Comparison of ultrasound-guided and landmark-based techniques for central venous catheterization via the external jugular vein in healthy anesthetized dogs

Danielle M. Hundley DVM
Aimee C. Brooks DVM, MS
Elizabeth J. Thomovsky DVM, MS
Paula A. Johnson DVM, MS
Lynetta J. Freeman DVM, MS, MBA
Ryan M. Schafbuch DVM
Hock Gan Heng DVM, MVS, MS
George E. Moore DVM, PhD

Received February 27, 2017.
Accepted September 11, 2017.

From the Departments of Veterinary Clinical Sciences (Hundley, Brooks, Thomovsky, Johnson, Freeman, Heng, Moore) and Comparative Pathobiology (Schafbuch), College of Veterinary Medicine, Purdue University, West Lafayette, IN 47907.

Address correspondence to Dr. Hundley (dhundle@purdue.edu).

OBJECTIVE
To compare time to achieve vascular access (TTVA) between an ultrasound-guided technique (UST) and landmark-based technique (LMT) for central venous catheter (CVC) placement in healthy anesthetized dogs.

ANIMALS
39 purpose-bred hounds.

PROCEDURES
Anesthetized dogs that were hemodynamically stable following completion of a terminal surgical exercise were enrolled in the study during 2 phases, with a 45-day intermission between phases. For each dog, a UST and LMT were used for CVC placement via each external jugular vein by 2 operators (criticalist and resident). The TTVA and number of venipuncture attempts and catheter redirections were recorded for each catheterization. Placement of the CVC was confirmed by contrast fluoroscopy. After euthanasia, a gross dissection was performed during which a hematoma score was assigned to the catheter insertion site. For each phase, nonlinear least squares estimation was used for learning curve analysis of the UST.

RESULTS
Median TTVA, number of venipuncture attempts and catheter redirections, and hematoma score did not differ significantly between the 2 operators for either technique. Median TTVA for the UST (45 seconds) was significantly longer than that for the LMT (7 seconds). Learning curve analysis indicated that 8 and 7 UST catheterizations were required to achieve performance stability in phases 1 and 2, respectively.

CONCLUSIONS AND CLINICAL RELEVANCE
Results indicated that the UST was comparable to the LMT for CVC placement in healthy dogs. The extra time required to perform the UST was not clinically relevant. Additional studies evaluating the UST for CVC placement in clinically ill dogs are warranted. (*Am J Vet Res* 2018;79:628–636)

Central venous catheterization is an essential technique in both human and veterinary critical care medicine. Central venous catheters facilitate central administration of fluid boluses as well as drugs or fluids with a pH or osmolality that is substantially different from that of plasma. Additionally, CVCs allow for repeated collection of blood samples and advanced hemodynamic monitoring such as measurement of central venous pressures.[1–5]

Central venous catheters are commonly placed by use of an over-the-wire catheter–advancement procedure known as the modified Seldinger technique, which has been extensively reviewed elsewhere.[6–8] Traditionally in veterinary medicine, CVCs are commonly placed in the external jugular vein by use of an LMT to achieve vascular access. To perform that technique, knowledge of the anatomic location and direct palpation and visualization are used to gain access to the external jugular vein with an introducer catheter or needle. However, the LMT can be technically challenging in patients with an existing hematoma, edema, cellulitis, or other abnormalities that make direct palpation and visualization of the jugular vein or groove difficult. Additionally, patients that require CVCs are generally in critical condition, and the risk for CVC complications is positively associated with the American Society of Anesthesiologists score, which increases as patients become increasingly compromised or ill.[9] Use of the LMT for CVC placement in small animals has been associated with mechanical complication rates of 20% and infectious complication rates of 10%.[8,9]

In human medicine, CVCs are typically placed into the internal jugular vein with an LMT that requires use of palpation and knowledge of the vessel's anatomic

ABBREVIATIONS

CVC	Central venous catheter
LMT	Landmark-based technique
TTVA	Time to vascular access
UST	Ultrasound-guided technique

location.[7,10–12] However, the LMT reportedly has a mechanical complication rate that is 10% to 15% greater and an infectious complication rate that is 10% to 30% greater than the corresponding complication rates for a UST.[7,10–14] In human patients, use of a UST increases accuracy of CVC placement on the first venipuncture attempt and thereby decreases catheter-related complications by nearly 70% as well as overall CVC maintenance costs.[11,12,15] Also, the TTVA for the UST is significantly less than that for the LMT.[12,14–16] Therefore, the UST for CVC placement in the internal jugular vein is currently the standard of care in human medicine.[11,14,16–20]

Despite the growing use of ultrasound for various procedures in veterinary medicine, descriptions of the use of a UST for CVC placement are limited.[21–24] One[24] of those studies describes the use of a UST to successfully achieve vascular access in 9 fresh canine cadavers with hematomas of various sizes. To our knowledge, the current veterinary literature does not contain any reports in which use of a UST was compared with use of the LMT for CVC placement in live dogs.

Whenever a new medical technique is developed, its equivalence to a previous standard of care must be evaluated to ensure that the technique is safe, feasible, easily mastered, and worthy of further investment and training before it is routinely implemented in clinical practice. Traditionally, learning curves are used to evaluate the feasibility of learning a task. Those learning curves assess the number of repetitions necessary to achieve performance stability as an indication of the speed of leaning. Performance stability for a technique is defined as the point at which the learning curve achieves a plateau or asymptote.[25] In human medicine, learning curves for intensivists training in the use of UST for CVC placement indicate that the TTVA decreased by approximately 79% between the first and eighth repetitions.[14]

The purpose of the study reported here was to compare the feasibility and ease of a UST relative to those of the LMT for CVC placement in healthy anesthetized dogs. The primary objective was to compare the TTVA between the 2 techniques. Secondary objectives were to compare the number of venipuncture attempts and subcutaneous catheter redirections required to achieve vascular access and severity of hematoma formation between the 2 techniques and to describe the learning curve associated with the use of the UST for CVC placement. We hypothesized that, compared with use of the LMT, use of a UST for CVC placement would be associated with a decreased TTVA, decreased number of venipuncture attempts and catheter redirections, and decreased hematoma severity. We also hypothesized that, similar to human studies, performance stability for the UST learning curve would be achieved after approximately 8 repetitions.

Materials and Methods

Animals and study design

The study was a randomized controlled pilot study in which use of a UST was compared with use of the LMT for CVC placement in healthy anesthetized dogs. For each dog enrolled in the study, a UST and LMT were used to place a CVC in each jugular vein. All study protocols were reviewed and approved by and conducted in compliance with the Purdue University Institutional Animal Care and Use Committee.

Dogs eligible for study enrollment were healthy purpose-bred hounds that were used in terminal surgical training laboratories. The dogs were enrolled in the study following completion of 1 of 4 laboratories during the months of February and March 2016. Data were analyzed in 2 phases. Laboratories 1 and 2 were conducted 2 days apart, and the dogs enrolled in the study from those laboratories were analyzed in phase 1. Laboratories 3 and 4 were likewise conducted 2 days apart, and the dogs enrolled in the study from those laboratories were analyzed in phase 2. There was a 45-day interval between laboratories 2 and 3.

To be included in the study, dogs had to be hemodynamically stable while anesthetized with isoflurane.[a] Hemodynamic instability was defined as a systolic blood pressure persistently < 90 mm Hg or a heart rate > 160 beats/min for > 15 minutes after traditional stabilization methods were exhausted. Traditional stabilization methods included decreasing isoflurane administration rate, administration of crystalloid fluid[b] boluses, and redosing of an opioid analgesic.[c] Hemodynamically unstable dogs were ineligible for study enrollment and were euthanized with a pentobarbital euthanasia solution[d] (1 mL/4.45 kg, IV) following completion of the laboratory exercise.

The surgical training exercise was an exploratory celiotomy for laboratories 1 and 2 (phase 1 dogs) and a forelimb amputation for laboratories 3 and 4 (phase 2 dogs). During each laboratory, dogs were anesthetized and monitored by third-year veterinary students. Following completion of the assigned exercise, registered veterinary technicians or veterinarians involved in the study reviewed the anesthetic record of each dog to determine its hemodynamic stability. For dogs that were hemodynamically stable and enrolled in the study, veterinary technicians or veterinarians involved in the study assumed anesthesia monitoring responsibilities until conclusion of the study procedures.

For each dog enrolled in the study, 3 separate coin flips were used to randomize which technique (UST or LMT) would be performed first, which jugular vein (left or right) was catheterized first, and the operator (resident [DMH] or board-certified veterinary criticalist [ACB]) who would perform the first catheterization. Heads were assigned to indicate UST, right, and resident, whereas tails were assigned to indicate LMT, left, and criticalist. For CVC placement, each dog was positioned in dorsal recumbency, and the ventral aspect of the cervical region was clipped and aseptically prepared.

CVC placement

For both the UST and LMT, a No. 11 scalpel blade was used to make a stab incision through the skin over the external jugular vein that was to be catheterized. Then, an assistant digitally occluded the external jugular vein at the level of the thoracic inlet during placement of the over-the-needle introducer catheter.[e]

All UST catheterizations were performed with a 6- to 14-MHz linear transducer and a point-of-care ultrasound machine.[f] The transducer was covered with ultrasound gel, and a sterile glove[g] was placed over the transducer and gel to serve as a sterile transducer cover. The external jugular vein was identified as a hypoechoic tubular structure in the superficial tissues of the ventrolateral aspect of the neck. Vessel patency was confirmed with color flow Doppler echocardiography when occlusion of the vein was released. The jugular vein was differentiated from the carotid artery on the basis of collapsibility and absence of pulsatile blood flow. The transducer was used in a dynamic manner in both the transverse and longitudinal planes to guide the introducer catheter into the jugular vein **(Figure 1)**. The TTVA for the UST was defined as the duration between insertion of the introducer catheter through the stab incision in the skin and flashback of blood though the hub of catheter, the tip of which was ultrasonographically confirmed (visualized) to be within the external jugular vein.

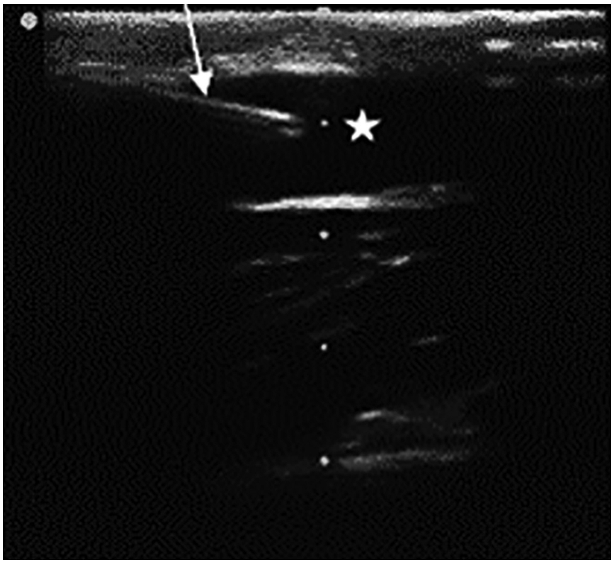

Figure 1—Representative ultrasonographic image obtained in the longitudinal plane of an external jugular vein of an anesthetized healthy adult purpose-bred hound during CVC placement with the UST. The introducer catheter (arrow) appears as a hyperechoic linear structure that is penetrating the hypoechoic tubular lumen (star) of the external jugular vein. The vertically aligned dots in the middle of the image represent 1-cm increments.

For the LMT, the introducer catheter was advanced percutaneously through the stab incision in the skin and into the external jugular vein until a flashback of blood was observed in the catheter hub. The TTVA for the LMT was defined as the duration between insertion of the introducer catheter through the stab incision in the skin and flashback of blood in the catheter hub.

For both techniques following confirmation of vascular access, placement of a single-lumen CVC[h] was continued by use of the modified Seldinger technique.[2,3,8] Each catheterization was video recorded. The video recordings were reviewed by 1 investigator (DMH) to confirm data accuracy and collect data that were not recorded during the procedure.

Both operators had clinical experience and were competent in the use of the LMT for CVC placement. The criticalist had more experience performing ultrasonography, but both the criticalist and resident were novices in the use of the UST for CVC placement. For each catheterization, the number of venipuncture attempts (number of times that the catheter was inserted through the stab incision in the skin) and number of redirections (number of the times that the catheter was redirected under the skin) were recorded by the operators in real time, and the accuracy of those numbers was verified during review of the video recordings. No more than 4 venipuncture attempts and no more than 16 catheter redirections (4 redirections/venipuncture attempt) were allowed for any catherization event. Catheterization was considered unsuccessful if vascular access was not achieved after 4 venipuncture attempts or the vein became devitalized as evidenced by the development of a visible hematoma. Catheterization was also considered unsuccessful if, after vascular access was achieved, the guidewire could not be inserted > 4 cm into the vein, the CVC could not be fed over the wire, or blood could not be easily aspirated from or saline (0.9% NaCl) solution could not be easily flushed into the CVC after it was placed. For learning curve analysis, unsuccessful catheterizations were assigned a TTVA of 498 seconds, which was 50 seconds greater than the maximum TTVA (448 seconds) for a successful catheterization by use of the UST.

Confirmation of CVC placement

For each dog following bilateral placement of a CVC, fluoroscopy was used to assess whether the distal tip of each CVC was correctly located within the cranial vena cava.

Iopromide contrast solution[i] (10 mL, IV) was instilled into each catheter, and fluoroscopic images were obtained with a mobile C-arm fluoroscopy unit.[j] A board-certified veterinary radiologist (HGH), who was unaware of the method used to insert each CVC, reviewed all fluoroscopic images to determine whether the distal tips of the catheters were correctly placed within the cranial vena cava.

With both CVCs still in situ, each dog was euthanized with pentobarbital solution[d] (1 mL/4.45 kg, IV). Cardiac arrest was confirmed by the loss of an audible pulsatile Doppler signal and absence of a heartbeat during cardiac auscultation. A veterinary pathology resident (RMS), who was unware of both the operator and technique used to place each CVC, performed a gross postmortem examination on each dog within 30 minutes after cardiac arrest and death were confirmed. Limited dissection was performed parallel to each external jugular vein, and the presence of a hematoma at the CVC insertion site was subjectively scored as mild, moderate, or severe. The CVC insertion site was also photographed. Dissection was then continued to document the location of the distal tip of each CVC.

Statistical analysis

A sample size calculation was performed prior to study initiation. The TTVAs for both the UST and LMT were assumed on the basis of published veterinary literature.[2,24] We wanted to be able to detect at least a 20% decrease in the TTVA for the UST relative to the TTVA for the LMT with a power of 90% and α of 0.05. Results of the calculation indicated that 37 vessels (37 dogs) would be necessary for each operator.

The data distributions for numeric variables were assessed for normality by means of Q-Q plots, and all variables were determined to be nonparametrically distributed. The Wilcoxon signed rank test was used to compare the TTVA for the UST with the TTVA for the LMT within dogs, between phases 1 and 2, and between early and late catheterizations (components) of both phases as well as the number of venipuncture attempts between the UST and LMT and between operators (resident and criticalist). The Wilcoxon signed rank test was also used to evaluate the first 8 catheterizations (early component) of each phase. The early component of each phase was removed from the comparison of the overall TTVA between the UST and LMT to account for improvement in TTVA owing to repetition.

Because there was a 45-day intermission between laboratories 2 and 3, we chose to analyze the learning curve for phase 1 separate from the learning curve for phase 2. Within each phase, the TTVA for the UST was regressed against the catheterization order by use of a fractional polynomial model that assessed the best power or combination of powers for the data set.[26] For each phase, the model with the lowest deviance was nonlinear. Predicted values from each model were fit, and a 2-segment (piece) pattern consistent with a change in learning rate was graphically evident, which suggested that the learning curve had distinct early and late components. Consequently, a nonlinear least squares estimation method was performed to estimate slopes, intercepts, and cut point parameters, which were then fit with an ordinary least squares regression function into 2 linear pieces as described.[26,27]

A Kruskal-Wallis test by ranks was used to evaluate the respective associations between hematoma score and the number of venipuncture attempts and number of catheter redirections. Fisher exact tests were used for comparisons of categorical variables (number of venipuncture attempts, number of catheter redirections, and hematoma score) between the UST and LMT. For each technique, the proportion and accompanying 95% confidence interval was used to summarize the percentage of successful catheterizations and percentage of CVCs for which the distal tip was correctly placed in the cranial vena cava (ie, successful tip placement). All analyses were performed with a commercial software package,[k] and values of $P < 0.05$ were considered significant.

Results

Dogs

Of the 43 dogs that were involved in the 4 teaching laboratories, 39 (93%; 23 from laboratories 1 and 2 [phase 1] and 16 from laboratories 3 and 4 [phase 2]) were hemodynamically stable at the completion of the surgical exercise and enrolled in the study. Three dogs were excluded from the study because of hemodynamic instability, and 1 was excluded from the study owing to iatrogenic pneumothorax dur-

Table 1—Comparison of the TTVA between the UST and LMT for CVC placement in each of 39 healthy anesthetized purpose-bred hounds.

Event stratification	UST	LMT	*P* value
All events	45 (5–498) [39]	7 (2–498) [39]	< 0.001
Events for which vascular access was successfully achieved	42 (5–450) [37]	7 (2–51) [38]	< 0.001
Phase 1 events	37 (5–498) [23]	9.5 (2–498) [23]	0.001
Phase 2 events	46 (6–354) [16]	6.5 (2–40) [16]	0.003
Early component events	57 (8–498) [16]	10.5 (2–150) [16]	0.001
Late component events	45 (5–450) [23]	7 (2–498) [23]	0.002

Values represent the median (range) TTVA in seconds unless otherwise indicated; numbers in brackets represent the number of catheterization events that contributed to the median. Anesthetized dogs that were hemodynamically stable following completion of a terminal surgical exercise were enrolled in the study during 2 phases, with a 45-day intermission between the 2 phases. Twenty-three dogs were enrolled in phase 1, and 16 dogs were enrolled in phase 2. For each dog, attempts were made to place a CVC in each external jugular vein, one by means of the UST and the other by means of the LMT. The TTVA of an event was defined as the duration between insertion of the introducer catheter through a stab incision in the skin over the external jugular vein and flashback of blood through the catheter hub (ie, successful vascular access). Catheterization events for which vascular access was not achieved were assigned a TTVA of 498 seconds. Early component events represent the first 8 events by each technique within a phase, and late component events represent those that were conducted after the early component events within each phase. Values of *P* < 0.05 were considered significant.

ing forelimb amputation. Of the 39 dogs enrolled in the study, 22 (56%) were sexually intact males and 17 (44%) were sexually intact females. All dogs were 18 months old and had a median weight of 22.9 kg (range, 18.2 to 29 kg) and BCS of 4 (range, 3 to 5) on a scale of 1 to 9. The median duration of anesthesia from induction to euthanasia for the 39 study dogs was 534 minutes (range, 400 to 707 minutes).

CVC placement

The UST was used to catheterize the left and right jugular veins of 22 and 17 dogs, respectively. Conversely, the LMT was used to catheterize the left and right jugular veins of 17 and 22 dogs, respectively. Vascular access was successfully achieved for 37 of 39 (95%) UST catheterizations and 38 of 39 (97%) LMT catheterizations. When both techniques were collectively considered, failure to achieve vascular access (n = 3 events) was the result of reaching the maximum allowed number of venipuncture attempts or catheter redirections. Despite successful vascular access, CVC placement was unsuccessful for 3 of 37 UST catheterizations and 3 of 38 LMT catheterizations owing to bending of the guidewire (n = 5) or a CVC that had a nonpatent lumen secondary to a manufacturing defect (1).

The median TTVA did not differ significantly between the resident and criticalist for either the UST (P = 0.76) or LMT (P = 0.23). Likewise, the median number of venipuncture attempts (UST, P = 0.32; LMT, P = 0.49) and catheter redirections (UST, P = 0.76; LMT, P = 0.99) did not differ significantly between the resident and criticalist for either technique. Therefore, data for both operators were pooled for all subsequent analyses.

The median TTVA for LMT catheterizations was significantly less than the median TTVA for UST catheterizations **(Table 1)** regardless of how the data were stratified. The TTVA data for UST **(Figure 2)** and LMT **(Figure 3)** catheterizations were plotted separately for phases 1 and 2. Visual assessment of those plots indicated that the TTVA varied substantially among UST catheterizations conducted early during both phases 1 and 2 and then appeared to plateau, whereas the TTVA was fairly consistent among the LMT catheterizations throughout the duration of both phases. When the line of best fit (learning curve) was applied to the TTVA data for the UST catheterizations, it had a steep negative slope during the early part (component) of both phases 1 and 2, which suggested that the operators had a rapid rate of learning, but then the slope of the line became less steep (late component), which suggested that operators achieved performance stability after repetitive catheterization events. During phase 1, the early component of the learning curve had a slope of –18 s/cath-

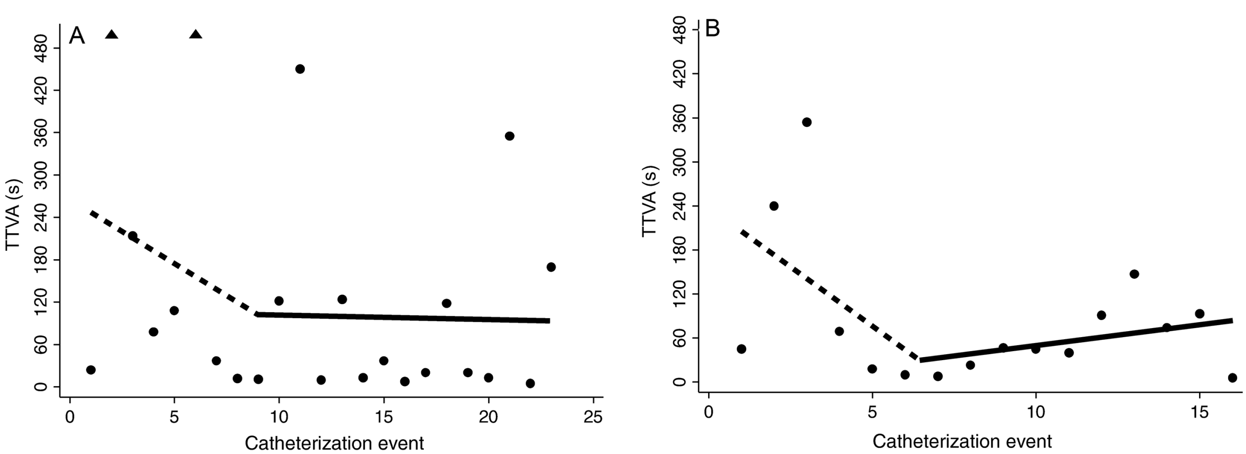

Figure 2—Scatterplot of TTVA of the external jugular vein for consecutive UST catheterization events in 39 healthy anesthetized purpose-bred hounds during phase 1 (A) and phase 2 (B) of a study conducted to compare the UST with the LMT for CVC placement in dogs. Anesthetized dogs that were hemodynamically stable following completion of a terminal surgical exercise were enrolled in the study during 2 phases, with a 45-day intermission between the 2 phases. Twenty-three dogs were enrolled in phase 1, and 16 dogs were enrolled in phase 2. For each dog, an attempt was made by each of 2 operators (board-certified criticalist and resident) to place a CVC in each external jugular vein; 1 CVC was placed by use of the UST and 1 was placed by use of the LMT. The operator, technique, and vein used for placement of the first CVC were determined in a random manner by flipping a coin 3 times. No more than 4 venipuncture attempts and no more than 16 catheter redirections (4 redirections/venipuncture attempt) were allowed for any catheterization. Catheterization was considered unsuccessful if vascular access was not achieved after 4 venipuncture attempts or the vein became devitalized as evidenced by the development of a visible hematoma. Catheterization was also considered unsuccessful if, after vascular access was achieved, the guidewire could not be inserted > 4 cm into the vein, the CVC could not be fed over the wire, or blood could not be easily aspirated from or saline (0.9% NaCl) solution could not be easily flushed into the CVC after it was placed. Unsuccessful catheterizations were assigned a TTVA of 498 seconds. Each symbol represents a successful (circle) or unsuccessful (triangle) catheterization event, and the events are represented left to right in the order that they were performed. The dashed line represents the early component of the UST learning curve, and the solid line represents the late component of the UST learning curve. The intersection of the 2 lines represents the point during the phase at which performance stability of the UST was achieved by the 2 operators. The slope of each line represents the rate of learning (negative slope) or skill decay (positive slope) for the operators during each component of the learning curve.

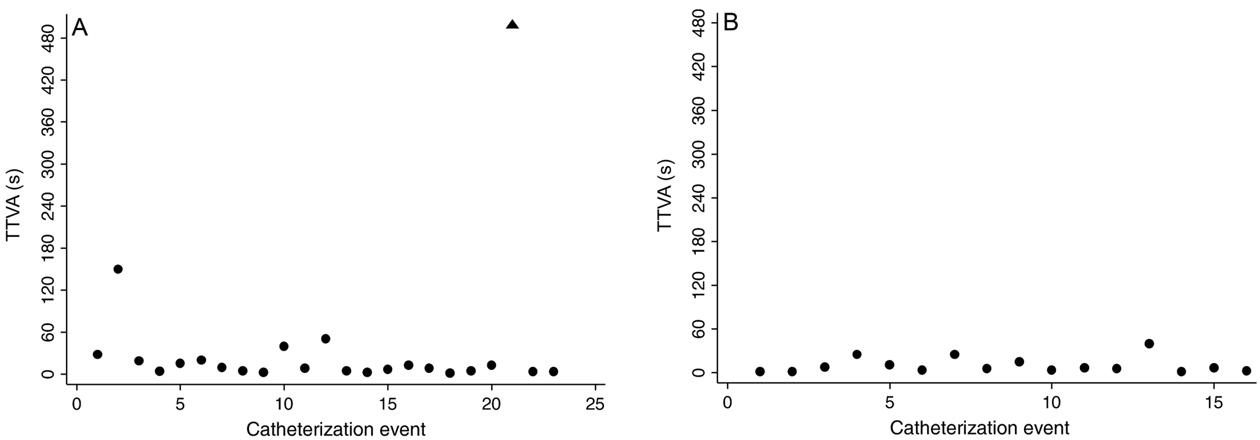

Figure 3—Scatterplots of TTVA of the external jugular vein for consecutive LMT catheterization events in 39 healthy anesthetized purpose-bred hounds during phase 1 (A) and phase 2 (B) of the study described in Figure 2. Notice that the TTVA was fairly consistent for all catheterization events throughout the duration of both phases. Therefore, learning curve analysis was not performed for the LMT. ***See*** Figure 2 for remainder of key.

eterization, and performance stability was achieved after 8 catheterizations. The late component of the learning curve for phase 1 had a slope of –0.6 s/catheterization. During phase 2, the early component of the learning curve was almost twice as steep (–32 s/catheterization) as that for phase 1, which indicated that the rate of learning (ie, relearning) for the UST was quicker for phase 2 than for phase 1, although it took approximately the same number of catheterizations (n = 7) to achieve performance stability. Also, the late component of the learning curve for phase 2 was not as flat as that for phase 1 (slope, 6 s/catheterization).

The median number of venipuncture attempts for UST catheterizations (1.7 attempts/catheterization; range, 1 to 4 attempts/catheterization) did not differ significantly ($P = 0.159$) from the median number of venipuncture attempts for LMT catheterizations (1.3 attempts/catheterization; range, 1 to 4 attempts/catheterization). Similarly, the median number of catheter redirections for UST catheterizations (4.6 redirections/catheterization; range, 0 to 16 redirections/catheterization) did not differ significantly ($P = 0.083$) from the median number of catheter redirections for LMT catheterizations (2.6 redirections/catheterization; range, 0 to 16 redirections/catheterization).

Among the 39 UST catheterizations, the subjective hematoma score was mild for 19, moderate for 17, and severe for 3. Among the 39 LMT catheterizations, the subjective hematoma score was mild for 25, moderate for 12, and severe for 2. The distribution of the hematoma scores did not differ significantly ($P = 0.453$) between UST and LMT catheterizations. Hematoma score was not significantly associated with either number of venipuncture attempts or number of catheter redirections.

Fluoroscopic images for the first 11 dogs catheterized in phase 1 were lost because of a technical error and could not be analyzed. Review of the fluoroscopic images for the remaining 28 dogs indicated that the distal tip of the catheter was correctly located in the caudal aspect of the cranial vena cava for all 28 CVCs placed by the UST and 27 of 28 CVCs placed by the LMT. The distal tip of the 1 misplaced CVC had curved cranially and was located in the contralateral external jugular vein.

Discussion

To our knowledge, the present study was the first to compare the UST with the LMT for CVC placement in live dogs. Contrary to our hypothesis and results of clinical trials[12,14–16] involving human patients, CVC placement by the UST took significantly longer than CVC placement by the LMT (median difference, 38 seconds) to achieve vascular access in the healthy anesthetized dogs of the present study. However, it is likely that the additional 38 seconds required for the UST would not be relevant in a clinical setting. Results of this study also indicated that the number of venipuncture attempts, number of catheter redirections, and hematoma score did not differ significantly between the UST and LMT. Therefore, we concluded that the UST was feasible and comparable to the LMT for placement of CVCs in dogs.

For the dogs of the present study, unlike human patients of other studies,[12,14–16] use of the UST for CVC placement took significantly longer than CVC placement by means of the LMT. The apparent discrepancy between the results of this study and those human studies[12,14–16] was likely because of anatomic differences between dogs and humans. Central venous catheters were placed in the external jugular veins of the dogs of this study, whereas CVCs are placed in the internal jugular veins of human patients. The external jugular veins of dogs are larger and more superficial than the internal jugular veins of humans. Thus, the external jugular veins of dogs are fairly visible and assessible for the LMT, whereas the internal jugular veins of humans are not readily visible, making the LMT a blind approach. In humans, the diameter of the right internal jugular vein is greater than that of the left internal jugular vein[28]; however, to our knowledge, the diameters of the right and left external jugular veins of dogs have not been compared. Additionally, because the external jugular vein of dogs is superficial, it may be predisposed to collapse under the weight of the ultrasound transducer, which might increase the difficulty of the UST in dogs relative to that technique in humans. In fact, in the present study, we discovered that the ultrasonographer must partially support the weight of the transducer to avoid collapse of the external jugular vein. In contrast, the internal jugular vein of humans is supported by adjacent tissues and is unlikely to collapse under the weight of the ultrasound transducer, which may also explain why the UST is faster than the LMT in human patients.

During the initial UST catheterizations (learning phase or early component) of the present study, the operators attempted to ultrasonographically visualize the jugular vein in the transverse plane while attempting to gain vascular access as described in the human literature.[12] After CVC placement in the first 2 dogs, the operators elected to hold the ultrasound transducer in the longitudinal plane because that orientation made it easier to visualize entrance of the catheter into the vessel. Use of the longitudinal plane for the UST allowed operators to visualize the distal tip of the catheter as it was advanced and judge its depth so that perforation of the posterior vessel wall could be avoided. The operators felt that the greatest challenge with the transducer oriented in the longitudinal plane was maintaining the introducer catheter in the same plane as the ultrasound beam to facilitate visualization of the catheter within the vessel without simultaneously compressing the vessel. It is unknown whether use of the longitudinal plane will be more advantageous than use of the transverse plane for the UST in a clinical population of dogs. It is possible that the best ultrasonographic plane for use with the UST may be operator dependent.

Assessment of the UST learning curves for both phases of the present study indicated that there was an early component of rapid operator learning characterized by a steep negative slope followed by a decrease in the magnitude of the slope of the curve as performance began to stabilize. The duration of the early components of the UST learning curves for the operators of this study (8 and 7 catheterizations for phases 1 and 2, respectively) was similar to that reported for the UST learning curves in human patients (8 catheterizations).[14]

Phase 2 of the present study occurred 45 days after phase 1. The early component of the UST learning curve for phase 2 was almost twice as steep as that for phase 1 (–32 s/catheterization vs –18 s/catheterization) and required only 7 instead of 8 catheterizations for performance stability to be achieved. That finding implied that the learning period for the UST was faster in phase 2 than in phase 1, most likely because both operators were UST novices in phase 1, whereas in phase 2, they were simply relearning the technique. We believe that this relearning was necessary because of skill decay during the 45-day intermission between phases 1 and 2. In human medicine, skill decay has been reported for humans trained in CPR as early as 30 days after certification[29] as well as for human physicians returning to practice after a 6-month maternity leave.[30]

The UST learning curves for the operators of the present study never achieved a definitive plateau, defined as an entirely flat line, indicative of complete automation of the skill.[31] This implied that 39 UST catheterizations were not sufficient for the operators to acquire the skills necessary for complete automation of the UST. Conversely, both operators appeared to achieve automation of the LMT, likely because both had experience with the LMT prior to study initiation. Additional studies that involve a large number of UST catheterizations performed by operators with various skill levels are warranted to fully assess how many repetitions are necessary to achieve complete automation of the skills required for UST.

Interestingly, the late component of the UST learning curve for phase 2 of the present study had a small positive slope (6 s/catheterization), which suggested a deterioration of operators' skills. A possible reason for that finding was operator fatigue because the data for phase 2 was collected during the late evening. Additionally, the dogs catheterized during the late component of each phase were anesthetized longer (up to 5 hours) than those catheterized during the early component. It is possible that prolonged anesthesia might have caused hemodynamic alterations that made achieving vascular access more technically challenging.

We suspect that the advantage of the UST relative to LMT for CVC placement will become apparent in dogs with less than ideal cervical anatomy. The dogs of the present study were young and healthy and purposely selected to investigate the safety and feasibility of UST in that species. However, the UST will likely be most useful for diseased dogs in which the external jugular vein is not readily visible or palpable, such as obese dogs, dogs with cervical edema or preexisting hematomas, or dogs with altered vasomotor tone or hypovolemia. In the human medical literature, multiple studies[15,18,20] indicate that UST is better than LMT for CVC placement in human pediatric patients and patients with cervical abnormalities or preexisting conditions such as obesity and hypovolemia.

In the present study, inclusion of the TTVAs for unsuccessful catheterizations in the UST learning curve assessment skewed the slope of the early component of the learning curve for phase 1. However, we felt it was appropriate to include TTVAs for the failed catheterization events in the analysis because failed events occur during skill development and are part of the learning process. To ensure that all failed catheterizations had equal weight in the analysis, a standardized TTVA of 498 seconds was assigned to each failed catheterization, which was 50 seconds greater that the maximum TTVA for successful catheterizations. For future studies, use of a clinically relevant time limit (eg, no more than 5 minutes) for each catheterization event rather than an absolute number of venipuncture attempts or catheter redirections might provide a better representation of the UST learning curve.

The present study had several limitations. The study population consisted of a homogenous group of healthy dogs with normal vascular anatomy, which likely facilitated rapid performance of the LMT (an established skill for the operators) relative to the UST (a new skill for the operators). Future studies in which the operators are novices to both the UST and LMT are warranted. Also, the study population did not allow for assessment of the use of the UST for CVC placement in a clinically relevant population (ie, dogs with cervical abnormalities or preexisting conditions that would make the LMT challenging). Although the number of venipuncture attempts, number of catheter redirections, and hematoma score did not differ significantly between the UST and LMT, it is possible that the study did not have enough power to detect differences in those secondary outcomes. Another limitation was that the hematoma score for each catheterization event was subjectively assigned by 1 investigator. To our knowledge, a grading scale for postmortem hematoma severity has not been established for dogs, and we felt that having 1 person, who was unaware of the operator and catheterization technique used, was an acceptable method to standardize the scores. Finally, all dogs had been anesthetized for a prolonged period prior to study enrollment, and the duration of anesthesia continued to increase for dogs as the catheterization sequence number (ie, order in which the dogs were catheterized) increased. Prolonged anesthesia may have adversely affected vascular volume, thereby making vascular access more challenging.[32] Because a patient-side modality capable of direct measurement of vascular volume is not readily available, we chose to limit the study population to only hemodynamically stable dogs to reduce that potential bias. Additionally, both techniques were used to place a CVC in a jugular vein of each dog in an attempt to limit intersubject variation or bias during comparison of the 2 techniques.

Results of the present study indicated that a UST can be used for CVC placement in healthy anesthetized dogs, and that technique was comparable to the LMT except that it took slightly longer. However, the increased time required to perform the UST relative to the LMT (median, 38 seconds) was not clinically relevant. Learning curve analysis indicated that approximately 8 UST catheterizations were required to achieve performance stability. Although the LMT remains the most efficient technique for CVC placement in normovolemic dogs with normal cervical anatomy, the UST may be useful for CVC placement in dogs and other species with cervical abnormalities or other preexisting conditions, such as obesity or hypovolemia. Thus, the use of UST warrants further investigation.

Acknowledgments

This manuscript represents a portion of a thesis submitted by Dr. Hundley to the Purdue University College of Veterinary Medicine as partial fulfillment of the requirements for a Master of Science degree.

Supported in part by MILA Inc.

The authors declare that there were no conflicts of interest.

The authors thank Tomohito Inoue, DVM; Kristen Marshall, DVM; Tami Lind, RVT; Kathleen Mowery, RVT; Deborah Ramirez, RVT; Amy Butcher, RVT; and Cassandra Simmons, RVT, for technical assistance.

Footnotes

a. Vetone isoflurane inhalant, MWI, Meridian, Idaho.
b. Plasma-lyte 148 replacement IV infusion, Baxter Health Care, Bloomington, Ind.
c. Dilaudid hydromorphone HCl injectable, West Ward Pharmaceuticals, Eatontown, NJ.
d. Beuthanasia-D, Schering-Plough Animal Health, Kenilworth, NJ.
e. Surflash peripheral IV catheter (20 gauge; 1.25 in), Terumo Medical Corp, Somerset, NJ.
f. Edge Ultrasound Machine, SonoSite Inc, Bothell, Wash.
g. ENCORE Perry style 42 sterile powder-free latex surgical gloves, Ansell Healthcare, Lake Forest, Ill.
h. MILACath long-term single-lumen catheter (18 gauge; 4F × 25 cm), MILA International Inc, Florence, Ky.
i. Ultravist nonionic contrast medium, Bayer HealthCare LLC, Springfield, Ill.
j. Vision C-Arm, Ziehm Imaging, Orlando, Fla.
k. Stata IC, version 12, StataCorp, College Station, Tex.

References

1. Lamperti M. The choice of a vein in critically ill patients: cost-effectiveness. In: Sandrucci S, Mussa B, eds. *Peripherally inserted central venous catheters.* Milan, Italy: Springer-Verlag Mailand, 2014;31–42.
2. Portillo E, Mackin A, Hendrix PK, et al. Comparison of the modified Seldinger and through-the-needle jugular catheter placement techniques in the dog. *J Vet Emerg Crit Care (San Antonio)* 2005;16:88–95.
3. Beal MW, Hughes D. Vascular access: theory and techniques in the small animal emergency patient. *Clin Tech Small Anim Pract* 2000;15:101–109.
4. Campbell MT, Macintire DK. Catheterization of the venous compartment. In: Burkitt Creedon JM, Davis H, eds. *Advanced monitoring and procedures for small animal emergency and critical care.* Chichester, England: WB Saunders Co, 2012;51–68.
5. Mussa B. Advantages, disadvantages, and indications of PICCs in inpatients and outpatients. In: Sandrucci S, Mussa B, eds. *Peripherally inserted central venous catheters.* Milan, Italy: Springer-Verlag Mailand, 2014;43–51.
6. Biffi R. Introduction and overview of PICC history. In: Sandrucci S, Mussa B, eds, *Peripherally inserted central venous catheters.* Milan, Italy: Springer-Verlag Mailand, 2014;1–6.
7. Yonei A, Nonoue T, Sari A. Real-time ultrasonic guidance for percutaneous puncture of the internal jugular vein. *Anesthesiology* 1986;64:830–831.
8. Williams K, Linklater A. Central venous catheter placement: modified Seldinger technique. *Clinician's Brief* 2015;1:71–75.

9. Adamantos S, Brodbelt D, Moores AL. Prospective evaluation of complications associated with jugular venous catheter use in a veterinary hospital. *J Small Anim Pract* 2010;51:254–257.
10. Legler D, Nugent M. Doppler localization of the internal jugular vein facilitates central venous cannulation. *Anesthesiology* 1984;60:481–482.
11. McGee DC, Gould MK. Preventing complications of central venous catheterization. *N Engl J Med* 2003;348:1123–1133.
12. Brass P, Hellmich M, Kolodziej L, et al. Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. *Cochrane Database Syst Rev* 2015;1:CD006962.
13. Denys BG, Uretsky BF, Reddy PS, et al. An ultrasound method for safe and rapid central venous access. *N Engl J Med* 1991;324:566.
14. Nguyen BV, Prat G, Vincent JL, et al. Determination of the learning curve for ultrasound-guided jugular central venous catheter placement. *Intensive Care Med* 2014;40:66–73.
15. Froehlich CD, Rigby MR, Rosenberg ES, et al. Ultrasound-guided central venous catheter placement decreases complications and decreases placement attempts compared with the landmark technique in patients in a pediatric intensive care unit. *Crit Care Med* 2009;37:1090–1096.
16. Miller AH, Roth BA, Mills TJ, et al. Ultrasound guidance versus the landmark technique for the placement of central venous catheters in the emergency department. *Acad Emerg Med* 2002;9:800–805.
17. Scoppettuolo G, Mussa B. Clinical problems associated with the use of peripheral venous approaches: infections. In: Sandrucci S, Mussa B, eds. *Peripherally inserted central venous catheters.* Milan, Italy: Springer-Verlag Mailand, 2014;95–109.
18. Muhm M. Ultrasound guided central venous access: is useful for beginners, in children, and when blind cannulation fails. *BMJ* 2002;325:1373.
19. Milling TJ Jr, Rose J, Briggs WM, et al. Randomized, controlled clinical trial of point-of-care limited ultrasonography assistance of central venous cannulation: the third sonography outcomes assessment program (SOAP-3) trial. *Crit Care Med* 2005;33:1764–1769.
20. Brusasco C, Corradi F, Zattoni PL, et al. Ultrasound-guided central venous cannulation of bariatric patients. *Obes Surg* 2009;19:1365–1370.
21. Viscasillas J, Sanchis S, Sneddon C. Ultrasound guided epidural catheter placement in a dog. *Vet Anaesth Analg* 2014;41:330–331.
22. Ringold SA, Kelmer E. Freehand ultrasound-guided femoral arterial catheterization in dogs. *J Vet Emerg Crit Care (San Antonio)* 2008;18:306–311.
23. Brederlau J, Muellenbach R, Kredel M, et al. Comparison of arterial and central venous cannulations using ultrasound guidance in pigs. *Vet Anaesth Analg* 2008;35:161–165.
24. Chamberlin SC, Sullivan LA, Morley PS, et al. Evaluation of ultrasound-guided vascular access in dogs. *J Vet Emerg Crit Care (San Antonio)* 2013;23:498–503.
25. Hopper AN, Jamison MH, Lewis WG. Learning curves in surgical practice. *Postgrad Med J* 2007;83:777–779.
26. Royston P, Sauerbrei W. *Multivariate model-building: a pragmatic approach to regression analysis based on fractional polynomials for modelling continuous variables*. Chichester, England: Wiley, 2008;76.
27. Davidson R, MacKinnon JG. Nonlinear regression. In: *Econometric theory and methods*. New York: Oxford University Press, 2004;213–256.
28. Tartière D, Seguin P, Juhel C, et al. Estimation of the diameter and cross-sectional area of the internal jugular veins in adult patients. *Crit Care* 2009;13:R197.
29. Anderson GS, Gaetz M, Masse J. First aid skill retention of first responders within the workplace. *Scand J Trauma Resusc Emerg Med* 2011;19:11.
30. Walsh A, Gold M, Jensen P, et al. Motherhood during residency training: challenges and strategies. *Can Fam Physician* 2005;51:990–991.
31. Hamdorf JM, Hall JC. Acquiring surgical skills. *Br J Surg* 2000;87:28–37.
32. Magder S. Volume and its relationship to cardiac output and venous return. *Crit Care* 2016;20:271.