited in veterinary patients for various reasons, including the need for calibration using invasive techniques, the size/shape differences found in dogs, and in the case of TEE, the patient must be anesthetized in order to maintain the probe in the esophagus. Because of the risks and limitations associated with these techniques, identifying a way to measure CO safely and easily on the clinical floor would mark a major advancement in the care of critically ill dogs and cats.

Despite the lack of agreement between the reference standard and the HS-IQ, the HS-IQ carries a number of advantages that support its continued clinical development. Of the most importance, the HS-IQ was easy to use in dogs. The sensor is a device that measures approximately 8 X 4 cm and attaches directly to a peripheral arterial catheter on one end, a bag of IV fluids in a pressure bag on the other end, and then the cable is connected directly to the monitor display like a typical arterial pressure recording setup. CO readings are then displayed continuously and updated every 20 seconds. Although not evaluated in this study, the software also has the ability to measure stroke volume, stroke volume variation, cardiac index, systemic vascular resistance, and pulse pressure variation. If the software algorithms can be modified to appropriately estimate CO in species other than humans, the HS-IQ platform has the potential to significantly expand the use of CO as a diagnostic and therapeutic tool in veterinary medicine.

There are a few important limitations to this study. Only 8 dogs were included, 2 dogs could not have a radial artery catheter placed, and 1 dog did not become hypotensive after withdrawal of the maximum amount of blood, for a total of 24 (dorsal metatarsal) and 21 (radial) paired measurements. A type II statistical error cannot be ruled out. A high CO state was not assessed, so conclusions cannot be drawn on the clinical acceptability of the HS-IQ in high CO states. Only 1 HS monitoring platform was available, so there was a short time difference in the collection of radial and dorsal metatarsal CO measurements as the set-up was being transferred from one arterial catheter to the other, including a 3-minute equilibration time. Although TD is commonly considered the gold standard for measuring CO, there are limitations to its use. TD becomes less reliable in very low CO states because the saline warms more rapidly when circulation is low, resulting in a small temperature change. It can also be affected by severe tricuspid valve disease and high flow states. Finally, the study was not blinded as 1 investigator performed and recorded the CO measurements, and all dogs received the same treatments in the same order.

In conclusion, CO measurements with the HS-IQ were easy to obtain, but the LOA were far outside the a priori limits of 30%, and therefore, this monitoring platform cannot be used currently for the estimation of CO in dogs. While the results from the radial artery and dorsal metatarsal artery were not significantly different, neither site produced CO estimations within a clinically acceptable range.

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Disclosures

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