Minimally invasive ultrasound-guided technique for central venous catheterization via the external jugular vein in pigs

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OBJECTIVE
To describe an ultrasound-guided technique for central venous catheter placement via the external jugular vein (EJV) in pigs.

ANIMALS
96 healthy Landrace–Poland China barrows (approx 16 weeks old with a mean weight of 70 kg).

PROCEDURES
Pigs were anesthetized. With ultrasound guidance, a needle was inserted into the EJV without a large incision or cutdown procedure. A guidewire was inserted through the needle into the vein. A modified Seldinger technique was used to advance a catheter into the vessel until the tip was in the cranial vena cava near the right atrium. A trocar was used to create a tunnel through the subcutaneous tissues from the catheter insertion site to between the dorsal borders of the scapulae. The free end of the catheter was passed through that tunnel. An extension was attached to the catheter and secured to the skin. Pigs were euthanized and underwent necropsy at completion of the study for which they were catheterized.

RESULTS
Central venous catheters were successfully placed in all 96 pigs and facilitated collection of serial blood samples with minimal stress. Catheters remained in place for a mean of 6 days (range, 4 to 10 days). Necropsy revealed abscesses along the subcutaneous catheter tract in 9 pigs. Twenty pigs had histologic evidence of phlebitis and fibroplasia in the cranial vena cava.

CONCLUSIONS AND CLINICAL RELEVANCE
The described technique, in combination with extensive socialization, allowed serial collection of blood samples with minimal stress and restraint and is an alternative to surgical cutdown procedures for catheter placement. (*Am J Vet Res* 2021;82:760–769)

Traditionally, in animals, intra-arterial or IV access of femoral or cervical blood vessels is achieved by a surgical cutdown procedure on the vessel of interest, which may be ligated and thrombosed, thereby limiting reuse of that vessel.[1] Surgical cutdown methods for vessel access are time-consuming, require experienced surgical personnel, and are associated with postsurgical signs of pain and complications such as bleeding, local infections, or systemic sepsis. Moreover, although surgical catheterization of a jugular vein is an effective technique, it requires general anesthesia and can lead to potentially demanding postoperative care of the animal.[2–6]

Guidewire-assisted vascular cannulation, first introduced in the early 1950s, is often called the Seldinger technique after its inventor.[7] This technique, with a few modifications, has become widely used for vascular cannulation in human and veterinary patients. A minimally invasive procedure for achieving vascular access with a minimal inflammatory response was needed for a planned study to investigate biomarkers of inflammation in swine. That study required the acquisition of a large volume (> 10 mL) of blood from study pigs at each sampling point, thereby necessitating vascular catheterization to eliminate stress associated with frequent blood sample collection and the types of physical restraint needed to obtain those samples. The purpose of the report provided here was to describe a minimally invasive, ultrasound-guided technique for central venous catheter placement via the EJV as an alternative to a surgical cutdown procedure in pigs. The described procedure used readily available commercial products for percutaneous catheterization and serial blood sample collection and was readily reproducible. It was also associated with fewer adverse events, compared with surgical cutdown procedures, and therefore has the potential to reduce stress and improve animal welfare.

ABBREVIATIONS

EJV	External jugular vein
VAP	Vascular access port

Materials and Methods

Animals

The experimental protocol was approved by the Institutional Animal Care and Use Committee at the Office of Research, Center for Veterinary Medicine, US FDA, and all procedures were conducted in accordance with the principles stated in the Guide for the Care and Use of Laboratory Animals[8] and the Animal Welfare Act of 1966 (PL 89-544), as amended. Research was conducted in compliance with the Public Health Service Policy on Humane Care and Use of Laboratory Animals[9] in an Association for Assessment and Accreditation of Laboratory Animal Care–accredited, climate-controlled facility.

Ninety-six Landrace–Poland China crossbred barrows were obtained from a laboratory animal supplier.[a] All pigs were approximately 10 weeks old at the time of purchase. When the pigs arrived at the research facility, they were briefly evaluated by veterinary staff, individually weighed, and moved into group pens with 3 to 4 pigs/pen in a quarantine building. After a 24-hour acclimation period, each pig underwent a more thorough health examination by veterinary staff. The pigs remained in the quarantine building for 2 weeks, were reexamined and confirmed healthy by veterinary staff, and were moved from the quarantine building to the building where the study was conducted.

In the study building, pigs were individually housed in pens (1.25 × 2.75 m) with rubber mats and had ad libitum access to water and a swine grower-finisher ration.[b] The pens were cleaned twice daily. The pigs were provided toys, which were rotated among pens to maximize enrichment. The study building was maintained at a temperature of 21 to 24 °C with ambient humidity and a 14-hour light to 10-hour dark cycle.

After the 2-week quarantine period and for approximately 4 weeks before initiation of experimental procedures, the pigs underwent a sustained socialization process designed to minimize animal stress and discomfort when study personnel were present. Pigs were allocated to cohorts consisting of 8 pigs, and each cohort was exposed to 1 to 2 hours of socialization twice daily. Initially, study personnel coaxed pigs to come to the front of their pens using commercial apple-, banana-, or cherry-flavored treats.[c] After a few days, study personnel entered the pens with the pigs and introduced them to human touch. Thermometer probe covers were used to acclimate pigs to having their rectal temperature taken without inducing stress. Once the pigs became accustomed to interactions with study personnel, treats became unnecessary for inducing suitable interactions. The pigs underwent catheter placement when they were approximately 16 weeks old and had a mean ± SD body weight of 70 ± 5 kg.

Ultrasound-guided catheter placement

Equipment—A sterile instrument pack was prepared for each animal. The pack included forceps, hemostats, needle holders, scissors, a trocar, a feeding needle, gauze pads,[d] surgical drapes, and a stainless steel bowl on a stainless steel tray. The instrument pack was sterilized by use of an autoclave with the following settings: 1-minute purge, 15 minutes at 121 °C, 10 minutes at a pressure of 30.54 inches Hg, and 15 minutes of drying time. Trays were cooled to room temperature (approx 22 °C) prior to use. Autoclave tape and biologic indicators were used to assess packs for successful sterilization.

An ultrasound system[e] with a vascular venous probe[f] was used for vessel visualization. The probe and cord were placed in a sterile sheath for use during the catheterization procedure.

Sedation—Food but not water was withheld from each pig beginning at approximately 4 PM on the day before catheter placement. Pigs were anesthetized for catheter placement. Sedation was achieved by IM administration of a mixture (mixture 1) of xylazine[g] (2 mg/kg) and zolazepam hydrochloride[h] (1 to 3 mg/kg). Each milliliter of mixture 1 contained 100 mg of xylazine and 100 mg of zolazepam, and it was administered at a dose of 0.5 to 1.5 mL/50 kg (0.01 to 0.03 mL/kg). This was followed by an IV injection of mixture 2, which was comprised of xylazine[g] (29 mg/mL), zolazepam[h] (14.7 mg/mL), ketamine hydrochloride[h] (58.8 mg/mL), atropine sulfate[i] (0.88 mg/mL), and butorphanol tartrate[j] (0.59 mg/mL). Mixture 2 was administered at a dose of 0.7 to 2.0 mL/50 kg (0.014 to 0.04 mL/kg).

Animal preparation—Once a pig was adequately sedated, the hair was clipped and removed from the surgical site (jugular furrows and adjacent areas of the neck). The pig was placed in a solid-panel hog hauler[k] and transported to the surgery table, where it was positioned in dorsal recumbency. The larynx of the pig and the end of an endotracheal tube (internal diameter, 7.5 mm) were lightly sprayed with an anesthetic spray[l] that contained 14% benzocaine, 2% butamben, and 2% tetracaine hydrochloride. The endotracheal tube was then inserted into the trachea and secured in place. An 18F, 50.8-cm-long esophageal stethoscope was inserted into the esophagus for patient monitoring. The pig was then positioned in lateral recumbency. The surgical site was aseptically prepared with iodine gel[m] and 70% isopropyl alcohol and covered with an adhesive iodine-inpregnated drape[n] in a routine manner. The pig was then repositioned into dorsal recumbency. The endotracheal tube was connected to an anesthesia machine, and anesthesia was maintained with isoflurane (2% to 4%) in oxygen. The forelimbs were retracted caudally and secured so they would not interfere with access to the surgical site. The surgical site was aseptically prepared with iodine gel[m] and 70% isopropyl alcohol and draped in a routine manner.

Catheter placement—The surgical table was adjusted so that the pig was in a 30° Trendelenburg position

to increase distension of the EJVs. Sterile ultrasound gel was applied to the skin of 1 jugular furrow, and that EJV was ultrasonographically assessed to determine whether it was compressible and not pulsatile. If that vein was not compressible, the contralateral EJV was ultrasonographically assessed. Color flow power Doppler ultrasonography was used to visualize and differentiate arterial and venous pulsations when necessary.[10,11]

After the EJV for catheter placement was selected, an 18-gauge, 7-cm-long, percutaneous-entry, thin-walled needle[o] was introduced into the EJV lumen with ultrasound guidance **(Figure 1)**. The needle tip was ultrasonographically observed as it was advanced into the lumen, with care taken to ensure that the needle tip remained within the ultrasound field of view at all times. A 5-mL slip-tip syringe was connected to the needle hub, and blood was aspirated into the syringe to confirm that the needle was successfully inserted into the EJV lumen. Then, a flexible guidewire (diameter, 0.038 cm; length, 11 cm) was passed through the thin-walled needle and advanced into the vessel lumen. The thin-walled needle was removed while the guidewire was maintained within the vessel lumen. A No. 11 scalpel was used to make stab incisions through the skin immediately cranial and caudal to the guidewire to enlarge the entry site for the catheter. The skin incision cranial to the guidewire was extended further cranially to 2.5 cm in length. Metzenbaum scissors were used to bluntly dissect the subcutaneous tissue and deep fascia. The scalpel was used to create a subcutaneous flap from each incision site for eventual closure of dead space. An introducer[p] was threaded over the flexible guidewire (ie, Seldinger technique), and the guidewire was removed. A 7F, 83.3-cm-long rounded-tip radiopaque silicone catheter[q] fed on a guidewire[r] was inserted through the introducer until the catheter tip was estimated to be located at the cranial aspect of the right atrium (the distance from the proposed catheter entry site to the second rib was measured, but fluoroscopy was not used to confirm the location of the catheter tip). The guidewire was removed. An 18-gauge, 5-cm curved feeding needle was connected to the free end of the catheter to provide access to the catheter lumen. Blood flow through the feeding needle was constantly monitored from that point forward to verify that the catheter remained patent. The catheter was flushed with 5 mL of heparinized saline solution (1,000 U of heparin added to 500 mL of sterile saline [0.9% NaCl] solution). If the heparinized saline solution did not flush easily into the catheter, it was assumed the catheter was inserted too far into the vessel, and the catheter was gently retracted a short distance or rotated until patency was restored.

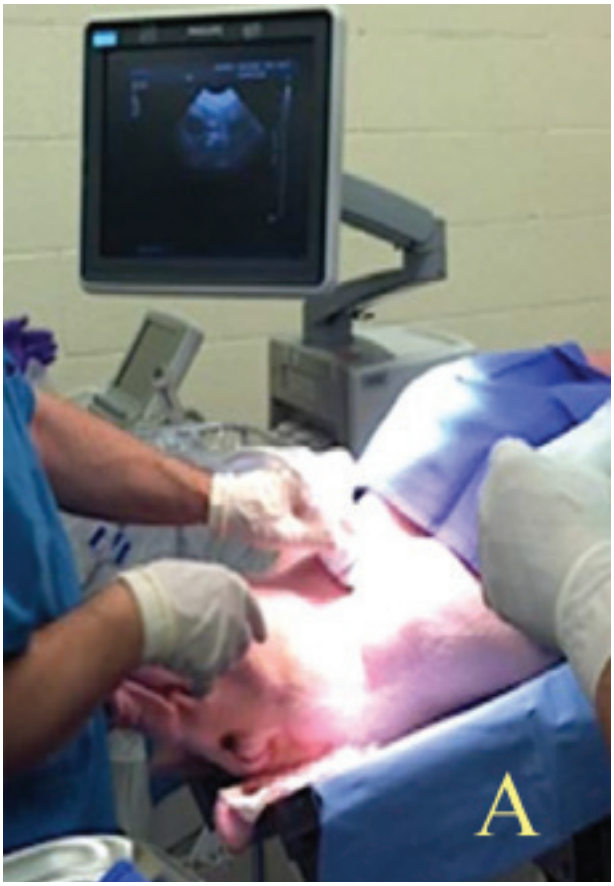
Two moveable beads and a moveable disk[q] were threaded onto the catheter as far as possible to the insertion site in the EJV. The beads and disk were secured in place around the catheter and to the deep fascia with 3-0 antibacterial-coated polyglactin 910.[s] The pig was then repositioned into lateral recumbency on the side contralateral to the side on which the catheter was placed (ie, if the catheter was placed in the right EJV, the pig was positioned in left lateral recumbency). A custom-made, 38-cm-long stainless steel trocar (cannula diameter, 6.7 mm; obturator diameter, 4.0 mm) with a slight curve to facilitate placement was inserted in the cranial aspect of the cranial incision and advanced through the subcutaneous tissue in a caudodorsal direction until it exited the skin near the dorsal midline between the dorsal borders of the scapulae. The obturator was removed from the cannula, and the feeding needle was removed from the catheter. The free end of the catheter was passed through the stainless steel cannula; then, the cannula was removed from the exit site, leaving the catheter in place. The catheter was checked for patency and flushed with 5 mL of heparinized saline solution. The previously created subcutaneous tissue flaps were closed over the catheter insertion site, and the skin was closed with a subcuticular suture pattern followed by staples. The animal was repositioned into sternal recumbency. A felt cuff was threaded onto the end of the catheter and pushed through the skin incision near the dorsal midline. A pigtail catheter extension was connected to the catheter and capped.[t] The skin around the catheter exit site was closed with size-0 polypropylene suture; 1 mL of penicillin G procaine[u] was injected in the subcutaneous tissues before placement of the last skin suture. The catheter was fixed to the skin near the exit site with a suture wing and cover of the 7F catheter.

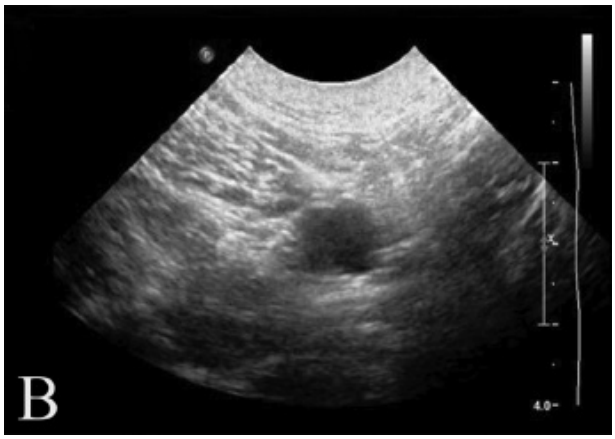
The external portion of the catheter was threaded through a hole in a custom-made denim patch (patch dimensions, 10 × 10 cm with a 7.6 × 7.6-cm flap secured by 2 pieces of self-fastening nylon fabric[v]) to protect it when it was not being used. The patch was secured to the dorsal aspect of the caudal portion of the neck with skin sutures.

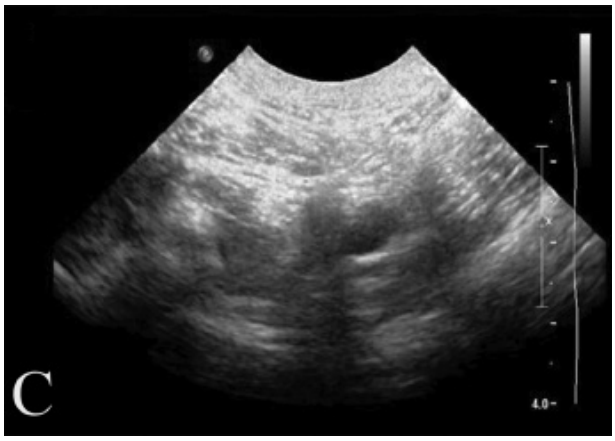
Postsurgical monitoring

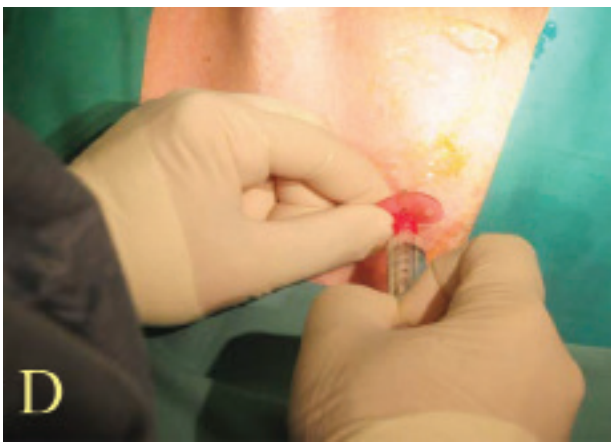
Isoflurane administration was discontinued, and the pig was moved to a recovery room, where it was monitored until it was extubated and had recovered from anesthesia. Rectal temperature, heart rate, respiratory rate, urine and feces production, attitude, posture, ambulation, and catheter patency were monitored and recorded at 2 and 4 hours after surgery. Food was offered at the 4-hour postsurgical evaluation, and appetite was assessed.

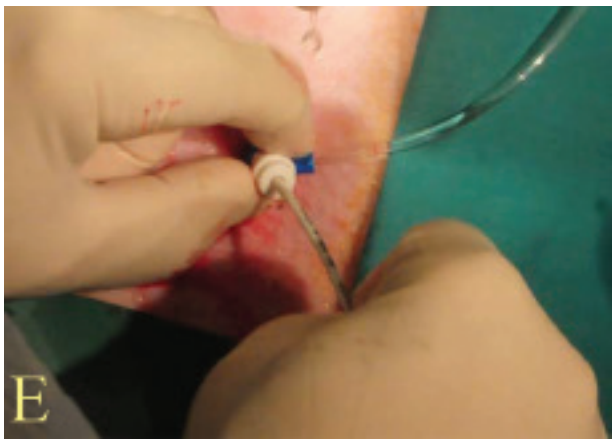
Veterinary staff performed a physical examination on each pig within 1 to 2 days after catheter placement, 1 to 2 days prior to study initiation, and at any time an adverse health observation was noted by animal care staff or study personnel. A physical examination included measurement of rectal temperature and evaluation of the respiratory, cardiovascular, and gastrointestinal systems and overall general health.

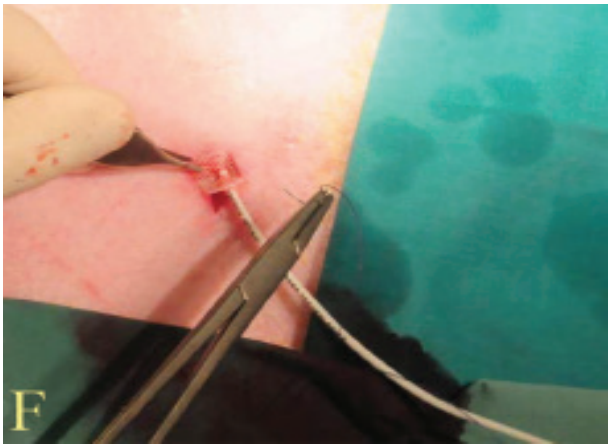












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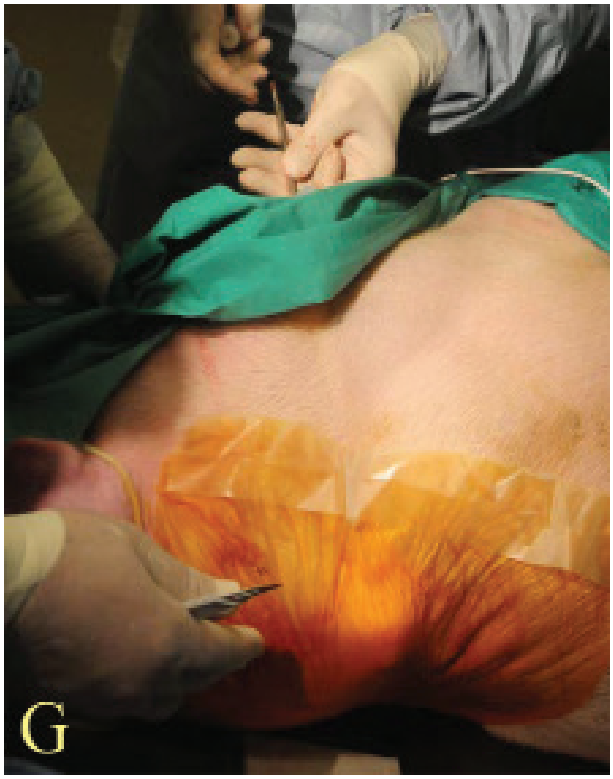
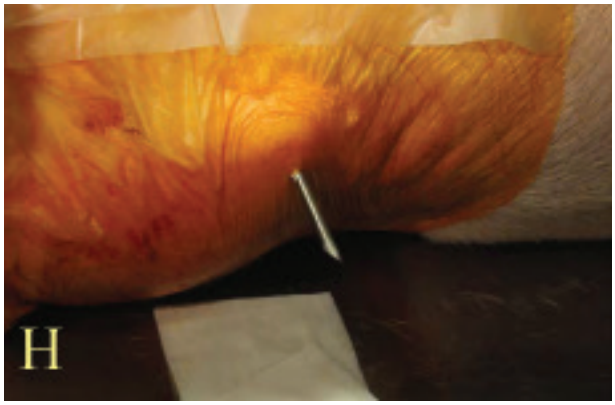
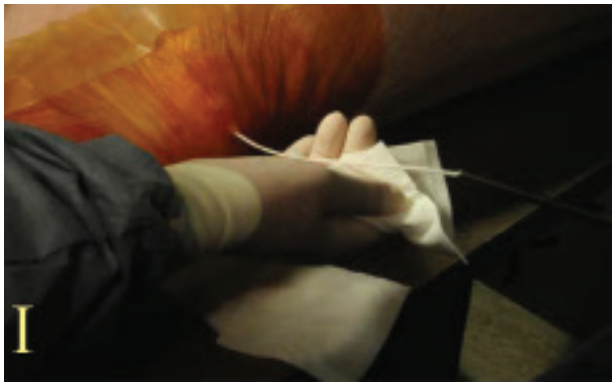
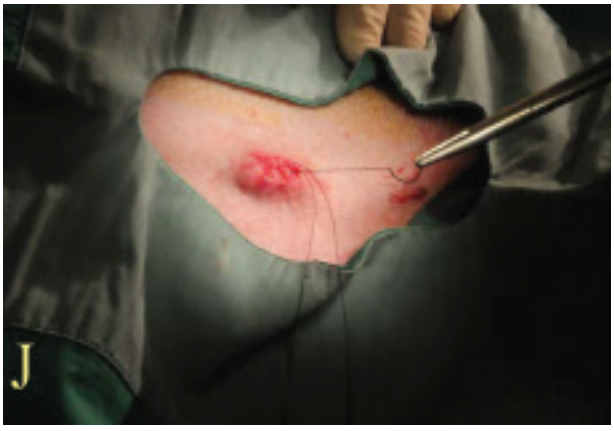
Catheter maintenance

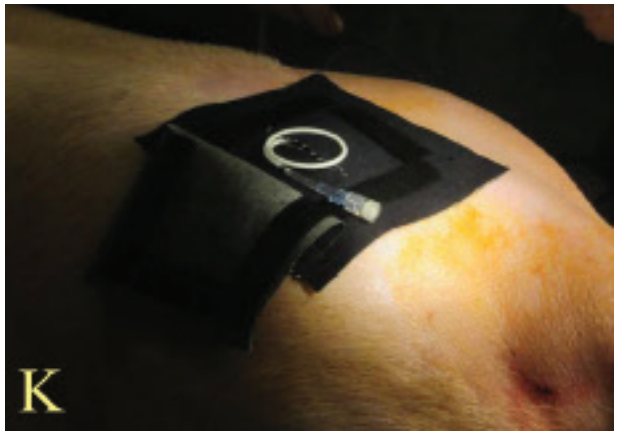
All catheters were flushed twice daily with 10 mL of saline solution in prefilled syringes[w] followed by 10 mL of heparin lock solution[w] (10 U of heparin/mL of saline solution) until study initiation and following each blood sample collection after study initiation. Catheters remained patent, and 60 mL of blood was collected from each pig 1 hour before and 1, 3, 6, 8, and 24 hours after study initiation **(Figure 2)**.











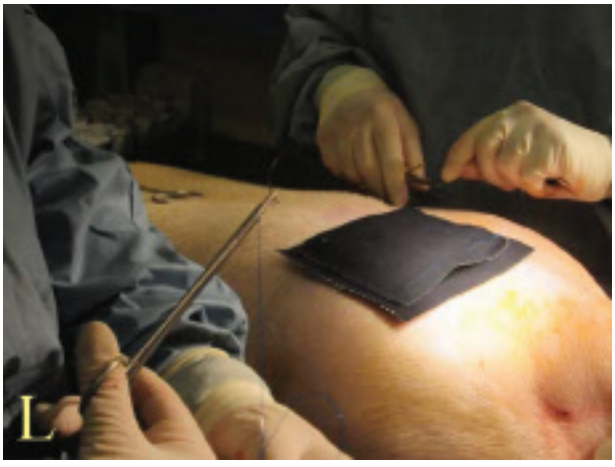


Figure 1—Photographs and ultrasonographic images that depict a novel minimally invasive ultrasound-guided technique for central venous catheter placement via the EJV that was used in 96 Landrace–Poland China crossbred barrows with a mean weight of 70 kg. A—Pigs were anesthetized, and the catheter entry and exits sites were aseptically prepared in a routine manner. The pig was positioned in a 30° Trendelenburg position with both forelimbs retracted caudally and secured so that they would not interfere with catheter placement. An ultrasound unit with a vascular venous probe, enclosed in a sterile sheath, was used to visualize the EJV. B—Transverse ultrasonographic image of an EJV immediately before catheterization. C—Transverse ultrasonographic image of an EJV as an 18-gauge, 7-cm-long, percutaneous-entry, thin-walled needle was introduced into the lumen. Notice that the vessel was compressed as the needle enters the vascular lumen. Care was taken to ensure that the needle tip remained within the ultrasound field of view at all times. D—A 5-mL, slip-tip syringe was attached to the needle hub, and blood was aspirated into the syringe to confirm that the needle was in the lumen of the EJV.

Figure 1 legend appears on the next page

Figure 1 (continued)—Then a flexible guidewire (diameter, 0.038 cm; length, 11 cm) was passed through the the thin-walled needle and advanced into the vessel lumen. The thin-walled needle was removed. An introducer was threaded over the flexible guidewire, and the guidewire was removed. E—A 7F, 83.3-cm-long, rounded-tip, radiopaque silicone catheter fed on a guidewire was inserted through the introducer until the catheter tip was estimated to be located in the cranial vena cava near the cranial aspect of the right atrium. The guidewire was removed, and an 18-gauge, 5-cm curved feeding needle was connected to the free end of the catheter to provide access to the catheter lumen. The catheter was flushed with 5 mL of heparinized saline solution (1,000 U of heparin added to 500 mL of sterile saline [0.9% NaCl] solution). If the heparinized saline solution did not flush through the catheter easily, the catheter was retracted a short distance or gently rotated until it did. F—Two moveable beads and a moveable disk were threaded onto the catheter as far as possible, and the disk was secured to the deep fascia with 3-0 antibacterial-coated polyglactin 910 suture. The pig was repositioned into lateral recumbency on the side contralateral to the side on which the catheter was placed. The catheter was again flushed with heparinized saline solution to ensure that it remained patent. G—A custom-made, 38-cm-long stainless steel trocar (cannula diameter, 6.7 mm; obturator diameter, 4.0 mm) with a slight curvature was used to create a tunnel through the subcutaneous tissue. The trocar was inserted at the cranial aspect of the catheter as it exited the EJV and was advanced through the subcutaneous tissue in a caudodorsal direction until it exited the skin near the dorsal midline between the dorsal borders of the scapulae. H—The obturator was removed from the cannula, and the feeding needle was removed from the catheter. The free end of the catheter was passed through the cannula. I—The cannula was removed from the exit site, leaving the catheter in place. The catheter was again flushed with heparinized saline solution to ensure it was patent. J—The subcutaneous and subcuticular tissues over the catheter insertion site in the EJV were sutured closed. K—A felt cuff was threaded onto the end of the catheter and pushed through the skin incision near the dorsal midline. A pigtail catheter extension was connected to the catheter and closed with a cap. The skin around the catheter exit site was closed with 0 polypropylene suture; 1 mL of penicillin G procaine was injected in the subcutaneous tissues before placement of the last skin suture. The catheter was secured to the skin near the exit site with a suture wing and cover of a 7F catheter. The external portion of the catheter was threaded through a hole in a custom-made denim patch (10 X 10 cm), which was secured to the dorsal aspect of the caudal portion of the neck with skin sutures. L—The denim patch had a flap (7.6 X 7.6 cm) that could be closed and secured with 2 pieces of self-fastening nylon fabric to protect the catheter when it was not being used.

Blood sample collection and analysis

From each pig, the clinical veterinarian collected blood from the indwelling catheter into blood collection tubes containing EDTA (4.5 mL) and citrate (4.5 mL) prior to study initiation. These blood samples were submitted to an independent laboratory[x] for a CBC and inflammation profiles, including determination of plasma protein and fibrinogen concentrations. All test results were within established reference limits for all pigs.

Euthanasia and necropsy

Following completion of blood sample collection 24 hours after study initiation, all pigs were euthanized with 12 mL of euthanasia solution[y] IV via the indwelling catheter. The pigs were euthanized in groups of 2. Two veterinarians (OAC and RG) performed complete necropsies on all pigs as soon as possible after death was confirmed. Gross findings were recorded. Tissue specimens were collected from areas associated with the indwelling catheter (entry and exit sites and midcatheter region), jugular vein, and cranial vena cava as well as from the heart, lungs, liver, spleen, kidney, prescapular lymph nodes, and adrenal glands. Additional specimens of grossly abnormal tissues were collected when present. All tissue specimens were placed in neutral-buffered 10% formalin for fixation.

Fixed tissue specimens were processed, embedded in paraffin, cut into 3- to 5-µm-thick sections, and stained for histologic evaluation in a routine manner. All tissue specimens were histologically evaluated by a diplomate of the American College of Veterinary Pathology (DR).

Figure 2—Photograph depicting blood being collected from a central venous catheter that was placed as described in Figure 1. The catheter was placed in this pig 8 days before this photograph was obtained. Notice that the pig appears calm and the blood sample is being obtained without the animal being restrained owing to extensive socialization to accustom the pigs to interaction with humans prior to catheter placement.

Data analysis

Descriptive data were generated. No formal statistical analyses were performed.

Results

The minimally invasive, ultrasound-guided catheterization procedure was successful in all 96 pigs.

Ultrasound-guided puncture of the EJV was satisfactory and free of complication in all 96 pigs. For most pigs, the EJV was easily identified and accessed on the first attempt. All needle insertions were double-walled punctures, whereby the needle passed through both walls of the vein and had to be slowly withdrawn while aspirating blood. The right EJV was catheterized in 95 pigs. The left EJV was catheterized in 1 pig because of difficulty in accessing the right EJV. The mean time required for catheter placement (ie, time from first introduction of the needle into the EJV until the catheter wings were sutured to the skin) was approximately 45 minutes for all pigs. The time required for catheter placement decreased over time as the person who was placing the catheter gained experience and was approximately 39 minutes for the last pigs catheterized.

For all pigs, catheters remained secure and patent for a mean of 6 days (range, 4 to 10 days). The duration that the catheters remained in place depended on the experimental schedule and catheter patency. Blood could be easily withdrawn from 95 of the 96 catheters immediately after catheter placement. In 1 pig, blood could not be withdrawn from the catheter until 48 hours after catheter placement even though saline solution and heparinized saline solution could be easily flushed through the catheter immediately after placement and kept the catheter patent until blood could be withdrawn from it. At the time of study initiation, 94 of the 96 pigs had a patent catheter. Two pigs were excluded from the study owing to issues with the catheter that were unrelated to catheter placement. In 1 pig, the catheter stopped working because the pigtail extension became disconnected from it. In the other pig, the catheter stopped working.

During necropsy, 9 of the 96 pigs had gross abscesses at the proximal (n = 5), middle (2), and distal (2) aspects of the subcutaneous catheter tract. Histopathologic observations included fibrin with enmeshed neutrophils and fibroplasia at the margins of the catheter tract. There was myofiber degeneration, regeneration, and dystrophic mineralization in areas where the catheter tract coursed through myofibers. Granulomas were associated with the sutures used to secure the catheter in place on the dorsal aspect of the neck in all 96 pigs. Localized abscess formation was identified near the catheterized EJV in 9 of the 96 pigs; however, the abscess did not breach the wall or alter the diameter of the EJV in any of those pigs. In 20 pigs, there was phlebitis and fibroplasia in the cranial vena cava.

Discussion

The purpose of the present report was to describe a novel minimally invasive catheterization technique that combined ultrasound-guided vascular access, introduction of a guidewire into the vessel, and advancement of a catheter over the guidewire without a large incision or performing a cutdotwn procedure on the vessel. This technique was developed to facilitate collection of serial blood samples from conscious unrestrained pigs and minimize the potential for environmental contamination of the catheter. The technique was successfully used for catheter placement in 96 pigs, which suggested that it can be used as an alternative to a surgical cutdown procedure for routine catheter placement.

The minimally invasive ultrasound-guided catheterization technique was used to place an indwelling catheter in an EJV of 96 anesthetized barrows that weighed approximately 70 kg. The catheters remained in place and patent for a mean of 6 days (range, 4 to 10 days). The research protocol that prompted development of this catheterization technique required serial collection of up to 12 blood samples without catheter-induced inflammation. In a research setting, a surgical cutdown procedure is typically used to catheterize an EJV. In our situation, surgical dissection of the tissues surrounding the EJV to access the vessel would have likely caused an inflammatory response that was unsuitable for the intended study. In 2 previous (unpublished) studies conducted in our laboratory, catheters in the EJVs of unsedated pigs were secured with elastic bandages, and those bandages had to be replaced often throughout the experiments owing to vascular leakage and swelling. The approach described for securing the catheters in the pigs of this report was an improvement on the use of elastic bandages.

In another study,[12] an ultrasound-guided technique was described for placement of a catheter in an EJV of adult Yorkshire crossbred pigs that were anesthetized for catheter placement and during the subsequent 24 hours while the catheters were maintained. The pigs of the present report were anesthetized during catheter placement but were awake and unsedated for up to 10 days while the catheters were maintained. In yet another study,[13] a modified surgical cutodwn method was used to catheterize an EJV of anesthetized grower pigs (mean ± SD body weight, 60 ± 2 kg). The pigs of that study[13] were allowed to recover from anesthesia, and catheters were maintained and remained patent for 72 hours. The mean time required for catheter placement was 65 minutes for the pigs of that study.[13] For the pigs of the present report, the mean time required for catheter placement was 45 minutes. However, after the first 30 pigs, we reduced the time required for catheter placement to ≤ 39 minutes by performing some presurgical processes while the pigs were still in the holding pen. For example, we applied an iodine-impregnated adhesive drape[n] over the catheter exit site on the dorsal midline immediately prior to initiation of the procedure instead of during the procedure after the pig was repositioned into lateral recumbency.

During development of the catheterization technique described in the present report, the primary consideration was the large volume (> 10 mL) of blood that needed to be collected at each sample ac-

quisition time. Secondary considerations were the need for easy catheter access without causing stress to the pigs and the need to minimize inflammation associated with catheter placement. The technique described in the present report met those requirements. In particular, the use of ultrasound guidance to access the EJV eliminated damage to the vessel and surrounding tissues, thereby minimizing the inflammation caused by catheter placement.

Vascular access ports facilitate serial collection of blood samples, but their use is often complicated by infections and fibrin deposition.[14] Prophylactic use of antimicrobials and anti-inflammatories during VAP implantation can help ensure asepsis and reduce swelling, wound tension, and tissue necrosis.[14] Catheterization of the pigs described in the present report was performed to investigate the effects of various endotoxin doses on inflammatory indices; therefore, anti-inflammatories could not be administered to the pigs. Vascular access ports are often used for small domestic pigs[15–17] or miniature pigs[14,18,19] that are generally restrained in a sling for blood sample collection.[20] Use of a sling immobilizes a pig and permits repeated percutaneous needle insertions into the VAP. However, use of a sling to immobilize larger pigs, such as those described in the present report, is not practical. It is also not practical to repeatedly restrain large pigs for collection of serial blood samples because the stress induced by both restraint and repeated needle sticks would alter blood concentrations of stress biomarkers (eg, cortisol).

In a previous study[21] conducted in our laboratory, a minimally invasive ultrasound-guided technique was used to provide vascular access in pigs. That technique involved exteriorization of the cannula, which was secured to the pig by flexible tape, which was wrapped around the pig's neck.[21] Although that technique, along with extensive socialization of the pigs, allowed easy collection of large volumes of blood (approx 50 mL/sample acquisition time), it was not without problems. Chief among those issues was ensuring that the flexible tape constantly covered the catheter insertion site. Moreover, once inflammation was experimentally induced, some pigs developed peripheral edema, leading to profound constriction of the tape around the neck, which necessitated frequent replacement of the tape throughout the sampling period.

The catheterization technique described in the present report did not involve the use of flexible tape wrapped around the animal's neck to secure the catheter in place; thus, we did not have to deal with the aforementioned problems associated with it. The technique described in this report also had some advantages over VAP implantation. Insertion of a VAP requires incision and dissection of tissues at the implantation site and to access the EJV, resulting in fairly extensive inflammation. The technique described in this report did not require such extensive tissue trauma, and inflammation was minimal, which obviated the need for anti-inflammatory administration. Also, pigs appeared to have less discomfort and recovered quicker following the catheterization technique described in this report, compared with after VAP implantation. Insertion of a catheter instead of a VAP eliminated the need to apply topical transdermal analgesic to the skin overlying the VAP to desensitize the area prior to each sample collection. Extensive socialization of the pigs prior to catheter placement allowed blood samples to be collected while the pigs were unrestrained. This method combined with the minimal time required for catheter maintenance and aforementioned advantages of catheter placement by a minimally invasive ultrasound-guided technique relative to VAP insertion make the described technique an attractive alternative for maintaining vascular access for several days. However, insertion of a VAP allows vascular access to be maintained for long periods of time.[20]

In another study,[22] long-term central venous catheters were percutaneously inserted in 4 pigs with body weights ranging from 24 to 30 kg. The percutaneous approach minimizes damage to tissues adjacent to the cannulated vessel and the vessel itself.[23] Patient recovery following percutaneous catheter placement is shorter than after catheter placement by an open surgical approach,[22] and the lack of surgical trauma minimizes the inflammatory response and release of cytokine mediators.[12]

In human medicine, the use of ultrasound guidance to achieve vascular access reduces complications, improves first-attempt and overall cannulation success rates, and reduces the number of cannulation attempts and time required to achieve successful cannulation, compared with percutaneous catheterization by use of anatomic landmarks only or acoustic Doppler ultrasonography.[10] In human patients, the internal jugular vein is ultrasonographically distinguishable from the carotid artery because it is compressible rather than pulsatile; it also becomes visibly distended when the patient is positioned in the Trendelenburg position or the Valsalva maneuver is performed.[11] Likewise, for the pigs of the present report, the EJV was compressible and not pulsatile on ultrasonographic examination and became visibly distended when the pigs were positioned in the Trendelenburg position. Additionally, as with human patients undergoing catheterization of the internal jugular vein, positioning of the head was crucial for successful catheterization of the EJV for the pigs of the present report. We observed that extreme contralateral rotation of the head decreased the diameter of the EJV. Correct positioning of the pig's head while it was in a 30° Trendelenburg position maximized the diameter of the EJV during ultrasonographic evaluation of the vessel in the transverse plane.

The catheterization technique described in the present report requires that asepsis be maintained to the extent possible, including placement of the ultrasound transducer and cord in a sterile sheath. It

also requires that the probe be maneuvered with the nondominant hand so that the dominant hand can be used to insert the needle into the EJV. Needle placement was guided by ultrasonographic imaging rather than anatomic landmarks. Accuracy of vascular access was improved when the needle tip was visualized within the lumen of the EJV on ultrasonographic images.[24]

Patient anatomy and anatomic variations can be visualized in real time by use of 2-D ultrasonography. The ability to visualize the needle path and tip directly into the lumen of the target vessel improves successful cannulation overall and on the first attempt and decreases mechanical complications associated with vascular access procedures.[10] For the pigs of the present report, passage of the introducer needle into the EJV was visualized on the transverse (short-axis) view. Use of the transverse view to visualize needle tip placement was a benefit because the generalized view could be quickly learned and accessed by the operator. It is crucial that the advancing tip of the needle be followed by ultrasonographic imaging, with care taken to ensure that the ultrasound plane was not too proximal or distal.[11]

Passage of an introducer needle into a blood vessel can be ultrasonographically visualized on either a transverse (short-axis) or longitudinal (long-axis) view, and it can be easier to visualize in small vessels, compared with large vessels. The primary advantage of the longitudinal view is that it allows better visualization of the advancing needle tip, which may reduce the risk for perforation of the posterior vessel wall and is the reason that the longitudinal view is recommended for ultrasound-guided catheter placement in human medicine. Although passage of the needle was ultrasonographically visualized on the transverse view for the pigs of the present report, the carotid artery was not inadvertently punctured during any of the 96 catherization procedures performed.

In another study,[23] a blind (ie, without ultrasound guidance) percutaneous approach was used to quickly and easily catheterize the EJV and achieve central venous access in piglets. However, the investigators of that study[23] reported occasional inadvertent puncture of the right carotid artery, hematoma formation, and premature clotting associated with that blind technique. For the pigs of the present report, the ultrasound-guided catheterization technique did not result in hematoma formation, inadvertent puncture of the carotid artery, or precipitous or unexpected clotting prior to insertion of the guidewire. Additionally, the introducer needle did not need to be flushed with saline solution to initiate insertion of the guidewire in any of the 96 pigs.

The ultrasound-guided catheterization technique described in the present report led to successful placement of a catheter in the cranial vena cava without complication in all 96 pigs. In another study[25] in which ultrasound guidance was used for placement of central venous catheters in 22 pigs with a mean ± SD body weight of 51.1 ± 4.3 kg, the catheter could not be successfully positioned in the cranial vena cava because of deviation of the guidewire into thoracic limb veins in 6 pigs.

None of the 96 pigs of the present report developed signs of systemic infection following catheter placement. The catheter became prematurely dislodged in only 1 pig. During necropsy, localized abscesses were observed along the subcutaneous catheter tract in 9 pigs, which was controlled with local administration of antimicrobials. Evidence of phlebitis and fibroplasia was observed in the cranial vena cava of 20 pigs. The pigs were administered endotoxin as part of the experimental protocol, and it is possible that the phlebitis was a localized response to the endotoxin.

In pigs, ultrasound-guided catheterization techniques have been successfully used to achieve vascular access to the EJV[12] and common carotid artery.[24] The minimally invasive ultrasound-guided catheterization technique described in the present report led to successful placement of central venous catheters in 96 pigs. Only a small proportion of pigs developed minor complications following catheter placement. The catheters remained patent for a mean of 6 days (range, 4 to 10 days). The catheters, in combination with extensive socialization of the pigs, allowed serial collection of fairly large volumes (> 10 mL) of blood with minimal stress to the animals, which facilitated study procedures and enhanced research results.

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Footnotes

a. Archer Farms, Darlington, Md.
b. Complete grow-finish feed with phytase, Keystone Mills, Ephrata, Pa.
c. Prima-Treats, Bio-Serv, Fleming, NJ.
d. VetOne, Boise, Idaho.
e. iU22, Phillips, Bothell, Wash.
f. C8-5 transducer, Phillips Healthcare, Bothell, Wash.
g. Bayer Corp, Shawnee, Kan.
h. Zoetis Inc, Kalamazoo, Mich.
i. Neogen Corp, Lexington, Ky.
j. Fort Dodge Animal Health, Parsippany, NJ.
k. QC Supply, Schuyler, Neb.
l. Cetylite Industries, Pennsauken, NJ.
m. Covidien, Mansfield, Mass.
n. Ioban 2 antimicrobial incise, 3M Corp, Saint Paul, Minn.
o. Cook, Bloomington, Ind.
p. Avanti Introducer, Cordis Corp, Fremont, Calif.
q. Access Technologies, Skokie, Ill.
r. GW35100 guidewire, Mila International Inc, Florence, Ky.
s. 3-0 Vicryl PLUS, Ethicon, Johnson & Johnson, New Brunswick, NJ.
t. IV Catheter Adapter Surflo Injection Plug Luer Lock, Terumo Medical Corp, Somerset, NJ.
u. VetriPen G, Bimeda Inc, Oakbrook Terrace, Ill.
v. Velcro fastener, Velcro Co, London, England.
w. Becton-Dickinson, Franklin Lakes, NJ.
x. Antech Diagnostics, Oak Brook, Ill.
y. Euthasol, Virbac Animal Health, Bridgeton, Mo.

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