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Case Report

Stent angioplasty for treatment of canine valvular pulmonic stenosis^{☆, ☆ ☆}



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Abstract Four dogs presented for evaluation and treatment of severe pulmonic valve stenosis and underwent stenting of the pulmonic valve annulus using bare-metal balloon-expandable stents. All dogs survived the procedure with immediate reduction of the transpulmonary valve pressure gradient and increase in activity levels. One dog had a stent fracture and migration 1 month after the intervention. This dog underwent a second procedure, in which multiple stents were used to alleviate the obstruction. The stents that were placed at the level of the right ventricular outflow tract fractured within 1 month of the procedure, and the patient died when a third (surgical) approach was attempted. The other three dogs remain alive 54, 42, and 29 months after the procedure. Stent angioplasty may be a viable option for dogs with valvular pulmonic stenosis in which routine balloon valvuloplasty does not

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provide a successful outcome. Aggressive attempts to diminish RVOT dynamic obstruction with high-dose beta blockade and avoiding deployment of the stent within the RVOT are recommended to prevent stent fracture and migration.

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Abbreviations

ATM	atmospheres
BV	balloon valvuloplasty
BIB	balloon-in-balloon
CTD	cor triatriatum dexter
PG	pressure gradient
PHT	pressure half-time
PS	pulmonic stenosis
RBP	rated burst pressure
RVOT	right ventricular outflow tract

Case 1

A 4-month-old 11-kg male Labrador retriever mixed dog from a rescue shelter presented to the Small Animal Hospital at the University of Florida for evaluation of a heart murmur. The dog was asymptomatic on presentation. Physical examination revealed a grade V/VI systolic heart murmur at the left base. Echocardiography showed severe right ventricular concentric hypertrophy with flattening of the interventricular septum in systole and diastole (Video 1). Pulmonic valve leaflets appeared severely dysplastic with a pulmonic valve annulus diameter of 12.2 mm (aortic valve annulus of 15.6 mm). Continuous wave Doppler interrogation across the pulmonic valve showed a peak systolic velocity of 5.58 m/s, reflecting an instantaneous transpulmonary systolic pressure gradient (PG) of 124.8 mmHg, consistent with severe pulmonic valve stenosis. There was mild pulmonic insufficiency (pressure half-time [PHT] 551 ms). Coronary artery anatomy appeared normal. Severe thickening of the right ventricular outflow tract (RVOT) was evident, and based on two-dimensional and spectral Doppler tracing,

this thickening appeared to create a dynamic subvalvular stenosis. Atenolol was initiated orally at 0.5 mg/kg every 12 h and titrated up to 2.4 mg/kg every 12 h based on intermittent heart rate checks. The patient returned 1 month later with a resting heart rate of 60 beats per minute. The second echocardiogram showed a reduction of the dynamic subvalvular obstruction but no change on the overall transpulmonary systolic PG (Figs. 1 and 2 available in Supplementary Materials online). Owing to the severe dysplastic pulmonic leaflets, there was concern that balloon valvuloplasty (BV) would not decrease the PG significantly. Consequently, we elected to stent the pulmonic valve. There was concern that the concentric hypertrophy of the right ventricle could result in stent fracture, but as the dynamic obstruction had been well controlled by beta blockers, this was felt to be less unlikely (see Table 1).

The dog was anesthetized the following day. The left femoral artery was catheterized, and angiography of the aortic root using a 5-Fr pigtail catheter^c showed normal coronary anatomy. Right heart catheterization was performed through the right external jugular vein as previously described [1]. The pullback peak-to-peak PG between the right ventricle and pulmonary artery was 46 mmHg. Right ventriculography was performed through a 5-Fr NIH angiographic catheter^c, and the pulmonary artery annulus diameter was measured in systole and diastole (Video 2). The pulmonic stenosis (PS) and dynamic RVOT compression could be visualized. In addition, the distance between the RVOT and the main pulmonary artery segment corresponding to the desired stent implantation site was measured to ensure the appropriate stent size was chosen. A Tyshak 20-mm by 4-cm balloon^d was used to perform balloon sizing of the pulmonary valve obstruction. This allowed us to confirm both the diameter and the anatomic location of the obstruction, which is important in choosing the balloon diameter used to implant the stent and provide confirmation of the desired stent implantation site. Manual inflation of the balloon showed

Table 1 Summary of the peak systolic pressure gradients in mmHg.

Case number	Pre-stent	24 h post stent	Longer term follow up
Case 1	125	60	55 at 36 months
Case 2	151	29	70 at 42 months
Case 3	160	60	N/A
Case 4	120	26	26 at 6 month

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a waist that measured 12 mm in diameter. A Cordis Palmaz XL 29-mm by 10-mm transhepatic biliary stent^e was mounted on a 20-mm × 4-cm balloon-in-balloon^f (BIB) catheter. The stent was mounted by placing it on the balloon and hand crimping it followed by further crimping using a piece of flat 1/8 inch umbilical tape^g (Fig. III available in Supplementary Materials online). The umbilical tape was soaked in contrast^h and wrapped once circumferentially around the stent. It was then sequentially tightened along the length of the stent beginning in the middle. The umbilical tape was then removed. The BIB system is beneficial because it contains a smaller inner balloon which, when inflated, may allow for more precise positioning of the stent before full deployment. Once the position of the stent is optimized, the bigger outer balloon is inflated to expand the stent fully. A balloon wedge pressure catheterⁱ was advanced into the pulmonary artery and a 0.035" 260 cm Amplatz Super Stiff guidewire^j advanced along it. The balloon wedge pressure catheter and the 9-Fr short introducer^c were removed from the external jugular vein, leaving the guidewire in position. A 12-Fr 75-cm Check-Flo Performer introducer sheath^c with dilator was advanced over the guidewire across the stenosis and the dilator was removed. The BIB balloon and mounted stent were advanced over the guidewire into the introducer sheath. Unfortunately, the stent could not be advanced past a kink that had developed in the sheath as the sheath took a turn in the right ventricle to the RVOT. The BIB catheter and stent were removed followed by the sheath and guidewire. The jugular vein was ligated with 3.0 PDS^k, and left femoral venous access was obtained as the dog was lying in left lateral recumbency using a 9-Fr introducer^c. The balloon wedge pressure catheterⁱ was used once again to position the Amplatz Super Stiff guidewire^j in the distal pulmonary artery. The 9-Fr introducer was removed, and a new 11-Fr 85-cm Super Arrow-Flex introducer^l sheath with dilator was then advanced over the wire to a position across the pulmonary obstruction, and the dilator was removed. The previously mounted stent was advanced over the guidewire

and through the sheath to the desired implantation site. The delivery sheath was withdrawn into the right ventricle uncovering the stent. A hand injection of contrast was performed to confirm proper positioning of the stent, and then, the inner balloon was inflated maximally to 10-mm diameter to partially expand the stent. Minimal adjustments were made to achieve the optimal stent position, and then, the outer balloon was inflated to fully deploy the stent at a rated burst pressure (RBP) of 5 atmospheres (ATM) using a balloon inflation device^d. The balloon and delivery sheath were removed. Repeat hemodynamics demonstrated a peak-to-peak pullback gradient of 6 mmHg between the right ventricle and pulmonary artery. The introducer was removed, and the femoral vein was ligated without complications. Dalteparin (150 units/kg once) and cefazolin (22 mg/kg IV every 90 min) were administered intravenously throughout the procedure. After recovery, aspirin at 5 mg/kg and a loading dose of 10 mg/kg of clopidogrel were given. Antibiotic therapy was continued for 2 weeks (cephalexin 30 mg/kg q 12 h orally), and prophylactic anticoagulation provided by clopidogrel (1 mg/kg q 24 h) and aspirin (5 mg/kg q 24 h) was continued for 6 months.

An echocardiogram was performed 24 h after stent placement, showing the stent successfully deployed across the pulmonic valve (Video 1). The systolic PG using continuous wave Doppler was 60 mmHg, with pulmonic regurgitation (PHT of 147 ms, Fig. IV available in Supplementary Materials online). The patient was discharged with a lower dose of atenolol (1 mg/kg q 12 h). One month later, the PG across the stent was 35 mmHg, and it gradually increased to 55 mmHg over the next 36 months. The dog remains alive and asymptomatic at the time of writing this article (54 months after procedure).

Case 2

A 5-month-old 5.3-kg male French bulldog dog presented to the Small Animal Hospital at the University of Florida for evaluation of a heart murmur. The dog had mild exercise intolerance. Physical examination revealed a grade IV/VI systolic heart murmur at the left base. Echocardiography showed severe right ventricular concentric hypertrophy, and the pulmonic valve leaflets appeared severely dysplastic with a pulmonic valve annulus of 7 mm (aortic valve annulus of 10 mm). Continuous wave Doppler across the pulmonic valve showed a peak systolic velocity of 5.62 m/s, reflecting an instantaneous systolic PG of

^e Cordis. Lindenstrasse, 10 6340 Baar, Switzerland.

^f NuMed, Inc. Hopkinton, NY 12965, USA.

^g Jorgensen Laboratories Inc Loveland, CO 80538, USA.

^h Omnipaque 300 mg/mL, GE Healthcare, Marlborough, MA 01752, USA.

ⁱ Arrow International Inc, Reading, PA 19005, USA.

^j Boston Scientific, Marlborough, MA 01752, USA.

^k Ethicon Inc. Somerville, NJ 08876, USA.

^l Teleflex Medical Wayne, PA 19087, USA.

126 mmHg, consistent with severe pulmonic valve stenosis. Atenolol was started at 0.5 mg/kg every 12 h titrated up to 1.5 mg/kg every 12 h to try to control the heart rate and reduce any dynamic obstruction as in case 1. One month later, an echocardiogram showed a PG across the stenosis of 151 mmHg. During BV, the levo phase of the right ventricular angiography demonstrated normal coronary artery anatomy. Dilation was attempted using a 10-mm by 3-cm Marauder balloon^f (RBP 20 ATM) but did not change the PG 24 h after the procedure. A Cordis Palmaz Genesis 28-mm by 10-mm stent^e was placed across the pulmonic valve 2 weeks later in the same manner as in case 1. Owing to the small patient's size, a 10-mm × 2-cm Mustang balloon^j was used to deploy the stent instead of a BIB catheter as the smallest diameter BIB catheter is 12 mm (Video 3). The echo-derived systolic instantaneous PG across the stenosis 24 h after placing the stent was 29 mmHg. The patient also had pulmonary insufficiency with a PHT of 66 ms. At discharge, the patient was continued on atenolol (0.5 mg/kg q 12 h) and started on antibiotics and anticoagulants as in case 1. Regular echocardiograms showed a gradual increase in the PG of up to 70 mmHg at the time of writing this article. The dog is currently alive and remains asymptomatic 42 months after the procedure.

Case 3

A 5-month-old 12.1-kg spayed female, mixed breed dog presented from a rescue shelter organization to the Small Animal Hospital at the University of Florida for evaluation of a heart murmur. The patient was asymptomatic at presentation. Echocardiogram revealed valvular PS with fused and dysplastic leaflets and an echo-derived instantaneous systolic PG of 155 mmHg. Balloon valvuloplasty was performed with a 16-mm by 4-cm Tyshak II balloon^d (RBP 2.5 ATM) and was unsuccessful, with an echo-derived instantaneous systolic PG of 133 mmHg 24 h after the procedure. One year later with the patient weighing 23.3 kg, an echocardiogram showed that the PG had increased to 160 mmHg. A Cordis Palmaz XL 29 mm by 10 mm transhepatic biliary stent^e was then implanted across the pulmonary valve as in case 1. Twenty-four hours after stent implantation, an echocardiogram showed an RVOT systolic PG of 60 mmHg and pulmonic regurgitation (PHT 150 ms). At discharge, the patient was continued on atenolol (0.5 mg/kg q 12 h) and started on antibiotics and anticoagulants as in case 1. One month later, a recheck echocardiogram showed migration of the stent more distally into the pulmonary artery and persistent PS with a systolic PG

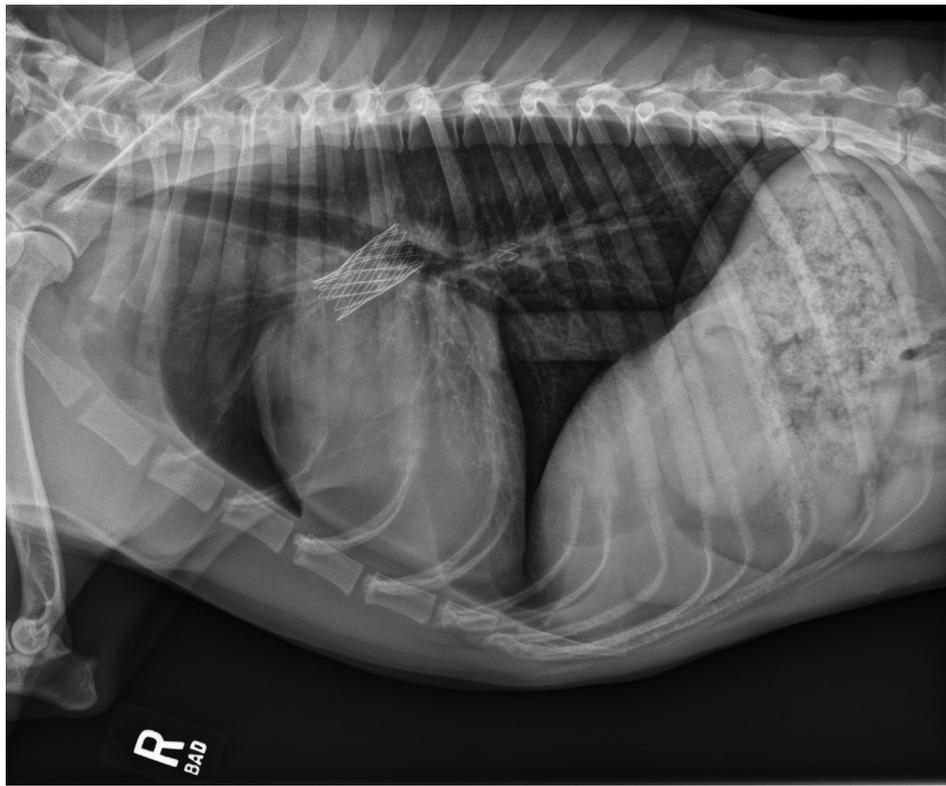


Fig. 1 Right lateral thoracic radiograph of case 3 showing stent fracture and migration toward the left pulmonary artery.



Fig. 2 Right lateral thoracic radiograph of case 3 showing fracture of multiple stents. Stent debris migrated throughout the pulmonary vasculature.

of 160 mmHg. Thoracic radiographs showed a fracture of the proximal edge of the stent and a displaced fragment further out in the pulmonary artery (Fig. 1). A second stent implantation procedure was planned. The first stent was flared proximally using a 14-mm by 4-cm Tyshak II balloon^d to better accommodate the distal section of the second stent and allow the stents to overlap (Video 4). The second Cordis Palmaz XL 39-mm by 10-mm stent^e barely spanned the obstruction so a third Cordis Palmaz XL 29-mm by 10-mm stent^e was deployed. Compression of the third stent in the RVOT was seen during systole so a fourth Genesis 28-mm by 8-mm stent^e was used. Unfortunately, during deployment of the fourth stent, the stent did not expand to the desired diameter and was unstable. Attempts to change the stent's conformation with a high pressure 18-mm by 2-cm Atlas Gold balloon^m (RBP 16 ATM) were unsuccessful, so a fifth Cordis Palmaz XL 29-mm by 10-mm stent^e was used to stabilize that stent. The 12-Fr 75-cm Check-Flo Performer introducer sheath^c kinked after the third stent and had to be replaced. Ultimately, a total of four new stents were placed in the main pulmonary artery and RVOT to achieve adequate relief of the RVOT obstruction

and pulmonary artery stenosis. Postoperative thoracic radiographs and echocardiogram showed an echo-derived systolic gradient of 36 mmHg across the RVOT. One month later, thoracic radiographs revealed fracture of the stents with migration of the fragments into the pulmonary arteries (Fig. 2). The patient was referred to Colorado State University for evaluation and possible surgical intervention. The dog died during an attempt to place a conduit between the right ventricle and pulmonary artery to bypass the obstruction.

Case 4

A 2-month-old 5.6-kg female mixed breed dog was referred for an evaluation of PS and perforate cor triatriatum dexter (CTD). There was marked ascites on presentation. The echocardiogram showed a systolic PG across the pulmonary valve of 140 mmHg and a systolic PG across the CTD of 18 mmHg. The CTD was dilated using a 10-mm by 3-cm Tyshak II balloon^d (RBP 3.5 ATM) followed by a 17-mm by 3-cm Tyshak II balloon^d (RBP 2.5 ATM). Balloon valvuloplasty of the PS was performed using a 10-mm by 3-cm Tyshak II balloon^d (RBP 3.5 ATM). The echocardiogram 24 h after the procedure showed a systolic PG across the pulmonary

^m Bard Peripheral Vascular Inc, Tempe, AZ 85281, USA.

valve and CTD of 29 mmHg and 1.5 mmHg, respectively. Shortly after discharging the patient, the ascites resolved. However, the patient presented 5 months later with dyspnea due to pleural effusion, requiring periodic drainage. An echocardiogram showed no change in the PG across the CTD but a PG across the pulmonary valve of 120 mmHg. There was concern that the pleural effusion was secondary to the PS, and a Cordis Palmaz Genesis 28-mm by 10-mm stent^e was placed as described in case 1 (Video 5). Angiography confirmed relief of the obstruction (Video 6). An echocardiogram 24 h after the procedure showed a systolic PG across the stent of 26 mmHg and pulmonic regurgitation (PHT of 178 ms). Further echocardiograms at 1, 3, and 6 months showed correct stent placement across the stenosis with unchanged pressures across the stent or CTD. However, the pleural effusion did not resolve, requiring frequent drainage. After periodic thoracentesis and antibiotic therapy, a computed tomography angiogram confirmed the presence of a torsion of the left cranial lung lobe. A lung lobectomy was performed, and patient recovered uneventfully. Pleural effusion resolved and did not recur. Patient is asymptomatic at the time of writing 29 months after the procedure.

Discussion

Despite the popularity of BV to treat valvular PS [2], there are a number of cases where an adequate reduction on the PG is not achieved. Locatelli et al. [3] found an optimal outcome with a PG of less than 50 mmHg in 56% of all dogs treated with BV in the long term, and this was poorer in the type B dogs (38%). Severely dysplastic valves, with or without hypoplasia of the pulmonary artery annulus, are important factors that may make routine valvuloplasty unsuccessful. This case report shows the long-term outcome of cases with PS that underwent stent angioplasty with an immediate reduction in PG (see Table 1). Three of the four dogs had a previously unsuccessful BV. In the case where a stent was chosen initially, the valve leaflets appeared very thick and dysplastic; it was felt unlikely that the dog would benefit from BV. A previous case report [4] described the successful deployment of stents in two cases of PS, with resolution of clinical signs. Restenosis led to euthanasia of both dogs 7 and 8 months after procedure. Stents were successfully deployed in all our dogs, and long-term follow-up (3 to 5 years at the time of writing this article) showed good results except in one dog. Case 3 of our study

had a stent fracture 1 month after the procedure. Compared with the other cases in this case series, the stent was placed considerably more proximally into the right ventricle, and there was more severe dynamic RVOT obstruction as noted from angiography, suggesting that compression by the RVOT may have contributed to cyclic fatigue on the stent material, ultimately leading to its fracture. The concept of cyclic fatigue states that any metallic stent will fatigue and eventually fracture depending on time, loading conditions, or deformation [5] and needs to be considered when choosing a stent. Despite using stents with the highest radial strength available, the combination of metal cyclic fatigue and the strength of the hypertrophied cardiac muscle make it difficult to avoid stent fracture and migration. We suggest that careful planning should be performed to avoid placing the stent too proximally within the RVOT to minimize this complication while making sure that there is adequate length proximal to the obstruction to anchor the stent in position. Maximizing the dose of beta blockers to reduce infundibular hypertrophy and dynamic obstruction may also help reduce the risk of stent fracture at the level of the RVOT. Using a BIB balloon may allow optimization of the stent position as the partially inflated stent can typically be repositioned more proximally or distally before full deployment. The BIB catheters have an inner balloon that is half the diameter and 1 cm shorter than the outer balloon with a burst pressure of 4.5–5.0 ATM. Other techniques such as rapid pacing [6] or inducing bradycardia [7] can also be used to minimize cardiac motion and help with successful deployment.

The coronary artery anatomy was assessed during the initial echocardiogram. If the dog was a breed believed to be at risk of an R2A anomaly and the left coronary artery could not be clearly visualized, the coronary artery anatomy was assessed by angiography at the time of the catheterization. Again, if the anatomy could not be identified during the levo phase of a right ventricular injection, selective aortic angiography was performed. Standard doses reported of atenolol range from 0.25 to 1 mg/kg q 12–24 h [8], but achieving a reduction of the heart rate may require higher doses. The reason for this disparity in therapeutic effects is unknown, but polymorphisms on adrenergic receptors play an important role in people [9]. Polymorphisms in the canine and feline beta-1 receptors have been identified [10,11], and this should be considered when evaluating the efficacy of beta blockers. Preoperatively, the authors used a dose of beta blockers based on the effect on the heart rate

rather than on body weight, reaching doses of up to 2.5 mg/kg every 12 h to obtain a heart rate around 70 beats per minute, with minimal increase in the rate during excitement. This was achieved in three of the four cases and slow up-titration helped to minimize side effects.

Placing vascular stents raises the concern for intravascular thrombosis. Whether anticoagulant and/or antiplatelet therapy is necessary in these cases is not known. In people, stent thrombosis after bare-metal stent typically occurs within the first 30 days after implantation [12]. The addition of dual-antiplatelet therapy for up to 6 to 12 months after coronary stent implantation has resolved this problem [13]. We followed the same approach, and no signs of thrombus formation were seen in our cases. Aspirin and clopidogrel were discontinued after a period of 6 months without obvious worsening of the echocardiographic findings.

After the first stent fractured in case 2, its migration did not impair the pulmonary blood flow. This was likely due to the uncovered nature of the stent. Although the use of covered stents can help minimize growth through the metallic skeleton of the stent, we recommend avoiding their use for the treatment of PS to prevent acute obstruction to blood flow should the stent migrate into the pulmonary arteries [14]. The large diameter covered stents currently available in the United States are made of platinum which provides less radial strength than their stainless steel counterparts. This may place them at higher risk for compression or fracture after implantation. In addition, the platinum–iridium stent frame of the large diameter covered stents currently available in the United States is similar to the platinum–iridium stent frame used to manufacture the Melody Transcatheter Pulmonary Valveⁿ which is known to commonly experience stent fracture after implantation in dysfunctional RVOT conduits [15]. Actual stent selection depends on availability and the size of the RVOT. Stents can be overdilated so their 'true' maximal expandable diameter is greater than the range indicated by the manufacturer [16].

Long-term evaluation of the three other cases in which the stent did not migrate showed mildly decreased right ventricular hypertrophy, with an increase of the right ventricular systolic and diastolic internal diameters, most likely secondary to the pulmonic regurgitation. Severe pulmonary regurgitation caused by a virtually absent pulmonic valve is a sequela that needs to be considered after stent implantation. However, none of

the patients that are alive at the time of writing this article demonstrate clinical consequences from this complication. It may be that the shorter lifespan of canine patients compared with humans makes this less of a consideration. Right ventricular outflow tract stenting in humans is more commonly a bridge to a definitive repair using cardiopulmonary bypass [16]. Perhaps, patients with concurrent severe tricuspid regurgitation may have a different outcome. None of the patients in this report had tricuspid regurgitation.

Owing to the severe regurgitation and volume overload after stent implantation, it is difficult to assess the systolic PG accurately. The increase in flow velocity across the stent typically indicates either a smaller orifice (obstruction) or increased flow due to regurgitation [17]. The shortened PHT of the pulmonic regurgitation observed in all patients suggests that the increase in flow velocity may be due to severe regurgitation, rather than true reobstruction/narrowing of the pulmonary outflow tract and may explain some of the increase in velocity with time.

Although these dogs did not have any obvious clinical signs at presentation, all owners reported an increase in activity after stent implantation, suggesting that exercise intolerance and/or reduced activity was initially present. Case 4 developed pleural effusion and lung lobe torsion after the intervention for the CTD and routine valvuloplasty, and the effusion resolved after lung lobectomy. Therefore, it is unlikely that the PS played an important role in the clinical picture of this case.

This case report shows the long-term evolution of patients with PS after stent implantation. Whether this procedure provides a longer survival compared with routine BV remains unknown, and future controlled studies are necessary. However, this procedure may be a viable option for those patients that do not respond to balloon dilation or those that are likely to have a poor outcome.

Conflicts of Interest Statement

No conflicts of interest are declared by any author.

Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jvc.2018.10.007>.

ⁿ Medtronic, Minneapolis, MN, 55432, USA.

Video table

Video	Title	Description
1	Case 1: Transthoracic two-dimensional echocardiography before and after stent procedure	Compilation of echocardiographic images of case 1, before and after stent implantation
2	Case 1: Right ventricular angiogram	Right ventricular angiogram from case 1 showing the right ventricular outflow tract obstruction and dynamic compression
3	Case 2: Stent intervention	Compilation of angiographic images of case 2 during and after stent implantation
4	Case 3: Second intervention with multiple stents	Compilation of angiographic images of case 3 during the second intervention.
5	Case 4: Inner balloon inflation	Angiogram during stent implantation in case 4 with the inner balloon inflated. The stent can be manipulated to ensure correct positioning
6	Case 4: Right ventricular angiogram after stent placement	Angiogram after final stent placement showing relief of the obstruction

References

- [1] Schrope DP. Balloon valvuloplasty of valvular pulmonic stenosis in the dog. *Clin Tech Small Anim Pract* 2005;20: 182–95.
- [2] Locatelli C, Spalla I, Domenech O, Sala E, Brambilla PG, Bussadori C. Pulmonic stenosis in dogs: survival and risk factors in a retrospective cohort of patients. *J Small Anim Pract* 2013;54:445–52.
- [3] Locatelli C, Domenech O, Silva J, Oliveira P, Sala E, Brambilla PG, Bussadori C. Independent predictors of immediate and long-term results after balloon valvuloplasty in dogs. *J Vet Cardiol* 2011;13:21–30.
- [4] Scansen BA, Kent AM, Cheatham SL, Cheatham JP. Stenting of the right ventricular outflow tract in 2 dogs for palliation of dysplastic pulmonary valve stenosis and right-to-left intracardiac shunting defects. *J Vet Cardiol* 2014;16: 205–14.
- [5] Gong XY, Chwirut DJ, Mitchell MR, Choules BD. Fatigue to fracture: an informative, fast, and reliable approach for assessing medical implant durability. *J ASTM Int (JAI)* 2009; 6:1–10.
- [6] Okamura A, Ito H, Iwakura K, Kawano S, Kurotobi T, Koyama Y, Date M, Inoue K, Ogihara T, Fujii K. Rapid ventricular pacing can reduce heart motion and facilitate stent deployment to the optimal position during coronary artery stenting: initial experience. *Euro Intervention* 2007 Aug;3:239–42.
- [7] Davidavicius G, Chieffo A, Shannon J, Arioli F, Lelasi A, Mussardo M, Takagi K, Maisano F, Montorfano M, Godino C, Latib A, Colombo A. A high dose of adenosine to induce transient asystole for valvuloplasty in patients undergoing transcatheter aortic valve implantation (TAVI): is it a valid alternative to rapid pacing? A prospective pilot study. *J Invasive Cardiol* 2011 Nov;23:467–71.
- [8] Papich MG. Appendix I: table of common drugs: approximate dosages. In: Bonagura JD, editor. *Kirk's Current Veterinary Therapy XV*. WB Saunders; 2013. p. 1307.
- [9] Pacanowski MA, Gong Y, Cooper-Dehoff RM, Schork NJ, Shriver MD, Langae TY, Pepine CJ, Johnson JA. INVEST investigators. β -Adrenergic receptor gene polymorphisms and β -blocker treatment outcomes in hypertension. *Clin Pharmacol Ther* 2008 Dec;84:715–21.
- [10] Maran BA, Mealey KL, Lahmers SM, Nelson OL, Meurs KM. Identification of DNA variants in the canine beta-1 adrenergic receptor gene. *Res Vet Sci* 2013;95:238–40.
- [11] Meurs KM, Stern JA, Reina-Doreste Y, Maran BA, Chdid L, Lahmers S, Keene BW, Mealey KL. Impact of the canine double-deletion β 1 adrenoreceptor polymorphisms on protein structure and heart rate response to atenolol, a β 1-selective β -blocker. *Pharmacogenet Genom* 2015; Sept25:427–31.
- [12] Kirtane AJ, Stone GW. How to minimize stent thrombosis. *Circulation* 2011;Sep 13;124:1283–7.
- [13] Waksman R, Ajani AE, White RL, Pinnow E, Dieble R, Bui AB, Taaffe M, Gruberg L, Mintz GS, Satler LF, Pichard AD, Kent KK, Lindsay J. Prolonged antiplatelet therapy to prevent late thrombosis after intracoronary γ -radiation in patients with in-stent restenosis. *Circulation* 2001 May 15;103:2332–5.
- [14] Hascoet S, Baruteau A, Jalal Z, Mauri L, Acar P, Elbaz M, Boudjemline Y, Fraisse A. Stents in paediatric and adult congenital interventional cardiac catheterization. *Arch Cardiovasc Dis* 2014;107:462–75.
- [15] McElhinney DB, Cheatham JP, Jones TK, Lock JE, Vincent JA, Zahn EM, Hellenbrand WE. Stent fracture, valve dysfunction, and right ventricular outflow tract reintervention after transcatheter pulmonary valve implantation: patient-related and procedural risk factors in the US Melody Valve Trial. *Circ Cardiovasc Interv* 2011 Dec 1;4:602–14.
- [16] Peters B, Ewert P, Berger F. The role of stents in the treatment of congenital heart disease: current status and future perspectives. *Ann Pediatr Cardiol* 2009;2: 3–23.
- [17] Oh JK, Seward JB, Tajik AJ. Hemodynamic assessment. In: *The Echo Manual*. 2nd ed. Lippincott-Raven Publishers; 1999. p. 59–71.