TITLE: Surgical treatment of pulmonic stenosis in dogs under cardiopulmonary bypass: outcome in nine dogs

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Surgical treatment of pulmonic stenosis in dogs under cardiopulmonary bypass: outcome in 9 dogs

Objectives: to describe the outcome for 9 dogs with pulmonic stenosis treated by open patch grafting using expanded polytetrafluoroethylene under cardiopulmonary bypass.

Methods: data were collected from the hospital records of all dogs that had undergone right ventricular outflow tract grafting with an expanded polytetrafluoroethylene patch under cardiopulmonary bypass between 2006-2012 for the treatment of pulmonic stenosis. Echocardiographic images were reviewed and the pressure gradient across the right ventricular outflow tract re-measured. Owners for dogs still alive at the time of writing were invited to return to the hospital for reassessment.

Results: 9 dogs met the inclusion criteria. Median pressure gradient pre-operatively was 118 mmHg, (range 102 to 259 mmHg) reducing to a median of 20 mmHg (range 7-53 mmHg) at 48 hours post-operatively and 14 mmHg (range 10 to 70 mmHg), with a median percentage reduction of 89% (range 41 to 94%) at long term follow-up. 8/9 dogs survived surgery, with 6/9 surviving to hospital discharge. Two dogs were still alive over 6 and 8 years post-operatively. No long term deaths were believed to be attributable to pulmonic stenosis.

Clinical significance: expanded polytetrafluoroethylene patch grafting of the right ventricular outflow tract for treatment of severe pulmonic stenosis in dogs is feasible and can be an effective method to reduce the severity of right ventricular outflow tract obstruction.

Introduction

Pulmonic stenosis (PS) is caused by a narrowing or obstruction of the right ventricular outflow tract (RVOT) in the region of the pulmonic valve. It has been reported to be the most common congenital heart disease in dogs, accounting for 32% of congenital defects in one study (Oliveira et al. 2011) and is most frequently caused by a valvular malformation (Oliveira et al. 2011, Ristic et al. 2001)1. Balloon valvuloplasty (BV) is generally considered to be the most appropriate first line treatment for valvular PS due to its safety and reportedly high success rates (Johnson et al. 2004a). Surgical intervention is considered in dogs in which BV has failed to reduce the pressure gradient (PG) within the RVOT, to relieve clinical signs, or in dogs considered to be poor candidates for BV. The latter include dogs with deformed, dysplastic valve leaflets (type B valvular stenosis) and hypoplasia of the pulmonic valve annulus (Bussadori et al. 2001, Locatelli et al. 2011), or those dogs in which there is significant infundibular hypertrophy contributing to dynamic outflow tract obstruction (Johnson et al. 2004b). For these dogs, the RVOT patching technique is considered more likely to be successful in reducing the RVOT PG (Hunt et al. 1993, Orton et al. 1990).

Patch grafting of the RVOT was originally reported in the human literature for the treatment of tetralogy of Fallot in 1956 (Lillehei et al. 1956). Since then a variety of patch materials and techniques have been described, including aortic homografts (Longmore et al. 1966), autologous fascia lata composite grafts (Ionescu et al. 1970), autologous pericardial patch grafts (Yang et al. 2013), cryopreserved homografts (Youn et al. 2007), polyethylene terephthalate (PET) (Breznock et al. 1976) and expanded polytetrafluoroethylene (ePTFE) (Matsumoto et al. 2001, Orton et al. 1990). Similarly there has been a wide variety of techniques reported in dogs. Initial reports in dogs describe variations of closed pericardial patch-grafting techniques, perfomed without the need for cardiopulmonary bypass or total venous inflow occlusion) (Breznock et al 1976, 1976, Shores et al. 1985, Hunt et al 1993, Staudte et al 2004) . Collectively these studies report experience from a total of 35 dogs, with a perioperative mortality rate of 11-17%.

A modified open technique has also been described using total venous inflow occlusion (TVIO) (Orton et al. 1990, Hunt et al 1993), incorporating an expanded polytetrafluoroethylene patch (ePTFE) or native pericardial patch with or without concurrent hypothermia. More recently, open patch-grafting has been described using bovine vena cava patch graft under cardiopulmonary bypass in 10 dogs (Tanaka et al 2009) and in 2 additional dogs using glutaraldehyde-fixed canine tunica vaginalis (Fujiwara et al. 2012).

Collectively, these descriptive reports present the short term results of a range of techniques and patch graft materials and document a range of follow up times, with a maximum follow-up time of 40 months. Notably many of these reports predate the time when balloon valvuloplasty became an established and widely performed procedure in dogs. Thus only a total of 12 dogs are reported that have undergone patch graft surgery under conditions of CPB.

The purpose of the study reported here was to describe the short and long term outcome for 9 consecutive dogs with pulmonic stenosis treated by open patch grafting using ePTFE under CPB, and to compare their outcomes to those previously reported in the literature using alternative techniques.

Materials and Methods

Cases were selected for surgery if they had a diagnosis of pulmonic stenosis and had either undergone balloon valvuloplasty without an adequate reduction in pressure gradient and/or clinical signs, or were considered at a high risk of failing an attempted balloon valvuloplasty approach, as discussed above. Owners were carefully counselled as to the emotional and financial commitment of the procedure and consented to surgery after full consideration of the risks involved. Data were collected from the medical records of all dogs that had been diagnosed with pulmonic stenosis that had undergone RVOT patching under CPB between 2006-2012. The diagnostic criteria for PS was the generation of an estimated PG in the RVOT of greater than 20mmHg, calculated from the modified Bernoulli equation, using the spectral Doppler derived peak blood flow velocity (Bussadori et al. 2000) with concurrent typical 2D lesions; the latter included the presence of pulmonic valve leaflet fusion and systolic doming, thickened or dysplastic leaflets or PA annulus hypoplasia. Dogs with 2D lesions consistent with double chambered right ventricle or infundibular PS were excluded. Data collected included signalment, clinical signs, previous and current medication, echocardiographic data, duration of anaesthesia, duration of CPB and surgery, and pre- and post-operative complications. Long-term survival outcome was determined by contacting the referring veterinarians. For dogs still alive, the owners were contacted and asked to complete the FETCH questionnaire (Freeman et al. 2005). Owners were invited to return to our centre for re-examination and a repeat echocardiogram. Minor complications were defined as those requiring no surgical intervention and major as those requiring surgical intervention or resulting in death.

Echocardiographic studies were performed by a board-certified cardiologist or supervised cardiology resident using the same ultrasound machine (Vivid 7 or Vivid E9, General Electric Medical Systems Ultrasound). Standard echocardiographic views were obtained according to recommendations by the Echocardiography Committee of American College of Veterinary Internal Medicine (Thomas et al. 1993). Spectral Doppler tracings were also acquired to demonstrate flow across the stenosis (from either the right parasternal short axis view or left cranial view, according to the view considered to optimise alignment with the maximal flow velocity). Echocardiographic data collected included the PG within the RVOT pre-balloon valvuloplasty (where applicable), pre-operative PG (PG_{pre}), the PG 48 hour post-operatively (PG_{48}) and the PG at the final assessment (PG_{final}). Pulmonic insufficiency was assessed and graded according to Locatelli et al. (2011); the presence and severity of pulmonary valve insufficiency pre- and post-operatively was assessed through colour flow mapping, considering the extension of the regurgitating jet and its width at the origin. Any pulmonic regurgitant jet with a proximal width greater than 50% of the right ventricular outflow tract diameter at that level was considered significant. If the jet extended only into the outflow tract, the regurgitation was classified as mild. If the jet proceeded to the tricuspid valve, the regurgitation was considered severe. Between both was considered moderate (Locatelli et al. 2011). All stored images were reviewed by and re-measured by a single examiner (JS).

The protocols for anaesthesia and CPB used in this study were performed as previously described (Orton et al. 2001, Orton et al. 2002). All dogs had a right central venous line placed and invasive arterial blood pressure monitoring was performed via a dorsal pedal arterial catheter or if unable to obtain cannulation at this site, via a "cut down" to the right femoral artery. Perioperative antibiotic prophylaxis was with cefuroxime (Zinacef, Galxosmith Kline) at 20mg/kg intravenously, every 90 minutes. A left 5th intercostal thoracotomy was performed. The cardiopulmonary bypass circuit consisted of either a single one-stage or two-stage venous drainage cannula placed through the right auricular appendage and into the right atrium/caudal vena cava, as appropriate. In one dog with tricuspid valve dysplasia, bicaval cannulation was performed with one cannula placed directly into the extracardiac cranial vena cava (CVC) and the caudal caval cannula placed across the right atrium, via the right auricular appendage, with snares around the cranial and caudal cavae to create total bypass and minimise the risk of air entering the circuit across the incompetent tricuspid valve. The arterial limb of the circuit was completed with an arterial cannula in the left external carotid. An aortic root cannula was placed through a pre-placed purse string suture of 5-0 Prolene. Following aortic cross-clamping, cold (4º C) cardioplegia solution (Cardioplegia infusion – Martindale), combined with blood from the bypass circuit, was infused into the aortic root through this cannula, in all but one dog who received no cardioplegia. Cardioplegia was delivered at 20 minute intervals or whenever mechanical cardiac muscular activity was observed. An incision was made across the valve from the main pulmonary artery extending into the ventricle, mid-way between the paraconal interventricular branch of the left coronary artery and the right coronary artery. The incision was extended two thirds of the way down the ventricular free wall towards the apex of the heart (Figure 1). The valve leaflets were examined and excised. A sheet of ePTFE was trimmed to the appropriate size in an ovoid shape and sutured into the defect in the pulmonary artery using GoreTex® suture material (CV-5). This was placed using a double armed suture with an ePTFE pledget started at the proximal end of the patch where a knot was tied. A line of sutures was then placed in a simple continuous pattern at the caudal border, followed by the same pattern with the other end of the suture at the cranial border. These were then knotted together with addition of a second ePTFE pledget at the ventral extent of the patch (Figure 2). The hearts were de-aired as the last sutures were placed in the patch. The dogs were re-warmed, the cross clamp removed and the dogs were weaned from CPB once normal sinus rhythm or a regular epicardial paced rhythm was established. The dogs were recovered from anaesthesia in the intensive care unit where their therapy was adjusted according to perceived needs based on changes in arterial blood gas measurements, blood pressure, urine production and fluid retrieved from the chest drain. Antiplatelet therapy (aspirin 0.5mg/kg PO q24 h) was instituted the day following surgery and continued for three months.

Statistical analysis was performed using a commercially available software package (GraphPad Prism 6). Descriptive statistics were performed and reported as median and range if not normally distributed and mean and standard deviation if normally distributed. Continuous data (PG, weight, age, time of anaesthesia, bypass and surgery) were assessed for normality using the Shapiro-Wilk Test.

Results

Nine dogs met the inclusion criteria. There were two Cocker spaniels and one each of Japanese Akita, Bullmastiff, English Bulldog, Flat coated retriever, German Shepherd dog, Miniature Schnauzer and Shetland Sheepdog. Seven dogs were male (four entire) and two were female entire. Body weight at time of surgery ranged from 7 to 43.6 kg with three dogs weighing 15 kg or under. Age at the time of surgery ranged from 7 to 38 months with 6 dogs less than one year old, (Table 1).

Pre-operative data

All dogs apart from one underwent balloon valvuloplasty prior to surgery. The 8 month old Shetland Sheepdog did not undergo balloon valvuloplasty as she had severe infundibular hypertrophy and a very hypoplastic pulmonary artery (with a main pulmonary artery:aortic diameter ratio of 1:2.35 and no evidence of post-stenotic dilation), and the chances of success with BV were considered to be low. Time from BV to surgery ranged from 56 to 454 days with a mean of 126 ± 57 days. The pre-balloon valvuloplasty PG was available for 5 dogs and consistent with severe stenosis in all, with a median value of 164 mmHg (range 127-210 mmHg). After balloon valvuloplasty the median PG was 113 mmHg (range 108-167 mmHg).

Five dogs had clinical signs attributed to their cardiac disease pre-operatively; 2 had exercise intolerance, one had a history of syncope, one was exercise intolerant and inappetent and another was polycythaemic and cyanotic. Two dogs had experienced episodes of right sided congestive heart failure pre-operatively. All dogs were receiving cardiac medications that included atenolol in all dogs (Teva, Tenormin; AstraZeneca), furosemide (Frusedale; Dechra, Frusemid; Millpledge, Frusol; Rosemont), n=3, benazepril (Fortekor; Elanco Animal Health or Benazecare; Animal Care Group plc), n=3 and spironolactone (Prilactone; Ceva), n=2. Three dogs were receiving 3 medications with the remainder receiving one (atenolol).

On echocardiography, 4 dogs had a patent foramen ovale (PFO), 3 of which were right to left shunting (the direction of shunting was not confirmed retrospectively in one dog due to the lack of a bubble study). One dog had a small (1.5mm) sub-aortic ventricular septal defect (VSD) with right to left systolic shunting (this was the dog with severe infundibular hypertrophy and a very hypoplastic pulmonary artery). As well as having a PFO, one dog also had tricuspid valve dysplasia, characterised by abnormal tethering of both valve leaflets and the presence of tricuspid regurgitation. Tricuspid regurgitation was estimated to be severe based on a subjective assessment of the size of the tricuspid regurgitation jet in relation to the size of the right atrium. Median PG_{pre} was 118 mmHg, (range 102 to 259 mmHg). Pulmonic regurgitation was able to be assessed in 4 dogs pre-operatively and was graded as moderate in 3 and as mild in 1.

Intra-operative data

Surgery was performed under CPB in all dogs, with one performed with the heart beating. In addition to patch grafting of the RVOT, all dogs had partial/subtotal pulmonic valvectomy.

Intraoperative complications occurred in two dogs. One dog was euthanatised intra-operatively due to inability to successfully wean from cardiopulmonary bypass; this dog had severe hypocalcaemia but the reason it could not be weaned from bypass remains speculative. In the other dog, haemorrhage from the aortic root cannulation site occurred and this was repaired with sutures.

Eight out of 9 dogs survived surgery. Median total anaesthesia time (n=6) was 404 minutes (range 294 to 531 minutes), median surgical time (n=6) was 273 minutes (range 180 to 366 minutes), and median CPB time (n=6) 71 minutes (range 27 to 168 minutes).

Short term post-operative data

Complications

Fatal complications in the immediate post-operative period occurred in 2/8 dogs. The dog that had bled intra-operatively from the aortic root cannula site developed haemothorax within a few hours of cessation of cardiopulmonary bypass, and during thoracocentesis the dog underwent cardiopulmonary arrest and died. One dog developed profound hypotension of undetermined cause and despite aggressive supportive care, suffered a fatal cardiac arrest. For the remaining dogs, median PG at 48 hours post-operatively (PG_{48}) was 20 mmHg (range 7-53 mmHg). Pulmonic regurgitation had increased to severe in 2 dogs, remained as moderate in 1 and was graded as moderate and severe in 2 further dogs who had no pre-operative measurement of pulmonic regurgitation.

Three dogs experienced complications in the peri-operative period, none of which were fatal. One dog collapsed 7 days post-operatively and developed severe pyrexia with multiple joint effusions and joint pain. Investigations revealed elevations in liver enzyme activity and hyperbilirubinaemia, in addition to thrombocytopaenia, anaemia and prolongation of clotting times. This dog recovered with supportive care including fluid therapy and analgesia. A further dog developed hypoxia 4 days post-operatively. Radiographic evidence of an alveolar pattern was present and the dog recovered with supportive care (oxygen supplementation and antibiosis). One dog developed pleural and peritoneal effusions 72 hours post-operatively that resolved following diuretic treatment. Therefore, six out of 9 dogs survived to discharge.

Medium to long-term post-operative data

Echocardiographic data

Medium to long-term post-operative data was available for all surviving dogs. Median time from surgery to last echocardiographic exam was 1977 days (range 429 to 3098 days). The PG at final echocardiographic examination (PG_{final}) was below 20mmHg in 62.5% of dogs (5/8). The median PG_{final} was 14 mmHg (range 10 to 70 mmHg), with a median percentage PG reduction of 89% (range 41 to 94%), (Figure 3). No dogs were receiving cardiac medications at their final assessment.

Survival data

None of the dogs that survived to discharge were believed to experience a death related to PS. At the time of writing 2 dogs were still alive at 6 years 9 months (Cocker Spaniel) and 8 years 7 months (German Shepherd) post-operatively. Both dogs returned to our clinic for re-examination. At re-examination both dogs had normal exercise tolerance and were considered well by their owners, with FETCH scores of 7/90 and 3/90 respectively (higher scores indicate poorer quality of life). Pressure gradients across the RVOT were 35 mmHg and 14 mmHg respectively.

In three dogs that had died, the cause of death was one each: systemic mast cell disease (5 years post-operatively), osteosarcoma (7 years post-operatively) and severe pancreatitis resulting in acute respiratory distress syndrome (5 years 2 months post-operatively). One dog died with right heart failure 5 years post-operatively, believed to be associated with concurrent tricuspid dysplasia. This was the dog diagnosed with tricuspid valve dysplasia prior to patch grafting and his PG had decreased from 113 mmHg pre-operatively to 14 mmHg at the date of his last examination (429 days post-operatively).

Discussion

The data reported here comprises the largest number of dogs treated using an ePTFE graft under conditions of CPB, and has the longest follow-up to date. In this population of dogs, ePTFE patch grafting of the RVOT under CPB for treatment of severe PS was associated with a significant and sustained reduction in the RVOT PG and excellent long-term survival in dogs surviving the peri-operative period. Although we were not able to obtain final assessment echocardiograms from all dogs that survived to discharge, only one dog's death was related to heart disease. This dog was evaluated by us with his death considered to be associated with the dogs pre-existing tricuspid valve dysplasia since his pulmonic valve PG remained low at 14 mmHg and apart from the tricuspid valve changes there were no other structural abnormalities in the heart. The PG remained markedly reduced in all dogs at the time of their final echocardiographic assessment and no evidence of sub-clinical restenosis was seen, further demonstrating the durability of this technique. Interestingly, two dogs had a PG of over 50 mmHg which has been described above the limit for an optimal outcome (Locatelli et al. 2011), post-operatively yet still had an excellent long term outcome. One dog had a PG of 70mmHg. We conclude, therefore, that this technique gave sustained long term resolution of PS-related signs in those dogs that survived to discharge.

In the study reported here, one intraoperative fatality occurred and two dogs died in the immediate postoperative period. The exact cause of death for these dogs is not clear although it is most likely one dog had fatal post-operative intrathoracic haemorrhage. Because post mortem examination was not permitted, this cannot be confirmed. The intraoperative death was associated with failure to successfully wean the dog from CPB. Possible causes for this include myocardial ischaemia secondary to poor myocardial perfusion/protection with cardioplegia, myocardial hypoperfusion (of the very thick right ventricle), coronary artery air embolization or coronary artery obstruction by blood clot formation; all of which might prove difficult to confirm definitively even with post-mortem examination. This dog's sustained hypocalcaemia may also have been a factor.

None of the previous reports are exactly alike in terms of patient selection criteria or surgical technique used. The main technical differences are between the use of a closed technique without total venous inflow occlusion (n=2) (Shores et al. 1985, Staudte et al. 2004), closed or modified open technique with TVIO (n=2) (Hunt et al. 1993, Orton et al. 1990), or an open technique under CPB (n=2) (Fujiwara et al. 2012, Tanaka et al. 2009). There are a variety of reasons for each institution having reported the use of different techniques including experience, cost, and availability of specialised equipment, such as that required to operate under CPB. The two most recent reports use CPB, perhaps reflecting the increasing availability of this equipment and expertise, and the success reported with its use for other conditions (Fujiwara et al. 2012, Mizuno et al. 2012, Orton et al. 2005, Uechi et al. 2012). In human patients that require surgical correction of PS caused by valve annulus hypoplasia and fibrous valvular malformation (analogous to type B morphology in dogs), an open approach under CPB is the standard of care, rather than surgery under TVIO, for reasons of safety, control and surgical accuracy. Our reasons for using CPB were multifactorial: firstly, as previously mentioned, this is considered preferable for surgical treatment of similar PS in humans. Secondly, use of CPB allows sufficient time to open the heart and fully evaluate the source of obstruction and the pulmonic valve, thereby allowing the surgeon to assess and accurately resect tissue likely to contribute to on-going obstruction. In addition, it allows accurate sizing and suturing of an ePTFE patch so as to reconstruct the outflow tract in a way that minimizes risk of residual or subsequent obstruction. Finally, we had already started using CPB for treatment of other surgical conditions at our institution and therefore had some experience with the technique. In contrast, TVIO allows only limited time to visualise and address abnormalities of the valve complex and so is described to facilitate either "closed" or "semi open" valvotomy. These techniques are arguably more suited to dogs with fused valve leaflets (type A) rather than type B PS. That is; a morphology of PS that would respond well to the much safer BVP approach. It is difficult to make meaningful comparisons between the use of CPB and TVIO for surgical treatment of PS in dogs given the small number of reports and low case numbers. Comparisons of mortality rate are somewhat similar with 4/4 dogs surviving surgery in Orton et al.'s report with TVIO (1990), and 7/8 surviving in Hunt et al.'s (1993), (Hunt et al. 1993, Orton et al. 1990). Similarly with the use of a closed technique, 8/9 survived (Staudte et al. 2004; Shores et al. 1985). With use of CPB 8/10 dogs survived surgery in one report (Tanaka et al. 2009) and 8/9 dogs in a further report (Fujiwara et al. 2012), which is comparable to our surgical survival rate of 8/9 dogs. In order to compare techniques in a meaningful way, a prospective comparison of a larger number of dogs with similar disease status and selected for surgical intervention using standard criteria, and with a long follow up time, would be needed.

As mentioned above, one advantage of the use of CPB is the increased time afforded to analyse and address the cause(s) of the stenosis. This operation does, however create almost complete pulmonic valvular incompetence. Pulmonic valvular incompetence is reported as a late (30 years after surgery) complication in humans that undergo complete repair of tetralogy of Fallot (Therrien et al. 2000). This has led some surgeons to recommend pulmonic valve replacement in this group of patients. The study reported here would suggest that pulmonic valvular incompetence is well tolerated in this canine population; we accept that this is a small number of dogs with limited follow-up, however in all dogs there was moderate to severe pulmonic insufficiency at the final examination but this was not associated with long term clinically significant adverse remodelling, ventricular arrhythmia or CHF. One dog did develop right sided CHF but this was the dog with tricuspid valve dysplasia. It is possible that a complication that takes 30 or so years to develop in a human might not be a concern in the context of a canine lifespan.

None of the dogs in our report died from heart disease directly related to their PS and both dogs with right sided heart failure pre-operatively had resolution of this. However one dog died of heart failure six months post-operatively in Hunt et al.'s study (1993) of patching under TVIO; and in Staudte et al.'s report of a closed technique with use of a valvulotomy-ventriculotomy wire one dog died of heart failure at 16 months post-operatively (Hunt et al. 1993, Staudte et al. 2004). In this latter report (Staudte et al. 2004), three dogs also experienced syncopal episodes upon extreme exertion or exercise after surgery, whereas all dogs in the study reported here remained free of clinical signs relating to PS (although, as mentioned, one dog did develop heart failure secondary to TVD five years after surgery). The fact that previous reports of surgical treatment of PS only contain relatively short term follow up mean that it is possible that recurrence of signs is an under reported complication. Without larger patient numbers and a carefully controlled prospective study, it is impossible to draw comparisons as to which technique may be superior.

Another difference in techniques to date is the use of differing materials for the patch with ePTFE, native pericardium, bovine vena cava patch graft and glutaraldehyde fixed canine tunica vaginalis all previously reported. Expanded polytetrafluoroethylene sheets are sterile "medical grade", "off the shelf" products with no known adverse health and safety side effects for user or recipient. It is easy to handle and can be cut to size, as needed. Because of the potential harmful effects of glutaraldehyde and the lack of availability of all natural products other than native pericardium, and the fact that ePTFE had been previously described for this use, we chose this in our dogs.

As in other reports of PS, some of our dogs had concurrent congenital cardiac abnormalities; VSD in one dog, PFO in four dogs and TVD in one. The VSD was only 1.5 mm in diameter and in the subaortic position. Surgical exposure of all of these defects would have been best achieved through a right atriotomy rather than the right ventriculotomy incision required for the RVOT patch. The decision not to address the PFOs surgically was based on the assumption that if the RVOT patch achieved the anticipated change in RV pressure, this would, in turn reduce right atrial pressure to a level that would no longer favour right to left shunting of blood across the PFO. This assumption was proved to be correct on follow-up echocardiography in one dog that had right to left shunting prior to patching. We were not able to perform a bubble study at long term follow up to confirm the absence of shunting in the second dog but one dog there was still evidence of right to left shunting on cardiac echo. This dog, however, did not show any clinical signs associated with right to left shunting of blood. The decision not to treat the TVD surgically in the dog with concurrent PS and TVD, was also based on the presumption that the tricuspid regurgitation secondary to TVD would reduce once the PS had been treated as well as the fact that there was no tried and tested surgical therapy for TVD at that time. Finally, the decision not to surgically manage the VSD in the two dogs that had this lesion was based on the small size of the VSD and the assumption that these would only have minor haemodynamic significance, once the PS had been treated. In addition, they were relatively inaccessibile via the right ventriculotomy. Again, this assumption proved to be correct based on follow up echo studies and the long term survival. Indeed, only one dog developed clinical signs relating to the concurrent cardiac abnormality (TVD) and this ultimately resulted in the death of the dog 5 years after surgery for PS. This dog still enjoyed a sustained period of a good quality of life following PS surgery.

Based on our results, ePTFE patch grafting of the RVOT is an effective and durable treatment for severe PS, in dogs that have failed BV. Whether it can also be an effective treatment for dogs who are not considered good candidates for BV due to their concurrent congenital malformations remains to be seen.

The peri-operative mortality rate can be high but if dogs survive the peri-operative period then a significant reduction in pressure gradient can be achieved with an excellent long-term prognosis. It is important to recognize that the dogs reported here, along with a group of 9 dogs that underwent tricuspid valve replacement and 3 dogs that underwent patching for double chambered right ventricle, represent the first 21 dogs operated on by the bypass team at our institution and as such, represent the beginning of the "learning curve". It is anticipated, therefore, that further familiarity with these operative techniques, and refinements in patient selection criteria, anaesthetic care and post-operative requirements, will result in significant reduction in short term mortality and therefore improve overall outcome, as shown by another team with vast experience (Uechi et al. 2012). Based on the small number of dogs reported here, open patch grafting under cardiopulmonary bypass is feasible and results in durable reduction in PG along with long term relief from the clinical signs of PS, providing the tricuspid valve function is good.

No conflicts of interest have been declared.

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