Reference Point

Interventional cardiovascular techniques in small animal practice—diagnostic angiography and balloon valvuloplasty

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Interventional radiology can be defined as the use of imaging modalities to guide percutaneous diagnostic and therapeutic procedures. In human medicine, interventional radiology is also called "21st century medicine" because it has been leading a trend in the use of minimally invasive treatments in medical practice. Interventional radiology also has appeal in veterinary medicine, and numerous interventional radiology techniques have been transferred to veterinary practice from human medicine, including interventional ultrasonography (eg, biopsy, fine-needle aspiration, and percutaneous drainage),[1] cardiovascular interventional techniques, and nonvascular interventional techniques.[2-4] Recent clinical reports of the use of cardiovascular interventional techniques in small animal practice are encouraging and suggest that these techniques are promising. In this review, we provide an overview of the current state of 2 interventional radiology techniques—diagnostic angiography and balloon valvuloplasty—in veterinary medicine, focussing on aspects that have recently been updated and that appear to have the greatest potential for use in veterinary practice. Some relevant clinical issues in human medicine are also discussed.

Diagnostic Angiography

Diagnostic angiography is a fundamental technique of interventional radiology and is the root of cardiovascular interventional radiology. In 1953, Dr. Sven-Ivar Seldinger published a new technique for percutaneous puncture and catheterization of the arterial system in the Scandinavian medical journal *Acta Radiologica*.[5] Since then, a number of diagnostic angiographic techniques, including the entire field of cardiovascular interventional radiology, have been developed. In veterinary medicine, angiocardiography has been used extensively in dogs with congenital and acquired cardiovascular diseases.[6,7] In the 1970s, abdominal angiography, selective renal angiography, and selective cerebral angiography were studied in depth.[8-11]

In the 1980s, as ultrasound technology advanced, ultrasonography became widely accepted as a first-line diagnostic technique in veterinary medicine and use of diagnostic angiography was supplanted in part by the use of ultrasonography. Unlike diagnostic angiography, ultrasonography is noninvasive. Thus, the complications associated with angiographic procedures and the adverse reactions associated with administration of iodinated contrast agents are eliminated. Not only can ultrasonography display detailed vascular anatomy, but it can also provide information about the vessel wall and surrounding tissue. Furthermore, color Doppler ultrasonography allows semiquantitative assessment of hemodynamics, such as velocity, direction, and pattern of blood flow.

Nevertheless, diagnostic angiography still has a role in veterinary medicine, particularly so since the advent of digital subtraction angiography. With digital subtraction angiography, the procedure time, amount of contrast medium that must be administered, and amount of ionizing radiation that must be used have been greatly decreased, compared with conventional angiographic techniques. Currently, diagnostic angiography remains the gold standard for diagnosis of cardiovascular lesions because of its high resolution and large field of view when demonstrating vascular anatomy, even though some newer noninvasive imaging modalities, such as computed tomography and magnetic resonance imaging, may have similar capability. Diagnostic angiography can be used to confirm, define, or exclude the diagnosis of cardiac vascular lesions, congenital shunts, and myocardial diseases when results of other noninvasive techniques are unconclusive.[12-16] Diagnostic angiography is also indicated before surgery in patients with cardiovascular diseases because it can be used to precisely localize vascular lesions and demonstrate the optimal surgical route to minimize or avoid the risk of damaging normal vessels. The clinical usefulness of diagnostic angiography is more pronounced in patients with extensive vascular anomalies, such as arteriovenous fistulae and multiple **portosystemic shunts (PSSs)**.[17-19]

Diagnostic angiography in the diagnosis of portosystemic shunting—Diagnostic angiography is fre-

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quently indicated in patients suspected to have PSSs. Ultrasonography and nuclear scintigraphy have been widely accepted as noninvasive imaging modalities to evaluate PSSs.[20-22] However, ultrasonographic techniques depend on the skill of the operator, and detection of extrahepatic shunts through the use of ultrasonography alone does not appear to be encouraging. For instance, Holt et al,[20] in a study of 63 dogs and cats with extrahepatic PSSs, reported that sensitivity and specificity of ultrasonography were 81% and 67%, respectively. Thus, failing to detect a shunt with ultrasonography does not exclude the possibility of PSS.

Transcolonic scintigraphy with sodium pertechnetate Tc 99m is a sensitive and specific screening test for PSSs. In a study[23] of 176 dogs, cats, and potbellied pigs that underwent transcolonic scintigraphy, results were confirmed in 85 of the 97 animals with positive test results, and results were proved to be falsely negative in only 1 of 79 animals with negative test results. Recently, use of ultrasound-guided percutaneous transsplenic portal scintigraphy with sodium pertechnetate Tc99m has been described,[a] and the technique appears to allow distinction of single, multiple, and portoazygos shunts, although it cannot differentiate between intrahepatic and extrahepatic PSSs.

Magnetic resonance angiography has also been described for diagnosis of PSSs in dogs,[24] and the technique appears promising, particularly if more sophisticated techniques used in human medicine[25,26] can be adapted for use in animals. However, the cost and availability of this modality may be prohibitive. Additionally, in animals with complicated anatomic abnormalities, portal vein angiography would still be required to definitively diagnose PSS prior to surgery.

Thus, diagnostic angiography remains a mainstay for the diagnosis of PSSs in small animals. A variety of diagnostic angiographic techniques for diagnosis of congenital PSSs in dogs have been reported since the first description by Ewing et al[27] in 1974. Suter[28] described 6 diagnostic angiographic techniques to outline the portal venous anatomy in dogs, including cranial mesenteric arterial injection, celiac arterial injection, transabdominal splenic injection (splenoportography), operative splenic injection, operative jejunal or mesenteric injection (mesenteric portography), and hepatic vein wedged injection (transabdominal hepatic portography). Techniques that have been described can be divided into 3 broad categories: percutaneous transvascular, percutaneous transabdominal, and intraoperative portography.

The percutaneous transvascular portography techniques include cranial mesenteric arterial, celiac arterial, and hepatic vein wedged portography. Cranial mesenteric and celiac arterial portography are performed by means of selective catheterization of the femoral artery and injection of contrast medium into the target artery. Hepatic vein wedged portography is performed with a jugular approach with the angiographic catheter wedged into a peripheral branch of the hepatic vein before injection of contrast medium. Because these techniques can be accomplished by use of a percutaneous transvascular approach, the need for a laparotomy is eliminated. However, cranial mesenteric and celiac arterial portography do not always provide images of optimal quality, even with digital subtraction angiography, because the contrast medium is diluted as it passes though the capillary bed to the portal system. Hepatic vein wedged portography can depict detailed portal anatomy but is seldom used in veterinary practice, possibly because of potential complications such as hepatic laceration and hemorrhage, which have been reported in humans.[29,30]

Percutaneous transabdominal portography methods include percutaneous transhepatic portography and percutaneous trans-splenic portography. The former is carried out by means of percutaneous puncture of the intrahepatic portal system and direct injection of contrast medium into the portal vein. But the technical success rate is low in patients with a PSS because of the reduced size and number of intrahepatic portal branches. In the latter procedure, contrast medium is injected into the splenic parenchyma, from where it drains into the portal tree, demonstrating its anatomy. The drawbacks of this technique include potential complications of splenic laceration and hemorrhage as well as poor image quality attributed to dilution of the contrast medium during passage from the splenic parenchyma to the portal vein.

Intraoperative portography techniques include intraoperative splenoportography and intraoperative mesenteric portography. Although direct placement of the catheter during intraoperative splenoportography can decrease the risk of splenic laceration and hemorrhage, the image quality remains as poor as that seen with percutaneous splenoportography. A modification of the technique developed to improve image quality is intraoperative transsplenic portal catheterization, by which contrast medium, rather than being injected into the splenic parenchyma, is injected directly into the splenic or portal vein.[31] A substantial advantage of this technique is that it allows direct measurement of portal vein pressure, which is a reliable indication of whether an extrahepatic shunt can be safely ligated. Intraoperative mesenteric portography can also provide high-quality images of the portal vein to delineate PSSs and allows measurement of portal vein pressure. From a technical viewpoint, intraoperative mesenteric portography is easier to perform than is intraoperative transsplenic portal catheterization because catheterization of mesenteric veins is simpler than transsplenic catheterization of the portal vein. Hence, intraoperative mesenteric portography has been more widely accepted in veterinary practice.[32,33]

Recently, a method for retrograde transvenous portography has been described for identification of PSSs in dogs.[34] In this procedure, a multipurpose angiographic catheter is inserted through the saphenous vein and positioned in the portion of the caudal vena cava between the renal and hepatic veins. Positive pressure is created in the thoracic cavity by manual compression of a respiration bag, and contrast medium is injected into the vena cava. The shunt is delineated by backflow of contrast medium into the portal vein. The method is simple and safe and does not require laparotomy. However, detection of a shunt depends on backflow of contrast medium, which requires blockage of

the caudal vena cava in the thoracic cavity. Failure to completely block blood flow in the thoracic portion of the caudal vena cava might lead to a false-negative result. Miller et al[35] described a modified technique for transvenous retrograde portography and reported results in 20 dogs. In this instance, a double-lumen latex balloon catheter was introduced from the jugular vein into the caudal vena cava or azygos vein. Following inflation of the balloon to occlude the vena cava or azygos vein, contrast medium was injected to outline the portal vein and any shunts. In the 20 dogs, only 1 false-negative result occurred, and this was attributed to technical errors. This modified technique provides a less invasive method to identify portoazygos shunts, which is advantageous when compared with other methods for diagnosis of PSSs. Furthermore, the modified technique allows for measurement of portal pressure and selective catheterization of shunts, even to the portal vein. Through this approach, selective portography may be performed to demonstrate underlying shunts in detail.

Diagnostic angiography in the clinical diagnosis of tumors—Diagnostic angiography is not a standard technique for diagnosis of neoplasms in small animals; however, in animals with hypervascular tumors, angiography can provide specific pathologic information that is helpful in establishing a clinical diagnosis.[36] In a study by Gelatt et al,[36] for instance, 14 dogs with orbital and nasolacrimal tumors underwent angiography following surgical dissection of the infraorbital artery and direct catheterization. Angiography revealed inconsistencies in the pathways of some small orbital vessels, deviation of the large orbital vessels, and increased vascularity attributable to neoplasms in the area, which could aid in determining tumor size and surgical approach. Recently, Sun et al[37] reported on the use of diagnostic angiography in a dog with a fibrosarcoma. Abnormalities that were seen included enlargement, displacement, tapering, and occlusion of supplying arteries; irregular hypervascularity; tumor staining; and premature filling of veins. The supplying arteries were larger in diameter than expected because of high-flow hemodynamics and hypermetabolism of malignancy. The arterial branches inside and surrounding the tumor were tapered and occluded, suggesting invasion by the tumor or displacement by a mass effect. The irregular hypervascularity was attributed to pathologic tumor vessels that appeared as small or large, deformed, tortuous channels with alternating areas of narrowing and dilatation along the course of the vessels. Tumor staining (ie, long-lasting parenchymal opacification within tumor tissue in the late arterial phase of angiography) was theorized to be a result of a lack of elasticity in pathologic arterial walls, resulting in contrast medium being held longer in the tumor tissue than in the unaffected soft tissue. Premature filling of veins was considered to likely be a result of pathologic arteriovenous shunting within the lesions. All of the angiographic abnormalities were believed to be tumor specific and suggestive of a diagnosis of malignancy. Another angiographic feature in this dog was heterogeneous vascularity. Some parts of the mass were hypervascular, whereas other parts were less vascular or avascular. The hypervascular portions were believed to represent malignant tissue, whereas the avascular areas were thought to most likely indicate necrosis within the tumor. Thus, angiography may be helpful in guiding biopsy specimen collection for pathologic examination.

Complications of diagnostic angiography—Although angiography is generally safe, it is an invasive modality and thus is associated with various risks. Understanding the potential complications of diagnostic angiography is as important as understanding its benefits and advantages. Unfortunately, there are very few reports on complications of diagnostic angiography in veterinary practice. In humans, complications of angiography can be divided into procedure-related and contrast-induced complications, with complications rates reported as 1.73% to 3.29% and 4.7%, respectively.[38,39] Procedure-related complications, which include bleeding and hematoma formation at the puncture site; vascular injury (dissection or perforation); vascular embolization by blood clots, air, catheter material, or a dissected intimal flap; stroke; adverse cardiac events; and death,[38] may be minimized by experienced operators with meticulous technique and proper manipulation.[40] In contrast, contrast-induced complications are more common and troublesome and include nephrotoxicosis, neurotoxicosis, arrhythmias, and hypersensitivity.

Iodinated contrast media can be classified on the basis of their physical and chemical characteristics, such as chemical structure, osmolality, iodine content, and ionization in solution. Diatrizoate anion and iohexol are categorized as ionic high-osmolar and nonionic low-osmolar contrast agents, respectively. It is well recognized that high osmolality plays an important role in inducing nephrotoxicosis and hemodynamic instability.[41,42] In a study[43] of 1,196 human patients, it was shown that patients receiving diatrizoate were 3.3 times as likely to develop nephropathy as were those receiving iohexol. Iohexol is also less neurotoxic and less likely to induce adverse cardiovascular reactions than is diatrizoate.[44,45]

In veterinary practice, diatrizoate is a commonly used contrast agent. To minimize possible adverse effects, especially damage to the kidneys, it has been recommended that the dosage of iodinated contrast medium used for angiography be restricted to 1 to 2 mL/kg (0.45 to 0.91 mL/lb).[13,14] Currently, iohexol has been widely used for diagnostic angiography in veterinary practice without major adverse effects. However, the higher cost of iohexol is of concern when it is routinely used in veterinary clinics.

Use of CO_2 for diagnostic angiography—Carbon dioxide has been widely used as a safe alternative to iodinated contrast agents in human medicine[46,47] but is rarely used in veterinary practice. A prerequisite for CO_2 angiography is the use of a digital subtraction angiography system that can provide optimal image quality with high-contrast resolution. Although use of CO_2 angiography in veterinary medicine was reported

in 1963,[48] the image quality was too poor for the technique to be useful. Recently, CO_2 angiography in combination with a digital subtraction angiography system has been described in conjunction with coil embolization of an intrahepatic PSS in a cat.[49] The authors placed an angiographic catheter with the help of a guidewire from the right jugular vein across the shunt to the portal vein. The angiographic catheter was then exchanged over the guidewire for a standard occlusion balloon catheter with the balloon at the level of shunt. After the guidewire was removed, the balloon was temporarily inflated to occlude the shunt and venography was performed by means of manual injection of CO_2 as a contrast agent. On the venograms, the reflux of CO_2 clearly demonstrated the anatomy of the shunt, left and right hepatic veins, caudal vena cava, and right atrium.

Carbon dioxide has unique physical, chemical, and biological properties that make it suitable as a contrast medium. It is nontoxic and has not been associated with renal toxicosis or hypersensitivity. It is 20 times as soluble in blood as is oxygen, and its viscosity is substantially less than the viscosity of iodinated contrast agents. In theory, CO_2 can be administered in an unlimited quantity if used appropriately. Furthermore, CO_2 is extremely cheap, compared with iodinated contrast agents.

In human medicine, CO_2 angiography is frequently used to detect abdominal and peripheral vascular abnormalities and to guide interventional procedures involving the vena cava. Because of controversies concerning the neurotoxicity of CO_2, it has been recommended that CO_2 not be injected in arteries cranial to the diaphragm. Likewise, CO_2 should not be used with nitrous oxide anesthesia because nitrous oxide saturated in the soft tissues of the patient might diffuse into the CO_2 bubble, resulting in air embolization.[47,50] More recently, a new technique for fine-needle percutaneous transhepatic parenchymal CO_2 portography has been described[51] in which portal vein structures were delineated by use of digital subtraction angiography following injection of CO_2 into the hepatic parenchyma. This technique appears to be less invasive, easier to perform, less time-consuming, and less costly than other portography procedures, such as intraoperative mesenteric portography, intraoperative splenoportography, and transvenous retrograde portography.

Balloon Valvuloplasty

Balloon valvuloplasty is the first of the therapeutic endovascular techniques to be applied in veterinary medicine. Early in 1980, an English Bulldog with congenital pulmonic stenosis underwent balloon valvuloplasty as an experimental treatment to test the safety and efficacy of the procedure before approval for use in human patients.[52] Balloon valvulotomy has been successfully performed in a neonate with pulmonary valve stenosis and tricuspid valve insufficiency.[53] Since then, balloon pulmonary valvuloplasty has been gradually popularized in human medicine and is currently accepted as the treatment of choice in patients with valvular pulmonic stenosis. Balloon pulmonary valvuloplasty has also been used extensively in dogs in clinical practice.[54-61]

Balloon valvuloplasty for treatment of pulmonic stenosis in dogs—Pulmonic stenosis is one of the most common congenital heart defects in dogs, accounting for 19.7% to 23.3% of all dogs with congenital cardiac diseases.[62,b] Pulmonic stenosis can be classified as supravalvular, valvular, or subvalvular on the basis of anatomic location of the obstruction. Valvular stenosis is the most common form, whereas supravalvular stenosis is rare in dogs. Subvalvular stenosis is observed in 8% to 10% of dogs with pulmonic stenosis.[60,63,64]

The pathology of pulmonic stenosis in humans has been extensively studied. Two basic forms of pulmonic stenosis have been described, typical pulmonic stenosis and pulmonic valve dysplasia.[65,66] The former is characterized by relatively thin valve cusps that are fused to form a narrow orifice. The degree of stenosis depends on the extent of the fused cusps and their thickness and rigidity. The latter is characterized by thick, immobile, unfused cusps with a narrowed and hypoplastic pulmonary valve annulus. Typical pulmonic stenosis is more common in humans, accounting for 82% of cases in 1 study[67]; pulmonary valve dysplasia accounted for 8% of cases, and a combined form accounted for 5%.

Abnormalities in dogs with pulmonic stenosis include thickened valves, fused valvular cusps, and hypoplastic valves that develop with various degrees of severity and exist alone or in any combination. Unlike in humans, typical pulmonic stenosis and pulmonic valve dysplasia might not be simply distinguished in dogs. Patterson et al[68] described 2 types of pulmonary valve dysplasia in 70 Beagles. Type I was defined as slightly thickened and fused valve leaflets and resembled typical pulmonary stenosis seen in humans. Type II was defined as moderate to severe thickening and hypoplasia of valves and was similar to pulmonic valve dysplasia in humans. Intermediate forms were also found; therefore, the standard classification of pulmonic stenosis used in humans is not suitable for use in dogs. For this reason, a new classification of pulmonic stenosis in dogs, which divides dogs into type A and type B according to the aortic-to-pulmonary annulus diameter ratio determined by means of 2-dimensional echocardiography, has been proposed.[59,69] Type A refers to dogs with an aortic-to-pulmonary annulus diameter ratio ≤ 1.2, in which annular size is normal with moderate to severe commissural fusion and moderate thickening of valve leaflets. Type B refers to dogs with an aortic-to-pulmonary annulus diameter ratio > 1.2, which is characterized by hypoplasia of the pulmonic ostium and severe thickening of immobile valvular leaflets.

Clinically, the severity of pulmonic stenosis is determined by the pressure gradient across the pulmonic valve. The pressure gradient can be measured directly (ie, by insertion of a catheter) or indirectly (ie, by means of Doppler echocardiography). The pressure gradient obtained by means of Doppler echocardiography in conscious dogs is 40% to 50% higher than that measured by a catheter when the dogs are anesthetized.[59] When peak systolic pressure gradient is measured by means of cardiac catheterization, pulmonic stenosis is considered mild if the pressure gradient is ≤ 50 mm Hg, moderate if the pressure gradient is between 50 and 80 mm Hg, and

severe if the pressure gradient is > 80 mm Hg.[70] When measured by means of Doppler echocardiography, pulmonic stenosis is considered severe only if the pressure gradient is > 125 mm Hg.[70] Dogs with moderate or severe pulmonic stenosis are more likely to develop clinical signs, such as exercise intolerance, syncope, or sudden death,[63] and thus are considered candidates for balloon valvuloplasty.[59,61]

The technique of balloon valvuloplasty is relatively easy and safe. Following general anesthesia, venous access is established, usually by cannulating the jugular vein or, occasionally, the femoral vein.[56] An angiographic catheter is positioned through the right atrium, right ventricle, and pulmonic valve to the pulmonary artery. After the pressure gradient is measured, right ventricular angiography is performed to outline the morphology of the abnormality and measure the diameter of the pulmonary annulus. A long stiff wire is advanced through the catheter to the pulmonary artery, and the catheter is then exchanged for a balloon valvuloplasty catheter with a balloon of appropriate diameter. The balloon catheter is positioned in the pulmonary outflow tract, and 2 or more attempts are made a minimum of 5 minutes apart to inflate the balloon, with each inflation held for 5 seconds.[71] The pressure gradient is remeasured by catheter immediately and by means of Doppler echocardiography 24 hours after the procedure.

Clinical outcome of balloon valvuloplasty for treatment of pulmonic stenosis in dogs is related to several factors, including patient-associated factors (eg, vascular anatomy and age) and operator-associated factors (eg, selection of proper size of balloon and adequate balloon inflation times). Vascular anatomy is accepted as one of the independent predictors of long-term results of balloon valvuloplasty. It is generally believed that balloon valvuloplasty is based on tearing the commissures of the fused valve cups. Thus, in patients with hypoplasia or narrowing of the valve annulus itself, balloon dilatation is often not effective.[72,73] In human medicine, balloon valvuloplasty has been most successful in patients with typical valvular pulmonic stenosis, whereas patients with pulmonic valve dysplasia more often have restenosis following balloon valvuloplasty.[74,75] In a study[59] of dogs, clinical resolution was achieved in 100% of dogs with type A pulmonic stenosis but in only 50% of dogs with type B stenosis, and dogs with type A or type I pulmonic stenosis are considered good candidates for balloon valvuloplasty. Interestingly, in 2 dogs with dysplastic valves and a hypoplastic annulus,[60] clinical signs were dramatically improved after balloon valvuloplasty when relatively small balloons (balloon-to-pulmonary annulus diameter ratio of 1:1 to 1.2:1) were used. Effects of balloon valvuloplasty on pulmonic stenosis remain to be studied in a large population of dogs.

Other important predictors of the long-term outcome of balloon valvuloplasty for treatment of pulmonic stenosis include size of the balloon (balloon-to-pulmonary annulus ratio) and pulmonary valve pressure gradient immediately following valvuloplasty. In humans, it has been concluded that restenosis directly relates to the use of a balloon with a balloon-to-pulmonary annulus ratio < 1.2:1 and an immediate postvalvuloplasty peak-to-peak pulmonary valve gradient ≤ 30 mm Hg.[76] Thus, it has been recommended that a balloon-to-pulmonary annulus ratio between 1.2:1 and 1.4:1 be used for pulmonary valvuloplasty in human patients with pulmonic stenosis.[71] A similar ratio seems to be appropriate for dogs. In 1 study,[60] for instance, restenosis occurred in 3 of 18 dogs in which the balloon-to-pulmonary annulus ratio was 1:1 to 1.2:1, whereas in a separate study,[61] restenosis occurred in only 8% of 37 dogs for which the balloon-to-pulmonary annulus ratio ranged from 1.25:1 to 1.55:1. The poorest results were associated with the smallest balloon (balloon-to-pulmonary annulus ratio, 0.9:1), and the best results were associated with the largest balloon (balloon-to-pulmonary annulus ratio, 1.28:1).[56] Therefore, it appears that for pulmonary valvuloplasty in dogs, the diameter of the balloon should be 1.2 to 1.4 times the diameter of the pulmonary annulus. Occasionally, a large-bore balloon is difficult to pass through a severe stenosis. In these instances, a small balloon can be used for predilatation, followed by a large balloon for valvuloplasty.[77]

Complications of balloon pulmonary valvuloplasty—Several complications of balloon valvuloplasty for pulmonic stenosis have been documented, including ventricular premature beats, transient right bundle branch block, ventricular fibrillation, cardiac arrest, and disruption of an aberrant coronary artery.[55,58-61] Pulmonic stenosis associated with a single coronary artery has been reported in English Bulldogs and Boxers.[52,78] In these dogs, the left main coronary branch arises from a single right coronary artery and encircles the pulmonary root over the hypoplastic pulmonic valves. Thus, valvuloplasty with a large balloon may be fatal in these dogs. Hence, coronary angiography is recommended before balloon valvuloplasty, particularly in English Bulldogs and Boxers.

Balloon valvuloplasty of subaortic stenosis and other defects—Aortic stenosis was traditionally documented as the third most common congenital cardiac defect in dogs, following patent ductus arteriosus and pulmonic stenosis.[79] Recently, an increase in the prevalence of aortic stenosis has been identified, particularly in Europe, and the condition is now ranked as the most common congenital cardiac defect in dogs,[64,b] accounting for 31.5% to 35% of all congenital heart abnormalities in dogs. The defect can be valvular, subvalvular, or supravalvular, with subvalvular aortic stenosis or subaortic stenosis being most common.[64]

Two-dimensional echocardiography with color Doppler echocardiography is currently the method of choice for making a definitive diagnosis of subaortic stenosis. Subaortic stenosis has been divided into 3 major types on the basis of Doppler echocardiographic findings.[69] Type I is defined as slightly raised nodules on the endocardial surface of the interventricular septum immediately below the aortic valve. Type II is defined as a narrow ridge of thickened endocardium partially around the left ventricular outflow tract. Type III is defined as a fibrous band, ridge, or collar that completely encircles the left ventricular outflow tract just below the aortic valve. Dogs with subaortic steno-

sis are also divided into 3 severity groups according to pressure gradients,[80] with gradients of 16 to 35 mm Hg classified as mild, gradients of 36 to 80 mm Hg classified as moderate, and gradients > 80 mm Hg classified as severe. Infective endocarditis (6.3%) and left-sided heart failure (7.3%) tend to occur mainly in dogs with mild or moderate subaortic stenosis and generally later in life, and sudden death (21.9%) tends to occur mainly in dogs with severe subaortic stenosis and generally in the first 3 years of life.[80]

Reports on balloon valvuloplasty for treatment of subaortic stenosis in dogs are limited to a single report[81] of 9 dogs with congenital subaortic stenosis. A carotid approach was used for the procedure, and the balloon diameter was chosen to approximate the diameter of the aortic annulus. Immediately after balloon valvuloplasty, 3 dogs had a ≥ 60% decrease in peak systolic pressure gradient and 6 had a 25% to 50% decrease. Clinical signs resolved or improved, but follow-up time was short (3 months to 1.5 years).

In humans, subaortic stenosis is uncommon, accounting for approximately 1% of all congenital heart defects and occurring in 13.7% of all patients with obstruction of the left ventricular outflow tract.[82,83] Balloon valvuloplasty to relieve subaortic stenosis is not frequently reported in humans, in part because of the low incidence of subaortic stenosis. More importantly, there is no general agreement as to whether balloon valvuloplasty should be used to treat subaortic membranous stenosis. Balloon valvuloplasty for treatment of discrete subaortic stenosis was first described in 1986,[84] and the technical feasibility and effectiveness of balloon valvuloplasty for treatment of subaortic stenosis were subsequently confirmed.[85,86] In a study[85] in which patients with subaortic stenosis were classified as having a thin, discrete membrane or a thick, fibromuscular ring, substantial improvement was seen in patients with the thin membrane, whereas patients with the fibromuscular ring often had a high residual pressure gradient. Rao et al[86] suggested that substantial relief of the obstruction could be maintained for at least 16 months after balloon valvuloplasty.

In view of the high incidence of subaortic stenosis in dogs, balloon valvuloplasty would seem to be of great potential in veterinary medicine. However, balloon valvuloplasty of subaortic stenosis in dogs remains a challenge, and several issues must be addressed. First, indications for balloon valvuloplasty have not been well defined. It might be reasonable to limit balloon valvuloplasty to dogs with severe stenosis (pressure gradient > 80 mm Hg) and dogs with moderate stenosis (pressure gradient between 36 and 80 mm Hg) that also have signs of left-sided heart failure. Second, criteria for patient selection are not clear. However, current data seem to suggest that dogs with type II subaortic stenosis might be more likely to benefit from balloon valvuloplasty, in that type II subaortic stenosis in dogs is similar to discrete membranous stenosis in humans. Third, criteria for selection of the proper balloon size must be developed. Experience in human patients suggests that the size of the balloon should be no larger than the size of the aortic annulus because oversized balloons are likely to cause aortic valve insufficiency. Finally, the safety of balloon valvuloplasty in dogs needs to be improved. In a previous report,[81] the major complications included vascular trauma, arrhythmias, and conduction disorders. All arrhythmias and conduction disorders were successfully controlled without further adverse effects; local trauma to the carotid artery associated with passing the large-bore balloon catheter required ligation of the carotid artery in most dogs. The complication rate is expected to reduce in the future with further refinement of balloon catheters and acquisition of more technical experience.

Balloon valvuloplasty has also been reported for the management of tricuspid stenosis, right ventricular outflow obstruction secondary to tetralogy of Fallot, double-chambered right ventricle, and cor triatriatum dexter.[87-91] At present, available information is not sufficient to evaluate the efficacy and safety.

Conclusions

Angiography as an invasive modality has great potential for the diagnosis of vascular anomalies in small animals. It may also provide information regarding the diagnosis of malignant tumors and help guide biopsy efforts. Because of its low cost and low nephrotoxicity, CO_2 might be a useful contrast agent in veterinary practice. Balloon valvuloplasty has become the treatment of choice for pulmonic stenosis in dogs, and short- and intermediate-term results are promising. However, long-term results are not known, and outcome following balloon valvuloplasty must be compared with outcome following medical or surgical treatment. Given the high incidence of subaortic stenosis in dogs, balloon valvuloplasty would seem to be a potentially useful treatment; however, large clinical trials are needed.

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