Bella, an 18-month-old, 18-lb (8.18-kg), intact female beagle, presented to the Veterinary Medical Teaching Hospital (VMTH) at Texas A&M University with a grade 6/6 heart murmur. Bella was in training for search-and-rescue work, and the owner noted that after 20 to 30 minutes of work, Bella appeared fatigued and dizzy. Two weeks before being seen at VMTH Small Animal Clinic, Bella had been taken to her referring veterinarian to be treated for nasal congestion and to receive vaccinations. The physical examination revealed that Bella had a grade 6/6 systolic cardiac murmur. Radiography and cardiac ultrasonography were performed. Radiographic interpretation was not immediately available; however, cardiac ultrasonography indicated pulmonic stenosis. Bella had been receiving monthly heartworm preventive.

Physical Examination
Bella was bright and alert with a body condition score of 4/9, a temperature of 100.9°F (normal: 100°F to 102°F), a heart rate of 80 bpm (normal: 80 to 120 bpm), and a respiratory rate of 26 breaths/min (normal: 16 to 30 breaths/min). The cardiac murmur was confirmed to be grade 6/6 systolic with a point of maximum intensity over the left base of the heart.

Diagnostics
Doppler echocardiography was repeated, revealing a transpulmonic velocity of 139.61 mm Hg (normal: ≤15.00 mm Hg). The severity of pulmonic stenosis is estimated according to the transpulmonic pressure gradients obtained by Doppler echocardiography. Mild stenosis is considered to be 16 to 49 mm Hg; moderate, 50 to 79 mm Hg; and severe, >80 mm Hg. In Bella’s case, the pulmonic valve leaflets appeared to be thickened and curled and to have restricted movement. The right ventricle was hypertrophied, and moderate to severe tricuspid regurgitation was reported with moderate right atrial enlargement. Electrocardiography (ECG) revealed a normal sinus arrhythmia with a right axis shift evidenced as a right bundle branch block; the average heart rate was 110 bpm.

Pulmonic stenosis is a congenital abnormality of the pulmonic valve resulting in a right ventricular outflow obstruction and is reported to be the third most common congenital cardiac defect in dogs. Thickened or malformed valve leaflets increase the resistance in the outflow tract to the pulmonary artery. Therefore, the right ventricle must work harder to move blood from the right side of the heart to the lungs, resulting in right ventricular hypertrophy in severe cases.

A systolic murmur is produced by the turbulent flow of blood across the pulmonic valve and is best auscultated on the left side between the third and fourth intercostal spaces. A systolic murmur can be difficult to distinguish from a murmur produced by subaortic stenosis. Clinical signs may include exercise intolerance, shortness of breath, cyanosis, and, in extreme cases, syncope. In severe disease, right-sided heart failure produces ascites, right-sided cardiomegaly, jugular pulses, and sudden death.

Predisposed breeds include the English bulldog, boxer, terriers (i.e., West Highland white, Scottish, wire-haired, and Yorkshire terriers), mastiff, Samoyed, miniature schnauzer, Chihuahua, cocker spaniel, and beagle. It is not uncommon to see English bulldogs and boxers with a
Case Report

Type of Pulmonic Stenosis

A type of pulmonic stenosis caused by an aberrant coronary artery. It is recommended that dogs diagnosed with pulmonic stenosis not be used for breeding.2,6

Bella was considered to be a good candidate for interventional catheterization (balloon valvuloplasty) to decrease her pulmonic outflow tract obstruction. She was categorized with a grade 3/5 physical status according to guidelines from the American Society of Anesthesiologists (TABLE 1) with the caveat that dogs with severe pulmonic stenosis are at risk of sudden death. To complete the preoperative workup, blood samples were obtained and submitted for a complete blood count, including packed cell volume, and a biochemical panel, including electrolyte levels and total solid levels. These results were normal. Bella was not tested for heartworm disease because no adult worms had been visualized in the right pulmonary artery during an echocardiogram and she had consistently received a heartworm preventive.

Treatment Planning

Successful interventional catheterization to relieve outflow tract obstruction was first reported in 1987 by Bright et al using balloon dilation in dogs.1 The use of interventional catheterization techniques for treating children with congenital heart disease was reported in 1966 by Dr. William Rashkind. In 2005, Miller1 reported the long-term results of 50 dogs with severe pulmonic stenosis that was treated with balloon dilation at Texas A&M University. Successful balloon valvuloplasty was defined as a 50% decrease in transpulmonic velocity. Based on this interpretation, treatment was considered successful in 78% of patients, and 71% of symptomatic patients had become asymptomatic.

Bella’s treatment was planned to enable constant monitoring. Bella would be premedicated with hydromorphone (0.2 mg/kg SC) with or without an anticholinergic agent, depending on her heart rate. Two peripheral IV catheters would be placed before induction to decrease overall anesthesia time. One of these catheters would allow a dedicated line for administering lidocaine by CRI. The second would have a T-port placed to facilitate the administration of crystalloid fluid therapy and a separate line for the administration of rescue drugs if necessary. In addition, ECG and noninvasive blood pressure monitoring using an oscillometric monitor would be used during induction to evaluate real-time changes in the patient’s cardiac function and blood pressure. Induction agents would consist of diazepam (0.2 mg/kg IV) followed by etomidate (IV to effect), and the patient would be intubated using a Murphy-style endotracheal tube. The inhalant anesthetic agent would be sevoflurane with oxygen. To decrease the minimal alveolar concentration (MAC) of sevoflurane, a constant-rate infusion (CRI) of fentanyl (0.8 µg/kg/min) and midazolam (8 µg/kg/min) would be initiated during surgical preparation. Crystalloid fluid therapy (10 mL/lb/h IV) would also be initiated in the preparation room to help maintain blood pressure.

After induction, a catheter would be placed into the right ventricle, which can be accessed via the right jugular vein by either percutaneous placement or jugular cutdown. This procedure allows angiography of the right ventricular outflow tract and the pulmonary artery to assess the size and location of stenosis. Additionally, pressures would be obtained from the right ventricle and the pulmonary artery before and after dilation. A closed-end, multi-sidehole angiography catheter would be placed in the pulmonary artery, and the pressures would be recorded using an invasive pressure-monitoring channel in the multiparameter patient monitor. The information obtained from this

TABLE 1 Preanesthesia Patient Assessmenta,b

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal patient with no disease</td>
<td>Healthy patient to be anesthetized for neutering</td>
</tr>
<tr>
<td>2</td>
<td>Patient with mild systemic disease that does not limit normal function</td>
<td>Patient with controlled diabetes mellitus or mild cardiac valve insufficiency</td>
</tr>
<tr>
<td>3</td>
<td>Patient with severe systemic disease that limits normal function</td>
<td>Patient with uncontrolled diabetes mellitus or symptomatic cardiac disease</td>
</tr>
<tr>
<td>4</td>
<td>Patient with severe systemic disease that is constantly life-threatening</td>
<td>Patient with heart failure, organ failure, or sepsis</td>
</tr>
<tr>
<td>5</td>
<td>Patient that is moribund and not expected to live 24 hr without surgery</td>
<td>Patient with gastric dilatation–volvulus or respiratory distress</td>
</tr>
</tbody>
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*bThis scoring system from the American Society of Anesthesiologists is widely used. The American College of Veterinary Anesthesiologists has not made a consensus statement on assessing patient status.
A catheter is necessary to determine the balloon catheter size required to achieve adequate balloon dilation of the pulmonary valve. Pressures obtained after dilation would be used to determine the efficacy of the procedure and Bella’s long-term prognosis. Additional patient monitoring consisting of sidestream end-tidal CO2, pulse oximetry (SpO2), and temperature would also begin after induction. Then an arterial catheter would be placed to monitor direct blood pressure once the patient arrived in the interventional catheterization laboratory suite.

After surgical preparation, Bella would be transported, with mobile patient monitoring equipment in place, to the catheter laboratory, and monitoring would be transferred to the stationary equipment in the suite. Lidocaine (a class IB antiarrhythmic agent) would be administered starting at 50 µg/kg/min CRI in anticipation of cardiac arrhythmias stimulated by cardiac catheterization. Two lidocaine boluses of 2 mg/kg each would be available as an additional precaution to prevent arrhythmias. The initial lidocaine bolus would be given just before placement of the cardiac catheter into the right atrium, and the second bolus would follow 10 minutes later to maintain an adequate level of the agent. Typically, the sevoflurane vaporizer can be set at 0.25% to 1.5% after the boluses have been given and the target level of fentanyl–midazolam has been achieved by CRI. The administration of fentanyl–midazolam and lidocaine by CRI provides analgesic and antiarrhythmic effects. The MAC of sevoflurane in dogs is reportedly 2.4%, which demonstrates the MAC-sparing effects of multimodal anesthetic/analgesic agents.7 In the catheter suite, the patient’s body temperature would be maintained using a forced warm-air blanket.

The anticipated complications included the following:

• Life-threatening arrhythmias caused by interventional catheter manipulation and complete occlusion of the right ventricular outflow tract
• Hypotension due to anesthetic agents
• Hypothermia due to anesthetic interference with normal autoregulatory response and ambient temperature of the catheterization suite
• Rupture of the pulmonary artery by overaggressive inflation of the balloon
• Death due to compromised cardiac function

Bella would recover in the intensive care unit (ICU) with orders to administer buprenorphine (7 µg/kg IV q6h), if needed, to keep her calm and relaxed. Vital signs would be monitored every 1 hour for the first 2 hours, then every 4 hours until the next morning. Any pain or discomfort due to the placement of the large-bore catheter or jugular cutdown would be managed with administration of buprenorphine.

**First Surgical Procedure**

Bella was scheduled to arrive in the catheter suite the morning after her diagnostics, so she was placed in the intermediate care ward, where her vital signs were reassessed before the preanesthetic medications were administered. Bella had
a heart rate of 80 bpm, respiratory rate of 32 breaths/min, and body temperature of 100.7°F. She received glycopyrrolate at 0.011 mg/kg SC and hydromorphone at 0.2 mg/kg SC. Thirty minutes after being medicated, she was brought to the induction area, where two peripheral IV catheters were placed and ECG and noninvasive blood pressure monitoring were initiated. Induction with diazepam and etomidate was uneventful, as was intubation with a 7.0-mm internal-diameter, Murphy-style endotracheal tube. Administration of sevoflurane, oxygen, fentanyl (0.8 µg/kg/min CRI), and midazolam (8 µg/kg/min CRI) was initiated. Monitoring was initiated by measuring end-tidal CO2 and SpO2 and placing a rectal temperature probe. The area over the left dorsal pedal artery was clipped and surgically prepared before placement of a 22-gauge over-the-needle catheter. IV crystalloid fluid therapy was initiated at 10 mL/lb/h for the first hour. Bella was placed in left lateral recumbency, and the right lateral cervical area (i.e., ventral to the trachea, dorsal to the cervical vertebrae, and from the point of the jaw to the point of the shoulder) was clipped and surgically scrubbed.

After preparation, Bella was transported to the catheter suite while fully monitored. She was positioned on the table in left lateral recumbency with a small towel roll under her neck to facilitate percutaneous catheterization of her right jugular vein. Her vital signs remained normal, and she was deemed to be in a surgical anesthetic plane. After lidocaine (50 µg/kg/min CRI) was initiated, surgery began. A catheter was placed in the right jugular vein without complications. The cardiologist used fluoroscopy to guide the angiography catheter into the right ventricle. Moments after the catheter passed through the tricuspid valve, Bella developed severe ventricular arrhythmias, so the first bolus of lidocaine was administered. During administration of the bolus, Bella developed a torsades de pointes arrhythmia as the catheter tip touched the wall of the right ventricle (FIGURE 2).

All anesthetic agents were discontinued, the opioids were reversed with naloxone, Bella was rotated to dorsal recumbency, and the cardiologist electrically defibrillated her with 100 joules using external paddles, resulting in a normal sinus rhythm. The cardiologist removed the angiography catheter and applied pressure to the insertion point to maintain hemostasis. Blood was drawn from the arterial catheter and sent to the ICU for arterial blood gas analysis. Most of the results were normal for a patient receiving 100% oxygen; however, the PaO2 value (30.4 mm Hg; normal: 35 to 45 mm Hg) was slightly decreased because of ventilatory assistance during the event.

Bella continued to receive oxygen and ventilatory assistance with monitoring equipment in place. She was extubated on the surgery table in the catheter suite when she regained an active swallow reflex and control of her tongue. Because of her positive response to the reversal effects of naloxone, it was decided not to administer flumazenil to reverse the benzodiazepine. Once Bella was moved to the ICU, a point-of-care blood chemistry analysis showed no abnormalities, and the arterial blood gas analysis was repeated with Bella breathing room air before the arterial catheter was removed. These values were normal. Bella recovered overnight in the ICU without complications.

Discharge From the Hospital

The owner was consulted about the outcome of the procedure and Bella’s prognosis. Bella was discharged with amiodarone (25 mg/kg PO q24h for 10 days, then decreased to 12.5 mg/kg q24h; a class III antiarrhythmic agent) and enalapril maleate (0.312 mg/kg PO; an angiotensin-converting enzyme inhibitor). There were no dietary restrictions, but it was suggested that Bella’s search-and-rescue training be discontinued and that she be allowed to set her own pace regarding her activity level. The owner was interested in continuing to try to correct Bella’s congenital defect. It was planned that Bella would return in 4 to 5 weeks for another balloon dilation. At that time, her laboratory values would be reassessed, and she would be placed in the ICU preoperatively to receive crystalloid IV fluid therapy. This would increase the volume of the right ventricle, facilitating the manipulation of catheters in an expanded space. With Bella’s degree of right ventricular hypertrophy, attempting to place guidewires and catheters could be likened to threading the eye of a needle within tight confines. A large volume of crystalloid fluid was not contraindicated and could be beneficial.

Second Surgical Procedure

Four weeks later, Bella was readmitted to the VMTH. Blood was obtained for a canine N-terminal brain natriuretic peptide (NT-pro-BNP) test (to provide a baseline value to evaluate the stage and the rate of progression of heart disease), a complete blood count, and a biochemical panel, including electrolyte levels. The complete blood
count and biochemical panel results were normal (NT-pro-BNP test results require 7 days). Systemic blood pressure was evaluated using Doppler ultrasound while Bella was in right lateral recumbency with the cuff on her left fore-limb. Her systemic blood pressure was 122 to 148 mm Hg, which was normal. The physical examination results were unremarkable except for the previously reported cardiac murmur.

The morning of the procedure, Bella was placed in the ICU, where a peripheral IV catheter was inserted and crystalloid fluid therapy was initiated at 1.5 times maintenance. The assessment of vital signs and administration of pre-medications proceeded as previously described. The primary departure from the initial anesthesia would be the administration of procainamide (15 mg/kg IM; a class 1A antiarrhythmic agent) after induction. It was hoped that the IM route would avoid hypotension, which can occur with rapid IV administration. The induction and maintenance anesthetic regimen would remain the same. It was hoped that IV crystalloid fluid therapy would increase the end-diastolic volume (as it relates to preload, resulting in an increase in stroke volume) and, therefore, the size of the right ventricle, assisting the cardiologist in catheterization. Bella’s cardiac dysfunction prevented a normal stroke volume from leaving the right side of the heart because of stenosis of the outflow tract, thus decreasing the volume delivered to the lungs and, eventually, the left side of the heart. The echocardiogram had previously demonstrated that Bella’s left ventricle was small, indicating a decrease in stroke volume. The antiarrhythmic agents amiodarone and procainamide were administered to decrease cardiac sensitivity and reduce the risk of life-threatening arrhythmias, allowing the procedure to continue.

Bella tolerated premedication and induction of anesthesia very well. Patient monitoring was initiated as previously described. Neither dorsal pedal artery could be catheterized; therefore, a 22-gauge catheter was inserted into the central artery of the pinna to monitor intraoperative direct blood pressure. Bella was maintained with sevoflurane, oxygen, and a fentanyl–midazolam CRI as previously described. A lidocaine CRI of 75 µg/kg/min was initiated.

After initial surgical preparation, Bella was transported to the catheterization suite, where she was placed on the surgical table in left lateral recumbency, and surgical preparation was completed. The cardiologist inserted an exchange catheter using a percutaneous approach and advanced the angiography catheter into the right ventricle, this time with minimal myocardial sensitivity, producing ventricular tachycardia that was easily controlled by administering lidocaine boluses. An angiogram was obtained (FIGURE 3), and the right outflow tract and pulmonary artery were assessed for location, size, and structure. Pressures from the right ventricle and pulmonary artery were also obtained. An exchange wire was threaded through the catheter into the pulmonary artery. The angiography catheter was removed and replaced with the appropriate-size balloon catheter in the right side of the heart, passing through the right atrium, tricuspid valve, and right ventricle. The catheter was positioned through the pulmonic valve, with approximately 50% of the balloon in the right ventricle and 50% in the pulmonary artery. The objective was to inflate the balloon with fluid, while under pressure, to stretch and dilate the stenotic valve and increase the diameter of the opening. At full inflation, a dramatic fall in systemic blood pressure and the SpO₂ reading is not unexpected because the right outflow tract is fully occluded. Additionally, a decrease in the end-tidal CO₂ due to a decrease in blood flow to the lungs can be expected.

After inflation and deflation of the balloon, Bella’s blood pressure was allowed to return to normal and stabilize. A second inflation was then performed. The balloon catheter was removed and replaced with another catheter to determine the postdilation pressures in the pulmonary artery and right ventricle (FIGURE 4). Bella’s initial pressures were 139 mm Hg; the postdilation pressures were 43 mm Hg. The lidocaine and fentanyl–midazolam CRIs
were discontinued. A vaporizer setting of 1% sevoflurane and oxygen was maintained. The measuring catheter was removed, and pressure was applied to the venipuncture site to provide hemostasis. Once hemostasis was achieved, the site was packed with ice for 15 minutes before Bella was taken to the ICU. Before the arterial catheter was removed, a postoperative arterial blood sample was obtained to assess limited chemistries and electrolyte values using a point-of-care machine. This machine also measured blood gas values, which were not a concern at this time. Bella had an uneventful recovery and spent the night in the ICU with nursing orders as previously described.

**Postsurgical Evaluation**

The following morning, Bella was bright but quiet. A cardiac evaluation indicated mild pulmonic stenosis as shown by a decrease in transpulmonic velocity, with a gradient of 46.38 mm Hg. Bella’s left ventricular internal dimensions had increased because of the ability of the right ventricle to move a greater volume of blood through the outflow tract. A moderate amount of pulmonic insufficiency was noted, as was mild tricuspid regurgitation. ECG showed sinus rhythm with deep S waves in leads I, II, and III, which typically indicates an enlarged right ventricle.6

**Discharge Instructions**

Bella was discharged to her owner with enalapril (0.312 mg/kg PO) and atenolol (0.25 mg/kg PO to be titrated up to a maintenance dose of 0.77 mg/kg), which is a relatively specific β1-blocker for decreasing the sinus heart rate. The atenolol dose would be gradually increased over time. Amiodarone was discontinued at this time. Bella’s defect was decreased from severe to mild. It has been reported that dogs with mild to moderate pulmonic stenosis tend to have a normal life span and quality of life. However, the pulmonic valves can develop scar tissue, resulting in a higher pressure gradient and requiring another balloon dilation procedure. It was suggested that Bella continue to receive her normal diet at home and, after 7 to 10 days of rest, be allowed to set her own pace of exercise. If Bella did not have weakness or exercise intolerance, it was recommended that she be brought to the VMTH for follow-up cardiac evaluations in 3, 6, and 12 months.

**Follow-Up**

Bella returned for a follow-up examination 4 months after the balloon valvuloplasty. Her vital signs were normal, she was bright and alert, and the owner reported that Bella’s energy level had increased to its previous level (i.e., approximately 30 days before the last visit). A grade 6/6 left basilar murmur was auscultated, and the femoral pulses were synchronous and normal. An echocardiogram revealed a further decrease in transpulmonic velocity, with a gradient of 27.04 mm Hg (normal: ≤15.00 mm Hg). It was recommended that administration of enalapril be discontinued, administration of atenolol be continued, and fatty-acid supplementation be initiated because some cardiac patients have been shown to have decreased circulating levels of fatty acids. The presence of certain fatty acids may help prevent cachexia, which occurs in some cardiac patients, and reduce inflammation and the occurrence of arrhythmias.8 Bella’s persistent right ventricle enlargement is expected to decrease over time and will be monitored, along with transpulmonic velocity, at future rechecks.

**References**