Use of a self-expanding occluding stent for nonsurgical closure of patent ductus arteriosus in dogs

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Objective—To evaluate the clinical application of a catheter-delivered, self-expanding occluding stent for closure of patent ductus arteriosus (PDA) in dogs.

Design—Prospective study.

Animals—23 client-owned dogs weighing at least 3 kg (6.6 lb).

Procedure—Dogs were evaluated by physical examination, electrocardiography, thoracic radiography, and 2-dimensional, M-mode, spectral and color-flow Doppler echocardiography to confirm the diagnosis and obtain baseline measures. Shunt severity and ductal size and anatomy were established by means of angiography. With fluoroscopic guidance, the occluding stent, attached to a delivery cable, was maneuvered through the right side of the heart into the ductus via a prepositioned introducer sheath. After angiographic verification of appropriate stent placement, the delivery cable was detached, and the introducer sheath was withdrawn. Closure of the PDA was evaluated by means of angiography 15 minutes after stent deployment and by echocardiography 1 and 3 months after the procedure.

Results—There were no operative deaths. There were 2 deployment failures, both attributable to avoidable operator errors. Angiography performed after stent deployment indicated PDA closure in 13 of 20 (65%) dogs. There were 2 postoperative deaths in dogs with heart failure; both deaths were thought to be unrelated to use of the occluding stent. Complete PDA closure, determined by Doppler color-flow echocardiography, was evident in 17 of 19 dogs within 3 months and in 1 additional dog within 1 year of stent deployment, resulting in closure in 18 of 19 dogs completing the study protocol.

Conclusions and Clinical Relevance—Results suggest that a catheter-delivered occluding stent can be used successfully to close PDAs in dogs. (J Am Vet Med Assoc 2003;223:999–1005)

Robert Gross performed the first successful surgical ligation of a patent ductus arteriosus (PDA) in a child at Children's Hospital in Boston, Mass, in 1938. Since that time, correction of a PDA has become the most common surgical procedure in children with congenital heart disease, with an operative mortality rate of < 1%. Commonly used surgical methods for PDA repair include suture ligation, ligation with metallic clips, and surgical division. The most commonly reported surgical complications include hemorrhage, infection, pneumothorax, vocal cord paralysis, and residual shunting. Other reported complications include heart failure and pulmonary hypertension, neither of which is necessarily related to the method of PDA repair. Overall complication rates in human patients reportedly range from 4 to 13%.

The first ligation of a PDA in a dog was performed in 1932 by Willis Potts at the Northwestern University Clinic in Chicago. As in humans, PDA repair is the most commonly performed corrective surgical procedure in dogs with congenital heart disease. The 2 largest studies of dogs undergoing surgical PDA repair reported operative and overall mortality rates of 2 and 8% and 7 and 11%. A more recent study reported a 3% surgical mortality rate, a 1% anesthetic death rate, and a 32% overall surgical complication rate. Persistent transduetal blood flow was evident in 23 of 31 (45%) dogs, as determined by means of color-flow Doppler echocardiography 1 month after surgery. Common complications of surgical PDA repair in dogs have included hemorrhage, infection, pneumothorax, cardiac arrhythmias, cardiac arrest, and heart failure.

Alternatives to surgical ligation of a PDA have been investigated for > 30 years, fueled primarily by the desire to avoid the complications associated with thoracotomy and reduce the duration of hospitalization and its related costs. In 1967, Porstmann et al accomplished the first transvascular closure of a PDA with a synthetic plug. Since then, a variety of devices have been developed that can be used for occlusion of PDAs in a minimally invasive fashion. During the 1970s and 1980s, several umbrella-like devices were used for PDA occlusion in humans, but none were widely embraced as acceptable substitutes for surgery. With the introduction of thrombogenic coils in the early 1990s and the subsequent development of occlusive stents, catheter-based techniques have begun to challenge surgical ligation as the preferred method for PDA repair in humans and dogs. The purpose of the study reported here was to evaluate the clinical application of a recently developed self-expanding occluding stent in dogs with PDA.

Materials and Methods

Description of the device—The occluding stent used in this study was a self-expanding, 7-mm-long, mushroom-shaped device consisting of a collapsible nitinol wire mesh...
frame filled with firmly attached polyester patches (Fig 1). Nitinol is a shape memory alloy composed of 53% nickel and 45% titanium. The wire frame of the stent holds the device in place in the PDA, and the polyester patches serve as a thrombogenic sieve to obstruct blood flow. The device is manufactured in 6 sizes. A stainless steel sleeve with a female thread is attached to the recessed pulmonic end of the device. The delivery system consists of a delivery cable with a matching male thread, a pin vise, a device loader, and a long, 5- or 6-F, Mullins-type, polytef introducing sheath.

Dogs—Twenty-three client-owned dogs that were confirmed to have a PDA and weighed at least 3 kg (6.6 lb) were included in the study. Owners of all dogs provided written informed consent. Five dogs, 4 of which had moderate to severe mitral regurgitation, were treated with diuretics (n = 5), enalapril (4), and digoxin (4) to resolve pulmonary congestion prior to enrollment in the study. All dogs were initially evaluated by means of physical examination, electrocardiography, thoracic radiography, and 2-dimensional, M-mode, spectral and color-flow Doppler echocardiography. Relative heart size was measured on a lateral radiographic projection with the vertebral scale system. Echo-cardiography was performed with a commercial echocardiographic unit, and all measurements were made in accordance with recommendations of the American Society of Echocardiographers. Dogs with other serious congenital heart defects or medical disorders that in the opinion of the investigator would preclude them from completing the experimental protocol were excluded from the study.

Description of the procedure—For all dogs, general anesthesia was used during catheter-directed deployment of the occluding stent. However, a variety of preoperative and anesthetic agents were used, depending on the circumstances of the patient and the preferences of the attending anesthesiologist. In most instances, dogs were premedicated with atropine or glycopyrrolate and an opiate, typically oxymorphone or butorphanol. Anesthesia was induced with propofol or a combination of ketamine and diazepam or midazolam and maintained with isoflurane. Nine dogs with clinical signs of preexisting congestive heart failure or gross cardiomegaly and depressed myocardial function, as determined by means of radiography and echocardiography, received a constant-rate infusion of dobutamine (5 to 10 µg/kg/min [2.2 to 4.3 µg/lb/min], IV) during the procedure.

Vascular access was obtained by use of the Seldinger technique to introduce a 5- or 6-F vascular sheath into the femoral vein and a 4- or 5-F vascular sheath into the femoral artery. Aortic pressures were measured proximal and distal to the duc tus arteriosus with a 4- or 5-F Halo or pigtail catheter. Ductus size and anatomy were established by means of aortography with iodinated contrast medium (0.5 to 1.0 mL/kg [0.23 to 0.45 mL/lb]) delivered over 1 second via the angiographic catheter positioned in the aorta just proximal to the ductus arteriosus. Correction for magnification was accomplished with a radiopaque scale incorporated into a transesophageal stethoscope positioned just cranial to the base of the heart. Ductus morphology was assessed by visual inspection and by measuring the length of the ductal ampulla from the pulmonic attachment to the ventral border of the aorta, the diameter of the ductal ampulla midway along its length, and the minimum diameter of the duc tus arteriosus, which in every dog was at the point of attachment to the pulmonary artery. Aortic angiograms were recorded digitally and on videotape and were later reviewed to characterize the magnitude of ductal shunting according to the following scale: grade 1, a trace shunt wherein injected contrast opacifies a portion of the pulmonary artery bifurcation but does not opacify the main or branch pulmonary arteries; grade 2, a small shunt wherein injected contrast opacifies the main pulmonary artery but the branch arteries are not well visualized; grade 3, a moderate shunt wherein injected contrast densely opacifies the main pulmonary artery and partially opacifies the branch pulmonary arteries; grade 4, a large shunt wherein injected contrast densely opacifies the main pulmonary artery and the branch pulmonary arteries to an extent similar to opacification of the aorta.

Immediately following angiography, a 5- or 6-F end-hole catheter was directed from the femoral vein through the right side of the heart and main pulmonary artery into the ductus arteriosus. In some dogs, a straight-tipped 0.035-in-diameter guide wire was used to facilitate passage of the catheter through the pulmonic end of the duc tus arteriosus and into the descending aorta. A J-tipped exchange guide wire was subsequently advanced into the descending aorta, and an 80-cm-long, 5- or 6-F introducer sheath was substituted for the angiographic catheter (Fig 2). The occluding stent, attached to a delivery cable, was then advanced through the introducer sheath, and the retention disk of the occluding device was deployed in the proximal portion of the descending aorta with fluoroscopic guidance. The retention disk and introducer sheath were withdrawn into the aortic end of the ductus arteriosus, and the tubular frame of the occluding stent was deployed in the body of the ductus arteriosus. Positioning of the device was evaluated prior to detachment of the delivery cable by means of aortography, using the previously placed arterial catheter.

After a 10- to 15-minute waiting period, heart rate and vascular pressure measurements were again obtained via the arterial catheter from sites in the aorta proximal and distal to the occluding stent to assess the hemodynamic consequences of device deployment. Aortography was repeated to determine whether there was any leakage of blood flow through or around the occluding device. The delivery cable was then detached from the device and retracted into the introducer sheath, and the introducer sheath was withdrawn. The day following ductal occlusion and prior to discharge from the hospital, dogs were reevaluated by means of physical examination, electrocardiography, thoracic radiography, and echocardiography, including color-flow and spectral Doppler echocardiography to evaluate for residual transductal blood flow into the pulmonary artery or iatrogenic stenosis of the left pulmonary artery by the stem of the occluding stent. These same studies were repeated 1 and 3 months later. Dogs with residual transductal blood flow 3 months after the pro-
and easily identifiable pulmonary overcirculation on Nineteen dogs (83%) had some degree of cardiomegaly. JAVMA, Vol 223, No. 7, October 1, 2003 Scientific Reports: Original Study

Results

Dogs—The 23 dogs enrolled in the study consisted of 15 females and 8 males. Median age was 6 months (range, 9 weeks to 7 years). Ten dogs were < 6 months old, 7 dogs were 6 to 12 months old, and 6 dogs were > 1 year old at the time of the procedure. Four dogs were mixed breeds, and 19 were purebred. Median body weight was 6.3 kg (13.9 lb; range, 3.4 to 32 kg [7.5 to 70.4 lb]; mean, 10.4 kg [22.9 lb]). Nine dogs weighed ≤ 5 kg (11 lb), 5 weighed between 5 and 10 kg (11 and 22 lb), and 9 weighed > 10 kg. All dogs had a grade 3 of 6 or louder continuous murmur heard best at the left heart base; 16 dogs (70%) had a palpable thrill at this same location. The presence of a left-to-right shunting PDA was confirmed in all dogs by means of color-flow Doppler echocardiography initially (Fig 3) and subsequently by means of aortography. Nineteen dogs (83%) had some degree of cardiomegaly and easily identifiable pulmonary overcirculation on thoracic radiographs. Mean ± SD VHS was 11.8 ± 1.3. Marked cardiomegaly, defined as a VHS > 12, was identified in 7 dogs (30%). Mitral regurgitation was detected by means of color-flow Doppler echocardiography in 10 dogs (43%). In 6 of these 10 dogs, the diameters and areas of the regurgitant jet were small (regurgitant jet area < 20% of left atrial area), but in the remaining 4, diameter of the regurgitant jet was moderate (regurgitant jet area between 20 and 40% of left atrial area) or large (regurgitant jet area > 40% of left atrial area). Of the 5 dogs treated for preexisting congestive heart failure, 4 had moderate or large mitral regurgitant jets. One dog had a small left-to-right shunting ventricular septal defect. Closure of the PDA had previously been attempted in 1 dog on 2 occasions at other institutions, first by surgery and subsequently by placement of Gianturco coils into the ductus via a femoral arterial catheter. In the first instance, surgery was abandoned when excessive bleeding developed during dissection of the ductus. Attempted closure with Gianturco coils was abandoned when the coils could not be coaxed to remain in the ductus.

Results of angiography and hemodynamic studies—Six dogs were classified as having a grade-4 shunt (large), 14 were classified as having a grade-3 shunt (moderate), and 3 were classified as having a grade-2 shunt (small). Four of the 5 dogs with evidence of preexisting congestive heart failure had a grade-4 shunt; the remaining dog had a grade-3 shunt. Prior to shunt occlusion, mean ± SD systolic, diastolic, and mean pressures in the aorta proximal and distal to the shunt were 96 ± 17, 49 ± 18, and 70 ± 16 mm Hg and 94 ± 20, 49 ± 21, and 69 ± 17 mm Hg, respectively.

Morphology of the ductus arteriosus—Two morphologic types of PDA were identified on the basis of angiographic appearance (Fig 4). In 20 dogs, the ductus arteriosus resembled a funnel or cone truncated to various degrees with length-to-diameter ratios ranging from 1:1 to 2.69:1. The minimum diameter of the ductal ampulla, which was always located at the pulmonic end of the PDA, ranged from 2.0 to 8.5 mm and was ≥ 4.0 mm in 8 dogs. There was a significant (P = 0.013) but weak (r² = 0.26) correlation between minimum diameter of the ductus and body weight.

In the remaining 3 dogs, the PDA resembled an elongated, narrow tube with a length-to-diameter ratio > 3:1 and minimal tapering along its length, other than

Figure 2—Sequence of angiographic images obtained during deployment of an occluding stent in a dog with a patent ductus arteriosus (PDA). A—A pigtail catheter has been positioned in the aorta, and contrast medium has been injected to demonstrate the location and morphology of the PDA. B—A J-tipped guide wire has been advanced into the descending aorta via an end-hole catheter that was directed through the right ventricle into the pulmonary artery and across the pulmonary orifice of the PDA. C—A delivery sheath with metallic markers at the tip has been advanced over the guidewire and is being directed into the PDA. D—Following removal of the guide wire, the occluding stent is advanced via a delivery cable through the delivery sheath and positioned in the PDA.

Statistical analyses—The Spearman rank correlation test was used to determine whether ductus measurements were associated with shunt grade. Echocardiographic values, arterial pressure measurements, and vertebral heart scores (VHS) were compared with body weight and were analyzed by means of paired Student t tests or repeated-measures ANOVA. All analyses were performed with standard software.

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Figure 3—Two-dimensional (A) and color-flow Doppler (B) echocardiograms obtained from a left cranial parasternal location of a dog with a PDA. The color-flow Doppler echocardiogram clearly shows blood flow from the aorta (AO) through the ductus arteriosus into the main pulmonary artery (PA).
a discrete narrowed segment at the pulmonic attachment. The minimum diameter of the ductal ampulla in these dogs ranged from 2 to 3 mm and was located at the pulmonic end of the ductus arteriosus.

The cross-sectional area of the ampulla at the pulmonic orifice (calculated as $\pi \times \left(\frac{\text{minimum diameter}}{2}\right)^2$), indexed for body weight, was significantly ($P < 0.001$) correlated with shunt grade (Fig 5). There was no significant correlation between length of the PDA, indexed for body weight, and shunt grade.

Deployment of the occluding stent—Four 4/6 mm, six 6/8 mm, five 8/10 mm, six 10/12 mm, and two 12/14 mm occluding stents (the first number refers to the diameter [in mm] of the pulmonic end of the stent; the second number refers to the diameter of the retention disk on the aortic end of the stent) were deployed in the 23 dogs. Stent size was selected to ensure that diameter of the retention disk exceeded the diameter of the ampulla by 20 to 30%.

There were 2 deployment failures, both attributable to operator error. In 1 dog, excessive traction on the delivery cable during detachment caused the occluding stent to recoil into the proximal portion of the ductal ampulla. The device rotated on its axis and settled passively into the body of the ductus in an upside-down orientation. In another dog, the occluding device was successfully deployed in the ductus but subsequently dislodged into the descending aorta as the aortic catheter was withdrawn from the aorta following detachment of the delivery cable. Both dogs survived, but both were removed from the study.

Postdeployment angiography and hemodynamic studies—Ten to 15 minutes after deployment of the occluding stent, mean $\pm$ SD systolic, diastolic, and mean pressures in the aorta proximal and distal to the stent had increased to $102 \pm 17$, $68 \pm 19$, and $83 \pm 19$ mm Hg and $104 \pm 20$, $70 \pm 23$, and $85 \pm 22$ mm Hg, respectively. Compared with predeployment measurements, mean arterial pulse pressure decreased by 13 and 11 mm Hg, respectively, in the aorta proximal and distal to the stent. None of the dogs developed a pressure gradient in the aorta between the proximal and distal sites following stent deployment. Aortography performed 15 to 20 minutes after deployment of the occluding stent (Fig 6) indicated immediate closure of the PDA in 13 of 20 dogs (65%). Two (10%) dogs had grade-1 (trivial) shunts and 5 (25%) had grade-2 (small) shunts after stent deployment. Protrusion of the occluding stent into the lumen of the aorta was not observed. Technical problems precluded aortic angiography in 1 dog. Four of the 6 dogs with residual transductal blood flow had grade-4 (large) shunts prior to stent deployment. Two 8/10, two 10/12, and two 12/14 stents were used in these 6 dogs. Mean procedure time, including postdeployment angiography, was 92 minutes (range, 55 to 150 minutes), and mean fluoroscopy time was 16 minutes (range, 11 to 41 minutes).

Postimplantation complications—Five dogs developed a large hematoma on the medial aspect of the hind limb in which angiographic catheters had been inserted despite the routine precaution of applying manual pressure over the cannulation site for a minimum of 20 minutes after catheter removal. A transfusion of fresh whole blood was administered to 1 of these dogs because of excessive blood loss through the arterial catheterization site. Neither of the 2 oldest dogs enrolled in the study survived to the 1-month follow-up examination. Both dogs were receiving medical treatment for congestive heart failure prior to enrollment in the study. The oldest dog, 7 years of age, died suddenly 6 hours after deployment of the occluding stent. Death was suspected to be a result of an arrhythmia, as the device was appropriately positioned at
necropsy and there was no evidence of hemorrhage, thrombosis, pulmonary congestion, or other identifiable adverse sequelae. The other dog, 5 years of age, developed transient atrial fibrillation following the procedure and was euthanatized 1 week after the procedure because of recurring signs of congestive heart failure.

Postimplantation evaluations—The day following the procedure, physical examination revealed a soft continuous murmur at the left heart base in 3 dogs and an absence of a continuous murmur in 17. Mean ± SD VHS the day after the procedure (11.1 ± 1.2) was significantly (P < 0.05) decreased, compared with values obtained prior to the procedure (11.8 ± 1.3), and pulmonary overcirculation was reduced in comparison to preoperative radiographs (Fig 7).

Echocardiographic examination of the pulmonary artery from a right parasternal location allowed visualization of the stem of the stent in every dog. Color-flow Doppler echocardiography indicated complete closure of the ductus arteriosus in 15 of 20 dogs (Fig 8). A small amount of transductal blood flow through or around the occluding stent was observed in 5 dogs. In each of the 3 dogs with an audible continuous murmur, a jet of high-velocity (> 4 m/s) transductal blood flow could be seen extending across the lumen of the pulmonary artery to the level of the pulmonic valve. In 2 dogs without audible murmurs, low-velocity (2 to 3 m/s) transductal blood flow could be seen in the immediate vicinity of the pulmonic end of the stent. Regurgitant jets were no longer visible in 5 of the 9 dogs with mitral insufficiency prior to the procedure. Three dogs had persistent trivial or small jets of mitral regurgitation, and 1 dog continued to have a large mitral regurgitant jet. Doppler interrogation of blood flow velocity in the proximal portion of the left main pulmonary artery indicated no obstruction to blood flow by the stent in any dog, as the maximum blood flow velocity at the origin of the left pulmonary artery downstream of the device ranged from 0.86 to 1.9 m/s (mean ± SD, 1.3 ± 0.3 m/s).

Significant (P < 0.05) changes in M-mode measurements the day following PDA occlusion, compared with baseline measurements, included decreases in left atrial dimension (mean ± SD decrease, 11.6 ± 14.5%), left atrial-to-aortic diameter ratio (16.3 ± 17.4%), left ventricular diastolic diameter (15.6 ± 12.2%), left ventricular systolic diameter (4.3 ± 11.8%), fractional shortening (32.2 ± 17.8%), and interventricular septal systolic wall thickness (10.3 ± 22.1%) and increases in left ventricular diastolic wall thickness (mean ± SD increase, 12.4 ± 15.2%) and interventricular septal diastolic wall thickness (12.6 ± 25.3%).

Nineteen dogs remained in the study 1 month after implantation of the occluding stent. Four dogs still had a small amount of residual transductal blood flow, as determined by means of color-flow Doppler echocardiography. A small jet of mitral regurgitation persisted in 4 dogs. Blood flow velocity in the origin of the left pulmonary artery had decreased to 1.1 ± 0.2 m/s, and VHSs had decreased to 10.7 ± 0.7. None of the dogs had clinical signs of cardiac disease, and administration of cardiac medications was discontinued in the 3 dogs previously treated for congestive heart failure.

When evaluated 3 months after stent implantation, all dogs remained free from clinical signs of cardiac disease. Low-grade transductal blood flow persisted in 2 dogs, and 3 dogs had small persistent jets of mitral insufficiency. Blood flow velocity in the origin of the left pulmonary artery was unchanged (1.1 ± 0.2 m/s), and VHSs had decreased to 10.4 ± 0.7.
Nine dogs were reevaluated 11 to 25 months after stent implantation, including both dogs with persistent low-grade transductal blood flow 3 months after the procedure. Complete closure of the PDA was verified in 1 dog evaluated 11 months after stent deployment, but a small jet of transductal blood flow persisted in 1 dog last evaluated 18 months after stent implantation. In no instance did transductal blood flow reappear once complete PDA closure was achieved.

**Discussion**

Results of the present study suggest that this occluding stent can successfully be used for occlusion of PDAs in dogs. Except for the exclusion of dogs weighing <3 kg, the study population reflected most of the anatomic challenges likely to be encountered among dogs with spontaneously occurring PDA. Most study dogs had moderate- to large-volume left-to-right shunts resulting in substantial left heart enlargement. Five of 23 (22%) dogs enrolled in the study had signs of congestive heart failure, and 10 (43%) had mild or severe mitral regurgitation. The dimensions and shape of the PDA were quite variable, and the minimum diameter of the ductus ranged from 2.0 to 8.5 mm, providing ample opportunity to evaluate a variety of different sizes of the occluding stent.

Several difficulties were encountered during cardiac catheterization and deployment of the occluding stent. In a few dogs, it was difficult to pass a catheter or guide wire across the pulmonic orifice of the ductus arteriosus, increasing fluoroscopy and procedure time. In small dogs, the introducing sheath tended to kink as it coursed through the body of the right ventricle into the outflow tract, impeding advancement of the stent and attached cable through the sheath. This problem was remedied by advancing the stent to a point just proximal to the bend in the sheath and then advancing the sheath and stent together into the right ventricular outflow tract. Once the sheath was pointed towards the pulmonic valve, the cable and occluding stent could again be readily advanced in the sheath across the ductus and into the thoracic aorta. Avoidable operator error was responsible for deployment failure in 1 dog and dislodgement of the device immediately following device deployment in another dog. On the basis of these experiences, it is advised that the aortic catheter be withdrawn from the vicinity of the ductus prior to detachment of the cable and that all tension be released from the cable prior to detachment. Hemorrhage from the site of entry of the catheter introducer into the femoral artery was a problem in 5 dogs despite the precaution of prolonged digital occlusion. The shape of the hind limb precluded application of an effective occlusive bandage. For these reasons, it may be advisable to perform a surgical cutdown on the femoral artery at the onset of the procedure to accomplish arterial catheterization. At the very least, the operator must anticipate the possible need for surgical repair or ligation of the femoral artery if bleeding is observed after digital occlusion.

Results for dogs in the present study were comparable to reported results of dogs undergoing surgical PDA closure.\(^5\)\(^,\)\(^6\) As with surgical repair, procedural success was most dependent on the skill of the operator and the underlying cardiac status of the affected dog. Operator-related errors occurred early in the study, did not occur in any of the last 16 dogs studied, and should be avoidable with careful attention to technique. The 2 dogs that died during the study period had clinical signs of congestive heart failure prior to implantation of the occluding stent, and neither death could be directly attributed to the technique or device used to accomplish PDA closure. The prevalence of death attributable to arrhythmia and heart failure is similar in dogs treated by surgical repair.\(^5\)\(^,\)\(^6\) In summary, the occluding stent appears to be a useful device for non-surgical closure of PDAs in dogs.

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\(^1\)Amplatzer Duct Occluder, AGA Medical Corp, Golden Valley, Minn
\(^2\)Amplatzer Delivery System, AGA Medical Corp, Golden Valley, Minn.
\(^3\)Vingmed System V, General Electric Medical Systems, Milwaukee, Wis.
\(^4\)CHECK-FLO Performer, Cook Inc, Bloomington, Ind.
\(^5\)Soft-Vu Halo, AngioDynamics Inc, Queensbury, NY.

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**Figure 8**—Color-flow Doppler echocardiograms of a dog following deployment of a stent for occlusion of a PDA. A—During systole, laminar flow was seen as blood was ejected from the right ventricle through the PA and past the occluding stent (arrows). B—During diastole, there was no evidence of blood flow through or around the occluding stent indicating complete PDA closure.
References

11. Porstmann W, Wierny L, Warnke H. Der Verschluß des duc-