Potential applications of interventional radiology in veterinary medicine

Chick W. Weisse, VMD, DACVS; Allyson C. Berent, DVM, DACVIM; Kimberly L. Todd; Jeffrey A. Solomon, MD, MBA

Following the description of percutaneous arterial catheterization by Seldinger in the 1950s, angiography developed into a widely used and essential diagnostic tool in human medicine. Technologic advances have since helped transform this diagnostic modality into a sub-specialization with enormous therapeutic potential. Interventional radiology involves the use of contemporary imaging techniques such as fluoroscopy and specialized equipment such as catheters, guidewires, and stents for therapeutic purposes. The field has grown considerably over the past 20 years, and many IR techniques are considered the gold standard for treatment of various conditions in human patients.

Although IR techniques would also seem to be applicable to veterinary medicine, they currently have not been widely adopted. Techniques that have been described include coil embolization for treatment of patent ductus arteriosus, stenting for treatment of tracheal collapse, coil embolization of the carotid and maxillary arteries for treatment of hemorrhage associated with mycosis of the auditory tube diverticula in horses, and coil embolization for treatment of intrahepatic PSSs in dogs. Other techniques that have been described in human medicine could potentially have applicability in veterinary medicine, although many are still investigational at this time. The purpose of the present review was to provide an overview of IR in veterinary medicine, including potential advantages and disadvantages and a description of the equipment that is needed. Although there is an overlap between IR and interventional cardiology, techniques involved with interventional cardiology are beyond the scope of the present review.

Advantages and Disadvantages of IR

In veterinary patients, IR offers a number of potential advantages, compared with more traditional treatment modalities. These techniques are minimally invasive and can, therefore, be associated with lower perioperative morbidity and mortality rates, shorter anesthesia times, and shorter hospitalization times. Techniques that are less equipment intensive can also potentially be associated with lower costs. In addition, some techniques, such as chemoembolization of tumors and palliative stenting of malignant obstructions, offer treatment options for patients with conditions that may not be amenable to standard treatments or for whom standard treatments are associated with excessive morbidity rates, high costs, or poor outcomes.

The primary disadvantages of IR include the technical expertise and specialized equipment that are required and the capital investment necessary to maintain a suitable inventory of catheters, guidewires, balloons, stents, and coils.

Equipment and Technique

Because most IR procedures are minimally invasive (ie, they are performed through natural orifices or small holes in the skin), use of traditional sterile operating rooms is not required, although ideal. Most of these procedures are performed in clean angiography suites. Entry sites receive a traditional sterile scrub, and operators wear lead aprons, lead thyroid shields, radiation dosimeter badges, caps, gowns, and masks. Radiation exposure during these procedures can be minimized by following guidelines for the lowest exposure that is reasonably achievable. The operator should review radiation safety protocols to minimize exposure time and ensure proper collimation, source-to-image distance, and shielding.

For many of the more commonly performed IR procedures, a traditional fluoroscopy unit is sufficient. A C-arm fluoroscopy unit has the advantage that multiple tangential views can be obtained without moving the patient. Occasionally, ultrasonography is useful for percutaneous needle access into vessels and other structures. Digital subtraction angiography involves using specialized computer software to manipulate fluoroscopic images and produce high-resolution images with a minimum amount of contrast agent, which often is important in smaller veterinary patients. In particular, digital subtraction angiography is required for super-selective angiography of small-caliber vessels and for angiography of vessels in the head or where there is substantial overlying bone making visualization difficult.

Abbreviations

IR Interventional radiology
PSS Portosystemic shunt

From the Department of Clinical Studies-Philadelphia, School of Veterinary Medicine, University of Pennsylvania; Philadelphia, PA 19104 (Weisse, Berent, Todd, Solomon); and the Section of Vascular and Interventional Radiology, Department of Radiology, Hospital of the University of Pennsylvania; Philadelphia, PA 19104 (Weisse, Solomon). Address correspondence to Dr. Weisse.
Before performing these procedures, the operator should be familiar with basic IR equipment, including guidewires, dilators, vascular sheaths and introducers, angiography catheters, stents, and embolic agents. There is a relative abundance of information available through various medical textbooks, although little information currently exists in the veterinary literature. Endoscopy can also be used in combination with fluoroscopy for various minimally invasive procedures, and this modality is termed interventional endoscopy. These endoscopic techniques are facilitated by the use of fluoroscopy to aid in the placement of guidewires, catheters, and stents. Endoscopes that are used for interventional endoscopy techniques include rigid cystoscopes (ranging from 1.9 to 7 mm in diameter), flexible ureteroscopes (ranging from 2.7 to 3.4 mm in diameter), nephrosopes (ranging from 5.3 to 7.3 mm in diameter), and side-view duodenoscopes (ranging from 7.5 to 11 mm in diameter).

**Current Veterinary Applications of IR**

Transarterial embolization for treatment of hemorrhage or vascular malformations—Veterinary patients occasionally suffer from hypovolemic shock as a result of severe hemor rhage secondary to a number of various causes, including neoplasia, coagulopathy, gastrointestinal tract ulceration, and trauma. In most cases, standard medical and surgical procedures can be used to stabilize the condition of these animals. Occasionally, however, standard methods fail and alternatives are necessary.

For example, severe epistaxis can typically be managed conservatively, but there are few options once bleeding becomes intractable. Ligation of the common carotid arteries may temporarily control clinical signs, but bleeding may recur once a collateral blood supply develops and further treatment is not available. Importantly, so long as the underlying cause of epistaxis persists, the patient remains at risk for bleeding. An alternative to carotid artery ligation that permits repeated treatments if necessary is super-selective embolization of the arterial supply of the affected vascular bed. Transarterial embolization entails selective, catheter-directed delivery of particulate material to induce thrombosis, control hemorrhage, occlude vascular malformations, or reduce tumor growth. Under fluoroscopic guidance, a catheter advanced through the femoral artery is used to super-selectively catheterize the maxillary artery. Polyvinyl alcohol particles are then injected through the catheter to embolize the nasal blood supply. This causes a mechanical obstruction to blood flow, induces thrombosis, and decreases pressure in the capillary bed that causes hemorrhage. This technique has been successfully performed in veterinary patients with intractable epistaxis secondary to severe rhinitis, neoplasia, inherited thrombocytopenia, and vasculitis. In addition, because the carotid artery remains patent, the procedure can be repeated in the future if necessary. Similar transarterial embolization techniques are used in human patients to treat severe, life-threatening hemorrhage secondary to trauma, infection, neoplasia, or other causes.

Clinically important vascular communications between an artery and vein are uncommon in veterinary medicine but can develop as a result of trauma or neoplasia (eg, arteriovenous fistulas) or may occur congenitally (eg, arteriovenous malformations or multiple arteriovenous fistulas). These vascular anomalies can cause various clinical signs depending on their anatomic location and the amount of blood flow. Those in peripheral locations are typically characterized as palpable, pulsatile vascular dilatations that can cause se-
vere hemorrhage if traumatized. In contrast, congenital arteriovenous malformations in the liver can result in severe portal hypertension, multiple acquired PSSs, and profound ascites. Surgical resection of these anomalies can be complicated, owing to their vascular nature and the fact that they can recur if incompletely resected. The periprocedural mortality rate associated with resection of hepatic arteriovenous malformations has been reported to be approximately 30%.\(^6\) Interventional radiology techniques that permit percutaneous embolization of these vascular anomalies with cyanoacrylate glue can result in complete occlusion, obviating the need for invasive and potentially life-threatening surgery (Figure 1).\(^8\)

**Thrombectomy**—In cats, aortic thromboembolism is a painful, debilitating, life-threatening condition. It is most common in cats with underlying heart disease and occurs when a thrombus develops in the left atrium and embolizes to the aortic trifurcation, resulting in various degrees of hind limb paresis, hind limb paralysis, and shock. Approximately 50% of affected cats have congestive heart failure, making them poor candidates for surgical thrombectomy, and treatment with thrombolytic drugs such as streptokinase or tissue plasminogen activator has not been associated with any improvements in the survival rate, compared with conservative management. In a recent report,\(^9\) however, use of an interventional technique called rheolytic thrombectomy was associated with successful thrombectomy in 5 of 6 cats. Although only 3 cats survived to the time of discharge, findings did indicate that the technique can be used to rapidly and successfully remove thrombi and restore perfusion. Given the arteriographic improvement that can be seen (Figure 2), it is possible that as the technique is refined, clinical outcomes will also improve.

**Percutaneous transvenous coil embolization of congenital intrahepatic PSSs**—Portosystemic shunts are anomalous vascular communications between the portal venous and systemic circulations that result in various neurologic, biochemical, and hemato logic abnormalities. Single extrahepatic PSSs are often amenable to surgical attenuation, with a reported rate for a good or excellent outcome of 94%.\(^10\) In contrast, single intrahepatic PSSs are often more difficult to treat surgically, with techniques for intrahepatic PSS attenuation that have been described ranging from careful dissection of the liver around the shunting vessel to technically demanding and complicated procedures involving temporary vascular hepatic inflow occlusion and intravascula

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**Figure 3**—Fluoroscopic and radiographic views obtained during percutaneous transvenous coil embolization of an intrahepatic PSS in a dog. A—Digital subtraction venogram obtained following administration of contrast medium through the jugular vein illustrating the portal vein (PV), shunt (PSS), and caudal vena cava (CVC). B—Digital subtraction venogram obtained following administration of contrast medium through 2 jugular vein catheters illustrating the shunt entrance into the CVC. A marker catheter used to adjust for radiographic magnification is visible. C—Radiograph obtained following deployment of a metal stent in the CVC at the level of the shunt orifice. D—Digital subtraction venogram obtained following administration of contrast medium through a catheter passed through the stent interstices into the shunt illustrating appropriate stent positioning. E—Digital subtraction venogram obtained following placement of multiple thrombogenic coils (white arrows) within the shunt. F—Radiograph illustrating final position of caval stent and coils prior to catheter removal.

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minimally invasive IR techniques, thus avoiding risks associated with surgical removal or with leaving the foreign body in place. As has been reported in human medicine, the increased use of vascular access and implantable devices in veterinary patients will likely result in an increased frequency of dislodged or migrated vascular foreign bodies.

Stent placement for treatment of tracheal collapse—Tracheal collapse is a progressive, degenerative disease of the cartilage rings in which hypocellularity and decreased glycosaminoglycan content leads to dynamic tracheal collapse during respiration. This is a condition of predominantly middle-aged, small and toy breed dogs. Clinical signs can range from a mild, intermittent cough to severe respiratory distress associated with dynamic upper airway obstruction. In many affected dogs, medical treatment with anti-inflammatory drugs, cough suppressants, and bronchodilators is palliative. Candidates for surgical treatment are those in which medical treatment has failed.

Various surgical techniques for the treatment of tracheal collapse have been described, with the currently recommended surgical treatment involving extraluminal placement of polypropylene prostheses around the trachea. In a previous study, the technique was successful in reducing the severity of clinical signs in 75% to 85% of 90 dogs with tracheal collapse. It is, however, not without complications, and in that study, 5% of animals died in the perioperative period, 11% developed laryngeal paralysis after surgery, 19% required a permanent tracheostomy, and approximately 23% died of respiratory tract problems, with a median survival time of 25 months. More importantly, although the extrathoracic portion of the trachea was involved in all of the dogs in the study, the intrathoracic portion of the trachea was involved in only 11% of the dogs. The authors advised against using this technique in animals with intrathoracic tracheal collapse because the associated morbidity rate was unacceptably high.

Owing to the high morbidity rates associated with surgical methods for treating tracheal collapse in dogs, various methods have been investigated for placement of intraluminal stents, including balloon-expandable and self-expanding stents. Clinical improvement has been reported in 75% to 90% of dogs treated with self-expanding, intraluminal stainless steel stents. Immediate complications were mostly minor, although there was a perioperative mortality rate of approximately 10%. Late complications included stent shortening, excessive granulation tissue, progressive tracheal collapse, and stent fracture.

Advantages of intraluminal tracheal stenting include the fact that it is minimally invasive and does not require dissecting around peritracheal neurovascular structures, is associated with shorter anesthesia times, and provides access to the entire intrathoracic portion

![Figure 4](image)

![Figure 5](image)
of the trachea. Although most intraluminal tracheal stents are placed under fluoroscopic guidance, some are now placed under endoscopic guidance. The search for a better intraluminal tracheal stent continues, and long-term studies will be necessary to determine late effects of these stents on the trachea and whether progression of tracheal collapse can be prevented or delayed through earlier intervention.

Palliative stenting for treatment of benign stenoses—In contrast to the dynamic obstruction often found in association with tracheal collapse, animals can also develop fixed obstructions in association with congenital (eg, nasopharyngeal stenosis) and acquired (eg, nasopharyngeal stenosis, esophageal stricture, and urethral stricture) conditions. Historically, stenting has been avoided in human patients with benign stenoses because of the potential risk of long-term complications such as stricture and granulation tissue formation or stent fracture. Removable and, more recently, bioabsorbable stents have been developed to help avoid these potential long-term complications, leading to reevaluation of the use of palliative stenting for treatment of benign stenoses. Balloon dilation under endoscopic or fluoroscopic guidance remains the standard of care for veterinary patients with benign strictures in most locations, particularly those with strictures not amenable to surgical excision or repair. However, in instances when balloon dilation fails or the owner is reluctant to have the animal undergo repeated procedures, palliative stenting may be a useful alternative. The authors have used IR techniques for palliative stenting of benign strictures involving the airway,24 esophagus,24 nasopharynx,25 colon, and urethra when conventional treatments failed or were declined.

Retrieval of tracheobronchial foreign bodies—Interventional radiology techniques may be useful for retrieval of obstructive tracheal or bronchial foreign bodies, particularly in small patients in which surgery or endoscopy would be dangerous or in which tracheal diameter restrictions would necessitate extubation before tracheoscopy or bronchoscopy could be performed. Interventional radiology techniques allow retrieval of foreign bodies under fluoroscopic guidance through the use of snares or stone baskets advanced through a bronchoscope adapter and endotracheal tube while a complete anesthetic circuit is maintained.25

Antegrade urethral catheterization—Urethral catheterization is typically a fairly simple and routine procedure in veterinary patients that is primarily used to monitor urine output, establish urine drainage in patients that are recumbent or have mechanical or functional urethral obstructions, or provide urethral patency following urethral or urinary bladder surgery. Occasionally, standard retrograde catheterization can be difficult in small female patients and in cats with urethral tears secondary to trauma or following attempts to remove urethral obstructions. Under fluoroscopic guidance, a guidewire is advanced through the cystoscopie catheter and passed antegrade into the bladder and through the urethra until it exits the penis or vulva. A urinary catheter is advanced over the guidewire in a retrograde fashion into the urinary bladder, and the guidewire is removed. The urinary catheter is secured in place in a routine fashion.
Cytospectroscopic treatment for idiopathic chylotorax—In animals with idiopathic chylotorax, the pleural space fills with a chylous effusion, resulting in dyspnea and sclerosing pleuritis if left untreated. Numerous surgical techniques for treatment of idiopathic chylotorax have been described,32–34 and success rates and degree of invasiveness vary. In addition, a thoracoscopy treatment method has been described.31 In humans, glue embolization of the thoracic duct with cyanoacrylate has been used to treat chylothorax.32,33 This technique has been evaluated experimentally in animals and has been used in a small number of clinical patients.32,35 The technique is performed under fluoroscopic guidance and involves performing lymphangiography with subsequent embolization of the cisterna chyli and thoracic duct with cyanoacrylate (Figure 6). Cyanoacrylate embolization may be a viable primary treatment in animals with idiopathic chylotorax or a useful follow-up treatment in animals in which a previous surgical attempt has failed.

Placement of percutaneous drainage (cystostomy, nephrostomy, and choledocystostomy) tubes—Cystostomy tubes are regularly placed during surgery to manage veterinary patients with urinary obstructions or to divert urine away from a traumatized urethra. Occasionally, these patients are severely debilitated, and even a relatively short period of general anesthesia would be dangerous. Thus, various techniques have been developed to quickly and safely place cystostomy tubes through a percutaneous approach. Locking-loop drainage catheters have been placed within the peritoneal cavity, thoracic cavity, kidneys, and gallbladder for similar purposes in veterinary patients (Figure 7). These tubes can be placed via palpation alone or with fluoroscopic or ultrasound guidance and can be placed in an emergency room setting.

Ureteral stenting—Ureteral stenting can be useful in patients with ureteral obstruction due to ureterolithiasis or obstructive ureteral or trigonal neoplasia; in patients that have undergone ureteroscopy, percutaneous nephrolithotomy, or retrograde ureteral stone retrieval (ie, basket retrieval or laser lithotripsy); and in patients undergoing ureteral anastomosis or undergoing surgery for treatment of ureteral tears, ureteral spasm, or ureteritis. Ureteral stents have been placed in veterinary patients endoscopically in a retrograde fashion, percutaneously in an antegrade fashion, and manually during open laparotomy.36 The retrograde endoscopic technique is currently under investigation for use in veterinary patients with ureterolith-induced obstructions, particularly in cats (Figure 8).

Percutaneous nephrolithotomy—Nephrolithiasis or obstruction of the proximal portion of the ureter secondary to ureterolithiasis can result in progressive renal insufficiency, intractable pyelonephritis, ureteral colic, and hydronephrosis. Although smaller stones may pass spontaneously; or remain subclinical, larger stones require intervention to relieve the obstruction or avoid permanent nephron damage. Nephroscopy, pyelotomy, and ureterotomy are prolonged, invasive, and complicated surgeries that can potentially be associated with high morbidity rates.36 In humans, percutaneous nephrolithotomy is considered the standard of care for nephroliths or proximal ureteroliths too large to be treated by means of extracorporeal shockwave lithotripsy or retrograde ureteroscopy with laser lithotripsy,37,38 and has recently been performed successfully in 5 clinical veterinary cases by the authors.27 The procedure aims to minimize morbidity rates and preserve as much renal function as possible.39–41

Figure 8—Radiographic images obtained during retrograde ureteral stent placement in a cat with multiple ureteroliths. A and C—Latera and ventrodorsal radiographic views obtained prior to stent placement; notice the bilateral ureteroliths with a large obstructive ureterolith (arrow) in the proximal portion of the right ureter. B and D—Lateral and ventrodorsal radiographic views obtained following placement of a stent (black arrows) extending from the right renal pelvis to the urinary bladder (thin arrows).

Figure 9—Radiographic and fluoroscopic images obtained during percutaneous nephrolithotomy in a dog with a large nephrolith. A—Radiographic image obtained following percutaneous, ultrasound-guided placement of 2 guidewires (white arrows) through the right renal pelvis and into the ureter. A large sheath (black arrow) has been placed over the guidewires to gain access to the renal pelvis and nephrolith (asterisk). B—Radiographic image obtained following advancement of a lithotripter (white arrow) under endoscopic visualization through the sheath to the nephrolith (arrow heads). C—Fluoroscopic image obtained following lithotripsy; notice that the nephrolith is no longer visible. D—Radiographic image obtained following placement of a ureteral stent (white arrows).
function as possible, and success rates for percutaneous nephrolithotomy in adult and pediatric human patients have been reported to range from 90% to 98%, which is substantially higher than reported success rates for extracorporeal shockwave lithotripsy (50% to 81%).

Percutaneous nephrolithotomy requires the use of fluoroscopy, guidewires, balloons, and stents in conjunction with endoscopy and lithotripsy (Figure 9).

Endoscopic retrograde cholangiopancreatography—Endoscopic retrograde cholangiopancreatography involves the use of IR and interventional endoscopy techniques to image the biliary and pancreatic systems for the purpose of diagnosis and treatment of various diseases of these systems.7 In brief, a side-view duodenoscope passed per os is used to cannulate the major duodenal papilla, allowing access to the common bile duct. A sphincterotomy is performed to widen the papilla, and a biliary stent can be placed into the bile duct for decompression of extrahepatic bile duct obstructions. This diagnostic and therapeutic modality is currently being investigated in a research setting in veterinary patients (Figure 10), and findings in 5 healthy dogs have been reported.3

Percutaneous feeding tube placement—Hospitalized veterinary patients commonly require nutritional supplementation because of insufficient caloric intake secondary to vomiting, increased metabolic requirements, severe systemic or gastrointestinal tract disease, or surgery. Nutritional supplementation is routinely provided through nasoenteric tubes, esophageal tubes, percutaneous endoscopically placed gastrostomy tubes, and surgically placed gastrostomy or jejunostomy tubes. Parenteral nutrition can replace these methods but is costly and is associated with risks of catheter infection, hyperglycemia, and electrolyte disturbances. In addition, enteral feedings are preferred when possible because of improved gut mucosal integrity. Unfortunately, some patients cannot tolerate traditional enteral feedings because of severe pancreatitis, intractable vomiting, or decreased mental awareness, and potential complications associated with surgical placement of jejunostomy tubes in these animals can be severe. Recently, a fluoroscopic-assisted method for placement of nasojejunal feeding tubes in veterinary patients has been described,4 and fluoroscopic-assisted placement of esophagojejunalostomy tubes is currently being investigated by the authors (Figure 11).

Intra-arterial chemotherapy—Chemotherapy has a largely palliative role in the treatment of solid tumors in veterinary patients because most pet owners would not accept the complications encountered if their pets received chemotherapeutic drugs at the high dosages necessary to achieve the remission rates obtained in human patients. Intravenous dosages of chemotherapeutic drugs used in veterinary patients are selected to achieve effective plasma concentrations without causing excessive adverse effects. Adverse effects, when they do occur, often result in dosage reductions, which may decrease the chances of achieving tumor control. Importantly, following IV administration of a chemotherapeutic drug, only a small proportion of the drug actually reaches the tumor because of dilution in the bloodstream.

In contrast, use of IR techniques that permit fluoroscopically guided, super-selective catheterization of the arteries feeding the tumor or body region allows for intra-arterial administration of chemotherapeutic drugs directly to the tumor, resulting

![Figure 10](image1) ![Figure 11](image2)
in greater concentrations of the drug reaching the tumor without the adverse systemic effects that would be encountered had the necessary equivalent IV dosage been used. Experimental studies in dogs and rabbits have documented the efficacy of these techniques in achieving higher local drug concentrations and improved tumor remission rates for certain types of tumors. These techniques have been used in veterinary patients with osteosarcomas and are currently being investigated by the authors in dogs with transitional cell tumors of the urinary bladder, urethra, and prostate (Figure 12).

Transarterial embolization for treatment of metastatic disease—The same transarterial embolization techniques used to treat hemorrhage and vascular malformations can be used to treat metastatic lesions throughout the body. Transarterial embolization with polyvinyl alcohol particles and other materials has been performed in veterinary patients to control intractable epistaxis associated with nasal tumors, to reduce hemorrhage associated with nonresectable tumors, and to control pain associated with and slow growth of metastatic tumors. In fact, embolization of metastatic bone lesions in humans has been shown to provide faster analgesia than palliative radiation therapy, with less damage to nearby tissues in certain cases. In theory, certain veterinary patients may benefit from a similar treatment regimen.

Chemoembolization—Chemoembolization involves super-selective, intra-arterial delivery of chemotherapeutic drugs in conjunction with subsequent or simultaneous particle embolization. The rationale for using chemoembolization to treat primary and metastatic tumors of the liver is based on anatomic studies that demonstrated that most hepatic tumors depend on hepatic arterial blood supply (up to 95%) for growth, in contrast to the normal liver parenchyma, which receives most of its blood supply via the portal vein and only approximately 20% from the hepatic artery. Thus, hepatic artery embolization causes more ischemia to the liver tumor than to the liver parenchyma, which obtains sufficient oxygenation from the portal venous blood supply to remain viable. Furthermore, pharmacologic studies indicate that for certain body locations, chemoembolization results in a 10- to 50-fold increase in intratumoral drug concentrations, compared with IV administration.

Particle embolization has a synergistic effect with the intra-arterial delivery of chemotherapeutic drugs because the ischemia it induces in tumor cells inhibits the excretion of the chemotherapeutic drugs, resulting in higher drug concentrations within the cell. This maximizes cell death while minimizing systemic toxicoses. The procedure is most commonly used for treatment of diffuse hepatocellular carcinoma or metastatic liver disease in humans.

With chemoembolization, the chemotherapeutic drug can be mixed with an oily, radiopaque carrier...
Palliative stenting of malignant venous obstructions—Perivascular tumors can occasionally invade a vessel lumen, resulting in vascular occlusion and peripheral edema (eg, obstruction of the vena cava), ascites (eg, obstruction of the hepatic vein), or both. Examples include vascular sarcomas and adrenal gland tumors. The authors have placed self-expanding metallic stents under fluoroscopic guidance across malignant obstructions in 3 animals to relieve vascular occlusions and reduce venous congestion, resulting in profound clinical improvement (Figure 14). Similar findings have been reported for human patients that undergo palliative stenting of malignant obstructions involving the hepatic veins.\textsuperscript{30–32}

Palliative stenting of malignant nonvascular obstructions—Animals are routinely euthanized because of the local effects of tumors, rather than because of systemic effects associated with a large tumor burden. For example, malignant obstructions of the urinary tract associated with transitional cell carcinomas and prostatic tumors can result in life-threatening signs associated with complete urinary tract obstruction. Malignant obstructions in the gastrointestinal tract typically occur secondary to carcinomas or leiomyosarcomas, and clinical signs can include chronic vomiting, weight loss, tenesmus, dyschezia, and constipation, depending on the location of the obstruction. Interventional radiology techniques involving placement of intraluminal stents to palliate similar malignant obstructions in humans have been described.\textsuperscript{2} Palliative stenting procedures in the upper (Figure 15) and lower (Figure 16) portions of the urinary tract, respiratory tract, cardiovascular system, and upper and lower portions of the gastrointestinal tracts to relieve luminal obstructions caused by tumors in animals as small as a ferret have been performed by the authors under fluoroscopic guidance.\textsuperscript{24,33}

**Percutaneous tumor ablation**—Percutaneous tumor ablation techniques, such as radiofrequency ablation as well as microwave ablation, laser thermal ablation, cryoablation, and percutaneous ethanol injection, are being performed commonly in human medicine and have been described in veterinary patients.\textsuperscript{24–30} These procedures are typically performed under ultrasound or computed tomographic guidance and will likely play a growing role in local tumor treatment as advanced imaging techniques identify smaller lesions earlier in veterinary patients.

![Figure 14](image14.png)

Figure 14—Radiographic images obtained during palliative stenting of a malignant venous obstruction causing hepatic congestion, portal hypertension, severe ascites, and hind limb edema in a dog. A—Digital subtraction venogram obtained following catheterization of the left hepatic vein (HV) and caudal vena cava (CVC). Notice the large filling defect (TUMOR) at the junction of the left HV and CVC, resulting in severe distension of the HV and CVC caudal to the tumor. B—Digital subtraction venogram obtained following placement of self-expanding metallic stents (arrows) in the left HV and CVC.

![Figure 15](image15.png)

Figure 15—Fluoroscopic images obtained during percutaneous antegrade placement of a ureteral stent to relieve malignant ureteral obstruction secondary to transitional cell carcinoma in a dog. A—Contrast ureteropyelogram obtained following administration of contrast medium through an 18-gauge catheter placed percutaneously in the renal pelvis; notice the hydronephrosis (asterisk) and hydrourerter (white arrows). A marker catheter (black arrows) has been placed in the colon for measurement purposes. B—Fluoroscopic image obtained during antegrade passage of an angled hydrophilic guidewire and catheter (white arrows) across the obstruction and out the penis. C—Fluoroscopic image obtained during retrograde ureteral dilatation with a 6-F ureteral dilator (white arrows) placed over the guidewire. D—Fluoroscopic image obtained following retrograde placement of an indwelling, multifenestrated 4.7-F ureteral stent (white arrows) from the urinary bladder (UB) to the renal pelvis (asterisk).
Figure 16—Images illustrating urethral stent placement for relief of malignant urethral obstruction in a dog. A—Retrograde contrast urethrocystogram demonstrating narrowing of the urethral lumen at the level of the prostatic urethra (black arrows). Notice the marker catheter in the rectum (3) used to determine radiographic magnification and extrapolate normal urethral diameter (4) and obstruction length. B—Urethroscopic view of the malignant urethral obstruction demonstrating loss of lumen patency. C—Retrograde contrast urethrocystogram obtained following placement of a self-expanding metallic stent in the prostatic urethra (black arrows). D—Urethroscopic view of the urethral lumen following stent placement.

Conclusion

Although most of the procedures described in the present review are investigational at this time, we hope that these short descriptions will generate increased awareness of them and increased interest in offering currently available techniques to veterinary patients. Veterinary medicine has tended to adopt changes that have occurred in human medicine, from increased specialization and imaging advancements to advancements in medical and surgical treatments. Although veterinary patients tend to recover more rapidly following surgery than do human patients and cosmetic concerns typically are not as great, animals can still benefit from interventional techniques. In addition, although many of the proposed benefits of these techniques, including reduced postoperative pain, shorter hospitalization times, earlier return to function, improved quality of life, and improved response rates, have not yet been critically evaluated, it would seem reasonable to suggest that further investigation is warranted. These and other minimally invasive techniques have the potential to replace some of the more invasive surgical procedures that are currently performed; however, the authors believe that the major application of these procedures will be in those patients in which traditional treatments have failed, were declined, or were contraindicated because of coexisting conditions.

References


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