**Use of ECG-gated computed tomography, echocardiography and selective angiography in five dogs with pulmonic stenosis and one dog with pulmonic stenosis and aberrant coronary arteries**

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**Running head**

ECG-gated computed tomography in dogs with pulmonic stenosis

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**Abbreviations**

|  |  |
| --- | --- |
| BVP | balloon valvuloplasty |
| CA | coronary artery |
| CT | computed tomography |
| CTA | computed tomography angiography |
| ECG | electrocardiogram |
| HR | Heart rate |
| MPA | main pulmonary artery |
| PDA | patent ductus arteriosus |
| PG | pressure gradient |
| PS | pulmonic stenosis |
| PSD | post-stenotic dilatation (of the pulmonary trunk) |
| PV | pulmonic valve |
| PVa | pulmonic valve annulus |
| RV | right ventricle |
| RVOT | right ventricular outflow tract obstruction |
| TOE | trans-oesophageal echocardiography |
| TTE | Trans-thoracic echocardiography |
| VSD | ventricular septal defect |

**Case 1**

A 3 month-old female entire English bulldog was referred for investigation of an asymptomatic grade V/VI systolic, left-basilar murmur.

Echocardiographya revealed severe type A pulmonic stenosis (PS) and a perimembranous ventricular septal defect (VSD) with exclusively left-to-right shunting (confirmed on echocontrast study) (table1).

A retrospective electrocardiogram (ECG)-gated-computer tomographic angiography (CTA)-coronaryb was performed to screen for aberrant coronary arteries (CA). The right and left CA (including its circumflex and paraconal interventricular branches), were normal. The computed tomography (CT) showed valvular PS, with severe post-stenotic dilation (PSD) of the main pulmonary artery (MPA) (figure 1), severe dilation of the right atrium (RA) and severe right ventricle (RV) hypertrophy. A VSD (approximately 10mm defect) in the perimembranous region of the interventricular septum and an overriding aorta were also evident (tables 2,3; figure 2).

Balloon valvuloplasty (BVP) was performed; RV pressure was directly measured initially at 103mmHg. An intra-operative Right ventricular outflow tract (RVOT) angiogram confirmed the PS and PSD (table-2). RV pressures post-BVP were 100mmHg, but due to the severity of arrhythmias associated with catheter manipulations in the heart, no more inflations were performed.

Serial echocardiographic assessments over the following 3 months showed consistently severe PS. When syncopal episodes were reported, a second BVP was recommended. The dog died from asystole during the procedure.

**Case 2**

A 7 month-old male entire French bulldog was referred for investigations of cough and a grade IV/VI left and right basilar, systolic murmur.

Doppler echocardiography showed severe type A PS (pulmonic flow velocity 7.7m/s, pressure gradient (PG) 240mmHg) with evidence of dynamic RVOT obstruction (table1). Thoracic radiographs showed a mildly enlarged and globoid cardiac silhouette without any evidence of PSD.

A retrospective ECG-gated-CTA-coronary was performed. This showed two normal CA. There was valvular PS with thickened and dysplastic valve leaflets mild PSD of the MPA and moderate RV hypertrophy (tables 2,3; figure 3).

BVP was performed; RV pressures were directly measured intra-operatively at 105/5mmHg. A RVOT angiogram was performed prior to balloon inflation showing two areas of stenosis: valvular and supravalvular (Table2). RV pressures post-BVP were 90/4mmHg. Doppler echocardiography post-BVP showed pulmonic flow velocity of 5.2m/s, PG 110mmHg. The dog remains asymptomatic 4 months after admission, on atenolol (1mg/kg q12h).

**Case 3**

A 13 month-old, entire female Staffordshire bull terrier cross was referred for investigation of exercise intolerance and lethargy.

Echocardiography revealed severe type A PS with severe RV hypertrophy and tricuspid dysplasia with moderate RA dilation. Brief abdominal ultrasound confirmed free abdominal fluid and mildly dilated hepatic veins (table 1).

Thoracic radiographs showed marked right-sided cardiomegaly, loss of abdominal serosal detail and mild hepatomegaly.

A prospective ECG-gated-CTA-coronary showed valvular PS, severe dilation of the RA, severe RV hypertrophy (figure 5) and moderate PSD of the MPA. The CA were normal (table 2,3).

BVP was performed; RV pressure was directly measured intra-operatively at 96/9mmHg. RVOT angiogram showed both a valvular and more marked supravalvular stenosis. Balloon dilation was attempted but the balloon burst and upon retraction it became entangled in the jugular vein at the level of the thoracic inlet, requiring surgical dissection. The procedure was then aborted. The dog is currently doing well on treatment (Furosemide 4mg/kg total daily dose, Benazepril 0.4mg/kg q24h, Spironolactone 2mg/kg q12h, Atenolol 1mg/kg q12h).

**Case 4**

A 6 month-old, entire male English bulldog was referred for investigation of exercise intolerance. Physical examination revealed mild jugular distension, jugular pulsations, positive hepatojugular reflux, ascites and a grade V/VI left-basilar systolic and diastolic heart murmur.

Echocardiography revealed severe type A PS, tricuspid valve dysplasia, patent foramen ovale with bidirectional flow (confirmed by echocontrast study) and free abdominal fluid with marked hepatic venous congestion was seen on subcostal view (table1).

Thoracic radiographs revealed moderate right-sided cardiomegaly and poor serosal detail in the cranial abdomen.

Trans-oesophageal echocardiography (TOE) confirmed PS and PSD, distally followed by a supravalvular stenosis with another PSD. The peak velocitiy through the supravalvular stenosis was 5.78m/s (PG 134mmHg) (Table 2). Continuous left-to-right shunting high velocity flow between the aorta and the MPA distal to the supravalvular stenosis was identified by TOE (but not by trans-thoracic echocardiography (TTE)), consistent with a patent ductus arteriosus (PDA) (systolic and diastolic peak velocities of 4m/s (PG 65mmHg) and 2.26m/s (PG 20mmHg), respectively).

A prospective ECG-gated-CTA-coronary showed evidence of valvular PS and marked supravalvular PS, with RV hypertrophy and a PDA. Normal CA were seen (table 2,3). Poor abdominal serosal detail and moderate hepatomegaly were also seen.

BVP was not performed due to the presence of supravalvular stenosis (considered less amenable to BVP) and cost constraints. The dog was started on medical treatment (furosemide 1.5mg/kg q12h, torasemide 0.23mg/kg q12h, pimobendan 0.07mg/kg q12h, spironolactone 1.25mg/kg q12h), but was euthanized three months later due to recurrent right-sided congestive heart failure.

**Case 5**

A 6 month-old, entire female Yorkshire terrier was referred for investigation of occasional cough and a grade V/VI left-basilar systolic murmur.

Echocardiography identified severe type A PS with moderate RV hypertrophy and a left-to-right shunting PDA (table1).

Thoracic radiographs showed marked right-sided cardiomegaly and an enlarged MPA.

A retrospective ECG-gated-CTA-coronary was performed to further investigate the reported defects, showing a pulmonic valve annulus (PVa) with an abnormal bulbous root proximal to the pulmonary trunk. The pulmonic valve (PV) leaflets were abnormally thickened. Mild PSD of the MPA and severe RV hypertrophy were present. A small PDA was seen with a very small opening into the MPA. Normal CA were visualised (table 2,3).

The dog underwent BVP. The intra-operatively RVOT angiogram had low resolution (due to small catheter lumen) and therefore PVa could not be measured accurately. TOE was performed and pulmonic velocities under general anaesthesia were 4m/s (PG 64mmHg) (table2). Post-BVP the PG was estimated at 15-25mmHg. The dog remains asymptomatic on atenolol (0.9mg/kg q12h) at the time of writing.

**Case 6**

A 5 month-old female entire asymptomatic English bulldog was referred for further assessment of a previously diagnosed PS. Physical examination revealed a grade V/VI left basilar and a grade II/VI left apical systolic murmur.

Echocardiography identified severe type A PS with moderate RV hypertrophy, mild mitral dysplasia and mild/moderate sub-aortic stenosis. An aberrant CA transversally crossing the PV area was suspected based on echocardiography (figure 6, table 1). TOE was performed and confirmed severe PS (table 2).

A retrospective ECG-gated-CTA-coronary showed thickening of the PV leaflets. There was mild-to-moderate PSD of the MPA and moderate hypertrophy of the RV walls. There was an anomaly of the CA with a single left coronary ostium and an aberrant pre-pulmonic right CA originating together with the left paraconal interventricular branch (table 2,3, figures 7,8a).

At the time of writing, the dog remained asymptomatic on atenolol (0.86mg/kg q12h) after conservative BVP (due to aberrant CA) [1], resulting in 50% PG reduction.

**Discussion**

Pulmonic stenosis is one of the most common congenital cardiac diseases in dogs[2]. It can be valvular, subvalvular or supravalvular. In some cases, severe right ventricular hypertrophy at the level of the infundibulum can cause dynamic RV outflow tract obstruction and contribute to the PS. Boxers and English bulldogs are among the most commonly affected breeds[2]. A R2A-type anomaly of the CA with a single right coronary ostium has been described in these breeds[1,3], and recently also a single left coronary ostium with an abnormal pre-pulmonic right CA has been reported[4]. The detection of such anomalies is of vital importance prior to balloon BVP of the PV to avoid reduction of the coronary flow or CA avulsion during the procedure, which can be fatal[1].

If BVP is indicated and an aberrant CA is suspected, intra-operative angiography is recommended prior to BVP. Access to the RV and PV is made through the jugular or femoral vein. Injection of contrast in the RVOT is used to assess the PVa and the levophase is used to assess CA anatomy. Occasionally the quality of the levophase is reduced due to contrast dilution, superimposition of the aorta and CA with other areas of contrast accumulation and increased heart rate (HR). In these cases, an aortic root angiography is mandatory and femoral or carotid artery access is required. This extra step becomes particularly important in some breeds (e.g. Bull breeds) with small and muscular hindlimbs, where femoral artery access can be difficult.

Electrocardiogram-gated CT can be used to screen for CA anomalies[5], additionally allowing visualization of the cardiac chambers, valves and thoracic vasculature without superimposition of structures. There are two methods to acquire ECG-gated-CTA images: prospective gating (image acquisition is triggered during a certain phase of the cardiac cycle, usually not recommended with irregular or high HR) and retrospective gating (image acquisition occurs during the whole length of the cardiac cycle and retrospectively organized into segments, allowing functional and morphological evaluation)[6].

To the authors´ knowledge, this is the first study describing CT characteristics of PS and associated findings in dogs. CT characteristics of congenital abnormalities such as aberrant CA and overriding aorta are also described for the first time. The PVa, Aoa, valves, MPA, RA and RV were visualized with high resolution in all cases. In only two cases, the resolution of the pulmonary valve was slightly reduced most likely due to the high HR during the scan. It was possible to assess the origin and path of the CA in all cases and more accurately than with single-plane aortic root selective angiography (as CA are superimposed on other structures making the origins and paths difficult to confirm). Better assessment of concurrent congenital defects was also possible with CTA, which further supports its utility (overriding aorta and VSD in case 1, PDA in cases 4 and 5). Additionally, CT allows excellent visualization of the pulmonary arteries. These were symmetrical in all cases, in contrast to humans, where asymmetrical dilation of the left pulmonary artery has been associated with valvular PS[7].

The primary advantage of ECG-gated-CTA in patients with PS is the quick and minimally invasive ability to detect aberrant CA. With echocardiography, the origin of the CA is not always seen. Selective angiography is the usual method advocated for visualization of the CA, but it is an invasive procedure that entails a higher ionising radiation dose for the patient and clinician and an increased time of anaesthesia (considering that our approach is routinely made by the jugular vein, a femoral or carotid artery access would be required for an aortic root angiography). With ECG-gated-CTA-coronary, the heart and CA can be imaged in a few seconds; anaesthesia is brief and the clinician is not subjected to radiation. This allows better and early planning of the BVP procedure. Furthermore, 3D surface rendered images and specific vessel tracking functions in curved multiplanar reconstruction applications can provide additional information for evaluation of the CA with CTA[6]. In our study, one dog presented with a single left coronary ostium and an aberrant pre-pulmonic right CA arising from the left CA together with the left paraconal interventricular artery. This abnormality has been recently described in dogs[4], but to our knowledge this is the first CT description.

While diagnosis of PS is usually made by echocardiography, in some dogs the PV can be difficult to image clearly using TTE because of lung interference[8]. In these cases the use of additional imaging prior to BVP may be indicated. ECG-gated-CTA not only identifies the PS, but evaluates its precise location, severity and associated changes in the heart and MPA. In the present study, several parameters were measured to objectively assess the severity of the PS. The ratio of the PVa to the Aoa aims to evaluate the size of the PVa and to detect a possible hypoplasia (which would indicate a Type B PS)[9]. In normal conditions, PVa and Aoa should be similar in size[9]. In the current study, the ratio of PVa to Aoa measured on CTA ranged from 0.78 to 1.00. The ratio measured on echocardiography ranged from 0.80 to 0.99. In case 1 the ratio PVa/Aoa might be slightly altered by the volume overload caused by the shunt of the VSD and it could falsely increase the PVa. In the same case, due to the large VSD, an equalization between RV and LV pressures was expected, therefore oximetry should have been used to better assess the shunt and therefore the severity of the PS. The ratio pulmonic valve orifice to PVa was used to assess the severity of the stenosis. This ratio ranged from 0.21 to 0.46 for CT and from 0.24 to 0.43 for echocardiographic measurements. More stenotic orifices should be associated with higher blood flow velocity through the PV, a higher PG between RV and MPA and therefore increased severity[8]. Due to the small number of cases, no conclusions could be drawn regarding the relation between CT and echocardiographic measurements (or selective angiographic measurements). In a previous study in dogs with a low-slice number, non ECG-gated-CT, equivalence between CT and echocardiographic measurements for the Aoa was shown and only small differences were found for the PVa, mainly due to difficulties identifying the PV[10]. High-slice number ECG-gated-CT, as used in our case series, has a higher temporal resolution, allowing differentiation between systole and diastole, and good visualization of the valves; therefore reasonable agreement between CT and echocardiographic measurements is expected.

CT offers the possibility to obtain an overall view of the cardiovascular system, including cardiac functional analysis with restrospective gating, and to evaluate it with multiplanar, maximum intensity and 3D reconstructions (figure 8 a,b); concomitant defects not identified by TTE can be seen with CT[11,12]. In one case (case 4) a PDA not detected by TTE was identified by TOE and CTA. In three cases (cases 2, 3 and 4), supravalvular and valvular stenosis was reported from the angiographic study, but only in case 4 it was confirmed with CTA. This was likely a pseudo-stenosis above the pulmonic annulus caused by leaflet tips of the domed, fused pulmonic valves. In addition, in all cases, CA anatomy was more accurately and clearly seen with CTA than echocardiography (TTE or TOE) or selective angiography, which further supports the utility of this technique. Therefore, if available, this should be considered prior to BVP as it can offer additional diagnostic value.

The main limitation of ECG-gated-CT, especially prospective gating, is the higher HR of small animals compared to humans, where the target HR for ECG-gated-CTA is less than 65bpm[6]. In humans, the HR is commonly reduced with beta-blockers for the examination of CA[13].{Laborda-Vidal, 2015 #59} This has not been proven useful in small animals[5]. In the present study, prospective or retrospective ECG-gating was chosen in each case depending on the individual HR and rhythm of each patient.

The poor specificity and sensitivity of thoracic radiographs for the diagnosis of PS was also evident[14]. Only 1/4 cases with thoracic radiographs presented the typical bulge associated with post-stenotic dilation of the MPA (case 5).

In conclusion, despite echocardiography remaining the gold standard for diagnosis and assessment of PS, ECG-gated-CTA is a complementary diagnostic method that may provide additional information, not only regarding CA anatomy but also concurrent cardiovascular anomalies. In addition, this may shorten surgery/anaesthesia time and reduce the amount of radiation to which the cardiologist is subjected during BVP.

**Footnotes**

a Vivid 7 (General Electric Medical System, Wisconsin, USA)

b Toshiba Aquilion Prime (Toshiba Medical Systems, Japan)

**Conflicts of interest**

The authors have no conflict of interest to disclose.

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**Figures**

**Figure 1:** Multiplanar reconstruction (MPR) showing pulmonic stenosis (PS) and severe post-stenotic dilation (PSD) of the main pulmonary artery (MPA) (case 1). Ao, aorta; PVa, pulmonary valve annulus (stenotic). The pulmonary valve annulus was measured from the hinge points of the pulmonic valve leaflets at the level of the pulmonic valve.

**Figure 2:** Multiplanar reconstruction showing a ventricular septal defect (VSD, arrow) and overriding aorta (Ao) (case 1). IVS, interventricular septum; LV, left ventricle; RA, right atrium; RV, right ventricle; MPA, main pulmonary artery.

**Figure 3:** Multiplanar reconstruction showing valvular pulmonic stenosis (PS) and post-stenotic dilation (PSD) of the main pulmonary artery (MPA) (case 2). RV, right ventricle.

**Figure 4:** Maximal intensity projection at the level of the pulmonary valve (PVa) showing pulmonic stenosis, post-stenotic dilation of the main pulmonary artery (MPA), a supravalvular stenosis (arrowheads) and a patent ductus arteriosus (PDA, arrow) (case 4). Ao, aorta; RV, right ventricle.

**Figure 5:** Multiplanar reconstruction at the level of the ventricles showing a hypertrophic right ventricle (RV) causing flattening of the interventricular septum (IVS) towards the left (case 3). LV, left ventricle.

**Figure 6:** Right parasternal short axis view at the level of the heart base, showing an aberrant coronary artery crossing near the annulus of the pulmonary valve (arrow)(case 6). Ao, aorta; LA, left atrium; RVOT, right ventriculum outflow tract; MPA, main pulmonary artery.

**Figure 7:** Multiplanar reconstruction showing a single left coronary ostium, from where the left circumflex (LCx) and the left paraconal interventricular branches (LP) arise. The right coronary artery (RCA) arises from the LP and surrounds the pulmonic artery adjacent to the pulmonary valve annulus (PVa) (case 6). Ao, aorta; LA, left atrium; RA, right atrium.

**Figure 8**: a, 3-D surface rendered image showing the paths of the left coronary artery (LCA), with the circumflex (LCx), the paraconal (LP) and the aberrant right coronary artery (RCA), and the post-stenotic dilation of the main pulmonary artery (MPA) (case 6); b, 3-D surface rendered image showing the paths of the normal left and right coronary arteries in a different dog of the same breed (case 1). Ao, aorta; LAu, left auricle; LA, left aorta; RAu, right auricle; RV, right ventricle.