Journal of Veterinary Cardiology (2019) **23**, 129—141

Journal of Veterinary Cardiology
ESVC

www.elsevier.com/locate/jvc

Cor triatriatum dexter in 17 dogs☆

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Received 19 September 2018; received in revised form 27 March 2019; accepted 29 March 2019

KEYWORDS
Canine;
Congenital cardiac disease;
Ascites;
Pulmonary stenosis;
Tricuspid valve dysplasia

Abstract *Objectives:* The objective of this study was to report the signalment, presentation, clinical and imaging findings, interventions, and outcomes in a group of dogs with cor triatriatum dexter (CTD).
Animals: Seventeen client-owned dogs.
Methods: Medical records were reviewed retrospectively for signalment, history, physical examination findings, imaging and diagnostic findings, presence of concurrent congenital cardiac defects, description of interventional procedures, therapy information, and outcomes.
Results: Age at presentation ranged from two to 110 months, with 10 of 17 dogs (59%) aged <12 months. There was an equal distribution between the sexes. Peritoneal effusion was the most common presenting complaint, in 10 of 17 dogs (59%). The CTD was an isolated finding in 3 of 17 dogs (18%); the remaining 14 of 17 (82%) dogs had concurrent cardiac disease, with congenital anomalies present in 12 of 17

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https://doi.org/10.1016/j.jvc.2019.03.002

(70%). All except one of these 12 dogs had at least one additional condition affecting the right heart. Tricuspid valve dysplasia was the most common congenital comorbidity, present in 9 of 17 dogs (53%). Seven dogs (41%) underwent interventional treatment of their CTD. In 7 of 17 (41%) cases, the CTD was considered to be incidental and the dogs were asymptomatic; therefore, no interventions were performed. The remaining three cases were euthanized or lost to follow-up.
Conclusions: Cor triatriatum dexter in dogs is commonly seen in association with other right-sided congenital cardiac anomalies and may be an incidental finding. Dogs with CTD obstructing right atrial inflow can have a good outcome after intervention. Dogs with no clinical signs associated with the CTD may remain asymptomatic into adulthood.

Abbreviations

BPM	beats per minute;
CTD	cor triatriatum dexter
DCRV	double-chambered right ventricle
ECG	electrocardiogram
PCV	packed cell volume
PDA	patent ductus arteriosus
PE	peritoneal effusion
PFO	patent foramen ovale
PH	pulmonary hypertension
PS	pulmonary stenosis
RA	right atrial
TVD	tricuspid valve dysplasia
VHS	vertebral heart score

Introduction

Cor triatriatum dexter (CTD) is an uncommon congenital anomaly that results in a division of the right atrium into two parts because of the persistence of the embryologic right sinus venosus valve [1,2]. This membrane causes variable obstruction of venous return to the right atrium, with severity of clinical signs dependent on the size of perforation of the membrane, the location of the membrane relative to routes of right atrial (RA) inflow, the presence of atrial-level shunting, and any concurrent defects.

In people, CTD is an infrequently described condition with variable clinical signs and age at first detection. Cor triatriatum dexter incidence in children is reported to represent approximately 0.025% of congenital heart malformations [2]. In adults, reported clinical signs include exercise intolerance, exercise-induced dyspnea, palpitations, supraventricular arrhythmias, syncope, and peripheral edema [3—6]. Cyanosis is also reported in both adults and pediatric patients [6—8]. In many cases, the clinical signs may not occur until well into adulthood and are attributable to right-left shunting through a concurrent atrial septal defect or patent foramen ovale (PFO) [6—8].

Cor triatriatum dexter in humans has been reported as an isolated finding or as one component of a constellation of other right-sided congenital cardiac anomalies [1]. Observed concurrent abnormalities have included atrial septal defects (secundum and primum) [3—6], valvar pulmonary stenosis (PS) [5], PFO [7,8], stenosis of the cranial vena cava [7], tetralogy of Fallot [9], Ebstein's anomaly [4], persistent left cranial vena cava [6], and tricuspid and pulmonary atresia with intact ventricular septum [1].

Cor triatriatum dexter in dogs is also thought to be an uncommon congenital defect and has been described only in infrequent case reports. Age at detection in these reports ranges from puppyhood to senior dogs (2 months to 12 years), with the majority identified due to the onset of ascites as a puppy younger than one year [10—25]. Concurrent congenital abnormalities have been predominantly right-sided and are reported sporadically. Abnormalities noted concurrently in dogs with CTD have included double-chambered right ventricle (DCRV) [11], PFO [11,19,20], persistent left cranial vena cava [25], tricuspid valve dysplasia (TVD) [16,20], Ebstein's anomaly [13], PS [19], ventricular septal defect [19], and systolic anterior motion of the mitral valve with dynamic subaortic stenosis [16].

Currently, reported canine CTD cases have described dogs with clinical signs, many of which underwent interventional procedures. The incidence of CTD in dogs without clinical signs is unknown. In addition, the incidence of concurrent congenital disease associated with CTD across a larger population of dogs has not been well described. This case series describes the signalment, presentation, clinical and imaging findings, interventions, and outcomes of 17 dogs with confirmed CTD.

Animals

Medical records of dogs evaluated by the respective cardiology services of the UW Veterinary Care at the University of Wisconsin (1998–2018), Colorado State University Veterinary Teaching Hospital (2016–2017) and The Ohio State University Veterinary Medical Center (2008–2015) were reviewed. Dogs selected for inclusion in the study were required to have a complete echocardiographic examination that identified the presence of an intra-atrial membrane with Doppler and two-dimensional images available for review. Cases that did not have recorded historical data; recorded physical examination findings; and confirmation of the diagnosis of CTD by demonstrable flow across the membrane interrogated with pulsed-wave Doppler, agitated saline contrast study, angiography, or postmortem examination were excluded.

Materials and methods

Nineteen dogs with a recorded diagnosis of CTD were identified by medical records review. Two dogs were excluded because of lack of confirmatory testing. Seventeen dogs met the criteria for inclusion. In all subjects, demographic and historical data, including age, sex, breed, weight, and presenting complaint, were recorded. Any treatment at the time of diagnosis was recorded. Prior treatment with cardiac medications was not exclusionary. All patients had a complete physical examination performed by a diplomate or a resident in the American College of Veterinary Internal Medicine specialty of cardiology. Auscultatory findings were recorded in all dogs. Complete blood count, serum chemistry, and electrocardiogram (ECG) results were reviewed and recorded when available.

Thoracic radiographs, when available, were reviewed by a diplomate in the American College of Veterinary Radiology (L.F.). The reviewing radiologist was blinded to the focus of the case review and clinical history. Vertebral heart scores (VHS) were standardly performed on the left lateral projection; VHS of 9.7 $\pm$ 0.5 vertebrae was considered to be normal [26].

Full echocardiographic reports were required for inclusion in the study. All echocardiograms were performed by a cardiology diplomate or a resident under the direct guidance of a diplomate. Diagnosis of CTD was based on the identification of a membrane separating the right atrium into two distinct chambers. Pulsed-wave or continuous-wave Doppler images were assessed to determine pressure gradient (measured at peak velocity, typically at the end of ventricular systole in animals without right ventricular pressure overload) across the membrane, if perforate. Agitated saline contrast studies (Videos 1 and 2) were performed to confirm the presence of CTD in seven dogs and were interpreted as previously described [24].

When present, any concurrent congenital cardiac abnormalities were described using both subjective and objective criteria. For patients with follow-up imaging available, reports were reviewed and any changes from baseline were recorded. For patients who had undergone an interventional procedure (catheter-based or surgical), the method and outcomes immediately after procedure were recorded. Medical therapy initiated at the time of diagnosis was reported, along with response to therapy based on subjective owner assessment and findings from repeat imaging.

Date and cause of death were recorded when available. Date of the last follow-up and clinical signs at that time were recorded for patients still alive at the time of data analysis. Any available necropsy results were recorded.

Results

History and physical examination

Demographic data are presented in supplemental Table A (data available in Supplemental Material online). The 17 dogs included in this study ranged in age from two months to 110 months (median, 6.5 months). Ten of 17 (59%) were younger than one year at the time of presentation, and 15 of 17 (88%) were younger than five years. Sex distribution was nearly equal, with nine female and eight male dogs. Labrador retrievers and their mixes were the most commonly represented breed (n = 4). Median [range] weight was 15.5 kg [3.5–35.2 kg].

Fifteen of 17 dogs (88%) were referred to their respective referral institution for suspected cardiac disease. 'Ascites' or 'abdominal distention' was the most frequently listed presenting complaint, present in 10 of 17 dogs (59%). Four dogs were referred for evaluation of a cardiac murmur. Other presenting complaints included syncope, chylous pleural effusion, and a previously diagnosed patent ductus arteriosus (PDA; one each). One dog was referred to the internal medicine service for hepatomegaly and chronic gastrointestinal regurgitation. Five dogs had a recent

history of vomiting, all of which had peritoneal effusion (PE). Four dogs were reported to be without clinical signs, including two with incidentally detected PE. One of these dogs had PE detected at the time of ovariohysterectomy. Ten of 17 dogs (59%) had more than one presenting complaint. Presenting complaints are summarized in supplemental Table A.

Nine dogs were receiving or had received treatment for presumed cardiorespiratory or gastrointestinal disease before referral. Five of these were dogs with known or suspected PE, and medications included fenbendazole, furosemide, pimobendan, enalapril, metronidazole, and doxycycline. No resolution or change in clinical signs after medical therapy was reported in any of these cases. Two dogs referred for murmur evaluations were receiving medications, one receiving atenolol and one receiving benazepril, spironolactone, and prednisone. The dog referred for pleural effusion had a therapeutic thoracocentesis performed by the referring veterinarian and was prescribed furosemide and pimobendan before referral. The dog with the previously diagnosed PDA had been prescribed pimobendan by the referring cardiologist.

Heart rates were recorded for 16 of 17 dogs. Nine dogs (53%) were tachycardic (heart rate $\geq$ 140 beats per minute [bpm]) at presentation. The median [range] heart rate was 150 bpm [80—180 bpm]. Two dogs had a rhythm irregularity noted on initial physical examination. Thirteen of the 17 dogs (75%) had a cardiac murmur on auscultation, and one of these dogs also had an intermittent gallop sound. Three dogs, all of which had PE, had no cardiac murmur or gallop noted. In the 13 dogs with cardiac murmurs, twelve murmurs were systolic, one was continuous, and one was diastolic (characterized as a 3/6 right basilar diastolic) in timing. Location and intensity of the murmurs varied widely, coincident with concurrent cardiac disease. Murmur descriptions are presented in supplemental Table A.

Respiratory examination was normal in 16 dogs. One dog was tachypneic with a respiratory rate of 80 breaths per minute at presentation. One of the initially normal dogs also developed increased effort when placed into lateral recumbency for diagnostics. Ten dogs (59%) had PE at the time of initial assessment. One of the dogs with PE also had pulmonary infiltrates on radiographs. One dog had trace pleural effusion. Six dogs, all of which had a murmur, had no clinical signs of left- or right-sided congestive heart failure at the time of presentation. Cyanosis was not detected in any dog.

Clinical pathology findings

Laboratory testing was performed at the discretion of the attending clinician. Eleven dogs had a chemistry panel, seven had a packed cell volume (PCV) and total solids, and six had a complete blood count. The most commonly detected abnormality was hypoproteinemia (4/7 dogs on serum chemistry and 2/7 dogs with total solids value below reference range on PCV and total solids assessment). Three of seven dogs with serum chemistry had mild hypoalbuminemia. Two of 14 dogs were anemic based on PCV assessment (a puppy younger than six months with a PCV of 25% [reference, 31—39%] and an adult dog with a PCV of 24% [reference, 39—57%] and concurrent neoplastic disease). Five dogs had abdominal fluid analysis and cytological examination performed. In four dogs, PE fluid was characterized as a modified transudate and in one as a pure transudate. Laboratory reports of fluid analysis were available for review for 3 of 5 dogs. Protein concentrations ranged from 2.5 g/dL to 4.4 g/dL, and no cellular atypia was noted in the submitted samples.

Thoracic radiography

Ten dogs had thoracic radiographs performed within 24 h of diagnosis. Thoracic radiographs in nine of 10 dogs were performed at initial presentation at the University of Wisconsin Veterinary Care, and the remaining one dog had referral radiographs obtained the previous day. Radiographs were available for review in 9 of 10 dogs. Vertebral heart scores were assessed in 7 of 9 dogs (78%) and were increased, suggestive of cardiomegaly ($\geq$10.5) in 4 of 7 (57%) with a median VHS of 11.25 [range: 10—12.25]. In the remaining two dogs, the VHS was not assessed because of body conformation or vertebral malformation, but subjective heart size was noted to be enlarged in one of these two dogs.

A summary of radiographic findings is included in supplemental Table B (data available in Supplemental Material online). The most commonly noted abnormality on thoracic radiography was loss of cranial abdominal serosal detail in the visible portion of the abdominal cavity, noted in 5 of 9 dogs (56%). A distended caudal vena cava was noted in 2 of 9 dogs (22%). Overall, 7 of 9 dogs were considered to have cardiac or pulmonary abnormalities on radiographs. The two dogs with no radiographic cardiac or pulmonary abnormalities had evidence of PE.

Electrocardiographic findings

Eleven of 17 dogs (65%) had an ECG recorded. A summary of ECG findings is included in supplemental Table B. The median [range] heart rate was 140 bpm [100—160 bpm]. All dogs had an underlying sinus rhythm. The most common abnormality was a right axis deviation, which was present in 6 of 11 dogs (55%). P-pulmonale was present in three dogs (all with a P-wave amplitude of 0.5 mV, normal $\leq$ 0.4 mV). One dog had evidence of ventricular pre-excitation with delta waves and a shortened P-Q interval. This dog exhibited frequent paroxysms of suspected orthodromic atrioventricular re-entrant tachycardia that occurred at rates up to 350 bpm. An atrioventricular bypass tract (bundle of Kent) was suspected. A second dog had a low-to-normal P-Q interval (0.06 s) with no delta wave and normal QRS width, consistent with normal variant, accelerated atrioventricular nodal conduction, or an atrionodal bypass accessory pathway (Fig. 1). Paroxysmal tachycardia was not observed in this patient.

Echocardiographic findings

Echocardiograms were available for review in all dogs. The diagnosis of CTD was based on the presence of a visible membrane dividing the right atrium. This diagnosis was confirmed in all included cases by documentation of one or more of the following: Doppler-derived echocardiographic gradient across the obstruction (Fig. 2), agitated saline contrast study, contrast angiography/invasive intracardiac pressure assessment, or necropsy. The intra-atrial membrane was confirmed by echocardiography in 12 of 17 cases (71%), seven (41%) of which had an agitated saline contrast study. The majority (14/17; 82%) of the CTD membranes were perforate, and 3 of 17 (18%) were imperforate. The peak echocardiographic pressure gradient across those with a perforate membrane was reported in eight cases and ranged from 8.2 mmHg to 24.8 mmHg (median of 13.4 mmHg; Fig. 2).

Most included dogs (14/17) had concurrent cardiac disease, and in the remaining three dogs (18%), the CTD was an isolated finding. Twelve of 14 dogs (86%) had congenital cardiac abnormalities in addition to their CTD, and most of these dogs (11/12) had at least one additional disease affecting the right side of the heart. Two of 14 dogs (14%) had concurrent acquired heart disease.

Tricuspid valve dysplasia was the most common concurrent congenital abnormality and was identified in 9 of 17 (53%) dogs. Tricuspid valve stenosis of varying severity was a component of the valve malformation in 6 of 17 (35%; Fig. 3). Other concurrent congenital diseases identified included valvar PS (5/17 dogs; 29%); mild mitral valve dysplasia (4/17 dogs; 24%); and DCRV, left-to-right shunting PDA, perimembranous left-to-right shunting ventricular septal defect, thoracic arteriovenous malformation, right-to-left shunting PDA, and congenital hepatic fibrosis, each present in one

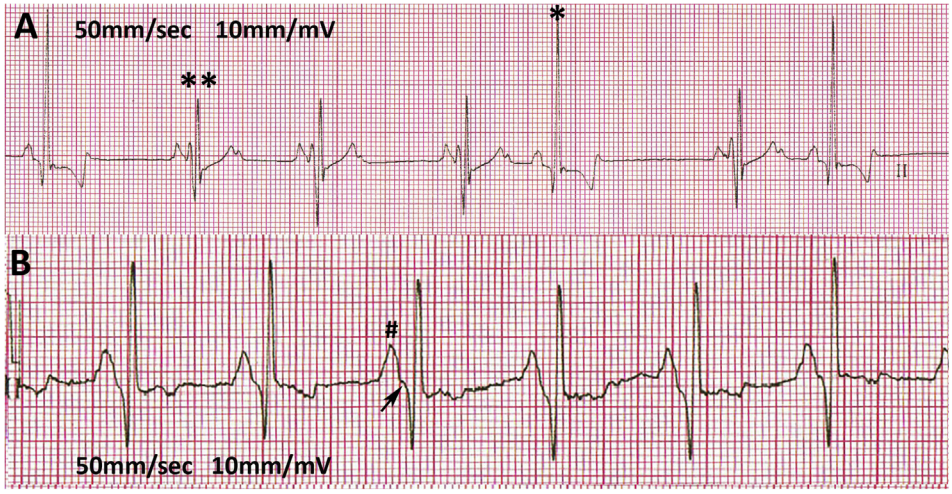

Fig. 1 Accessory pathway conduction: lead II electrocardiograms from two dogs with suspected accessory pathway conduction. (A) Suspected atrioventricular bypass tract (bundle of Kent). The ** denotes the complex with the shortened P-Q interval (0.05 s). Note the delta wave present on the QRS complex after the shortened P-Q interval. The * denotes a normal sinus complex. (B) Suspected accelerated atrioventricular nodal conduction vs. atrionodal bypass accessory pathway. The # denotes the low-to-normal P-Q interval (0.06 s) followed by a QRS complex with normal morphology. Paper speed 50 mm/s, calibration 10 mm/mv. Normal P-Q interval: 0.06—0.13 s.

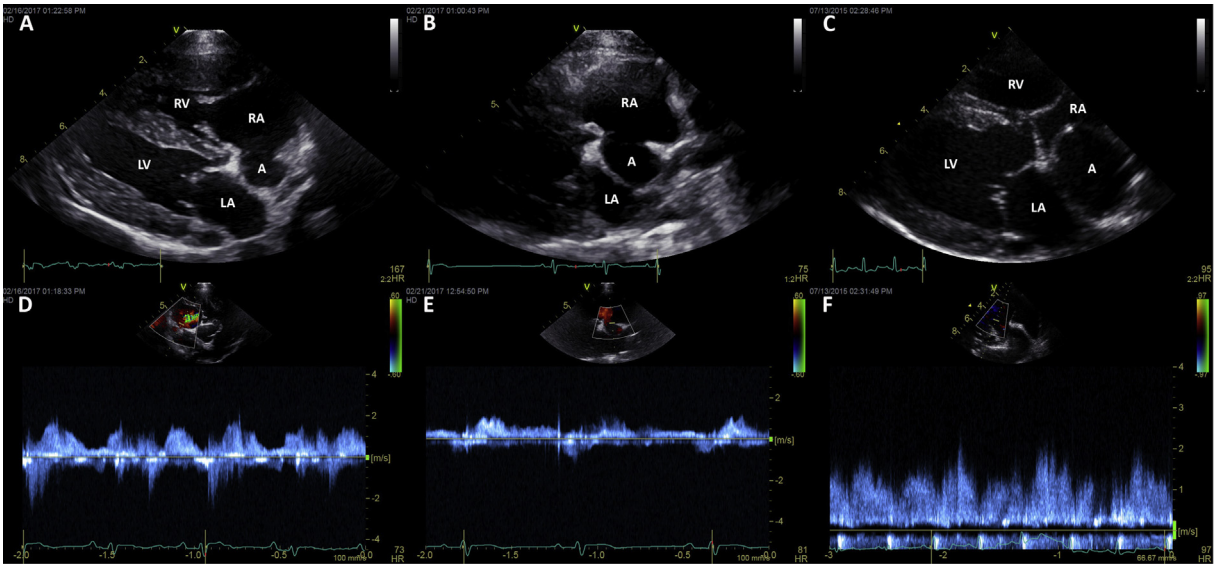

Fig. 2 Cor triatriatum dexter (CTD) morphology and pressure gradient: Right parasternal long axis images of CTD morphology from asymptomatic (A, B) and symptomatic (C) dogs are shown. (A) The accessory chamber is small and completely perforate. (B) The accessory chamber is moderately sized with a membrane that is visible, although widely perforate. (C) The accessory chamber is large with a small perforation in the membrane. This dog was presented for evaluation due to ascites. Transmembrane pressure gradients as measured by spectral Doppler are presented in the bottom panel. In all cases, the highest transmembrane gradient was recorded at the end of ventricular systole (end of atrial diastole). (D) Corresponds to dog (A) with the small chamber and widely perforate membrane. (E) Corresponds to dog (B) with the moderately sized chamber and perforate membrane. (F) Corresponds to dog (C), the symptomatic animal with the large accessory chamber and small membrane perforation. In all cases, the maximal transmembrane gradient at the end of ventricular systole is approximately 2 m/s. A: accessory chamber; LA: left atrium; LV: left ventricle; RA: right atrium; RV: right ventricle.

dog. Right-to-left shunting PFOs were present in 4 of 17 dogs (24%). Pulmonary stenosis, when present, was graded as severe in four dogs (transvalvular pressure gradients of 82 mmHg—184 mmHg, median of 132 mmHg) and moderate in one (transvalvular pressure gradient of 65 mmHg; Fig. 3). The dog with DCRV had a severe midventricular obstruction with a peak systolic pressure gradient of 180 mmHg. Of the 12 dogs with concurrent congenital disease, 7 of 12 (58%) had more than one concurrent right-sided cardiac anomaly. Concurrent congenital diseases are summarized in supplemental Table B.

Acquired cardiac disease was present in two dogs, one with myxomatous mitral valve disease and severe pulmonary hypertension (PH) and one with biventricular failure due to a suspected primary myocardial disease (aged 90 months and 53 months, respectively). One additional dog with right-to-left shunting PDA had severe PH.

Interventional procedures

A summary of the interventions for seven dogs is listed in supplemental Table B. Seven of 17 dogs (44%) underwent a catheter-based interventional procedure for treatment of the CTD. One dog underwent a PS balloon valvuloplasty with no treatment of the CTD. Another dog underwent placement of a Canine Duct Occluder device for treatment of the left-to-right shunting PDA with no additional treatment of the CTD. In both these cases, the CTD membrane was widely perforate and considered to be an incidental finding.

All seven of the dogs that underwent interventional procedures for treatment of their CTD had angiographic imaging performed before and after intervention. Angiography confirmed the presence of the CTD membrane in all cases (Fig. 4), which was described as imperforate (with no filling of the cranial RA chamber after caudal contrast injection) in three dogs and perforate with slow, incomplete filling of the cranial RA chamber in the remaining four dogs. In three dogs, a right-to-left shunting PFO was confirmed. In one dog, a three-month-old Labrador with an imperforate CTD, an anomalous vessel was observed on angiography which filled late, after complete opacification of the caudal RA chamber, and drained cranially before anastomosing with the internal thoracic vein at level of the first rib. This dog also was diagnosed with congenital hepatic fibrosis (ductal plate malformation) on liver biopsy taken during

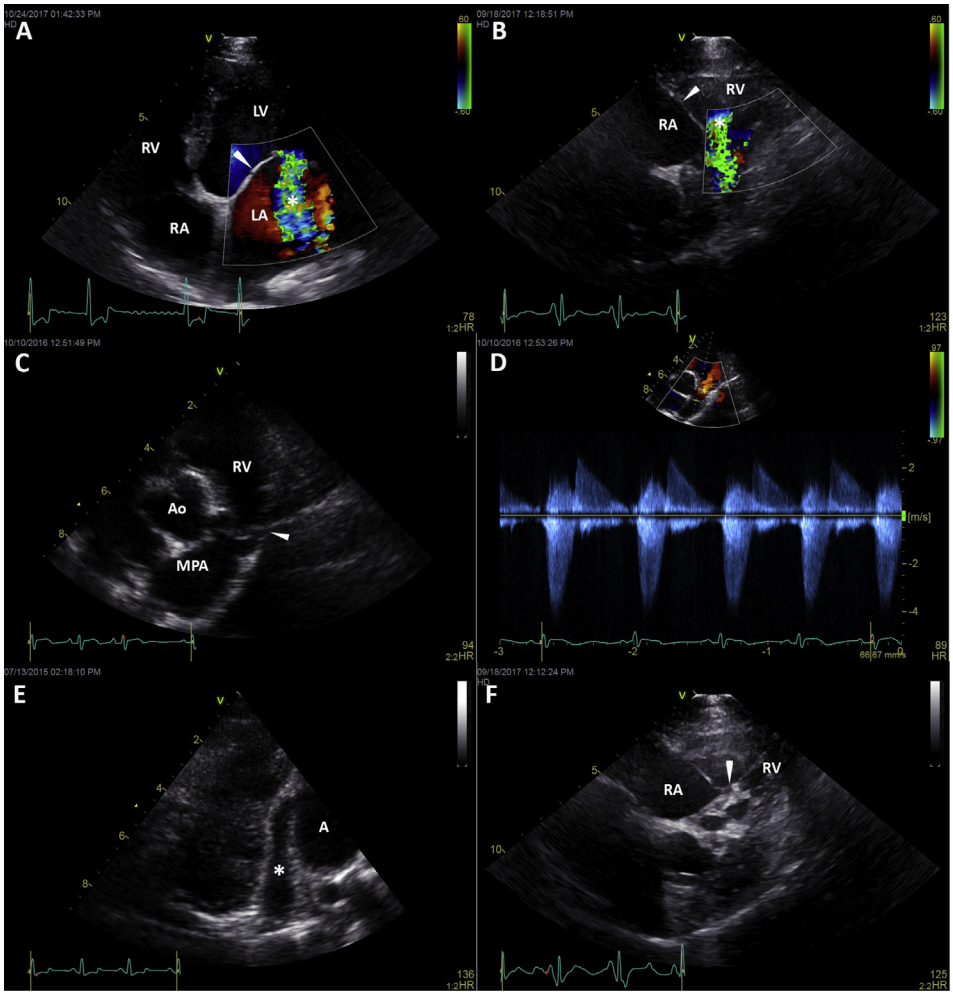

Fig. 3 Concurrent congenital anomalies: examples of concurrent congenital cardiac abnormalities noted in patients with cor triatriatum dexter. (A) Left parasternal long axis image from a dog with concurrent mitral valve dysplasia. White arrowhead: elongated anterior mitral valve leaflet. *: aliased color Doppler mitral regurgitant jet. The ECG tracing on this image is consistent with atrial fibrillation, which was noted at subsequent recheck evaluations and was not present at the time of initial presentation. (B) Obliqued right parasternal short axis view highlighting the right ventricle and right ventricular outflow tract. This dog had concurrent tricuspid valve dysplasia and a double-chambered right ventricle (DCRV). White arrowhead: elongated mural tricuspid valve leaflet. *: aliased color Doppler flow through the mid-right ventricular chamber, consistent with a midventricular obstruction. (C) Right parasternal short axis view at the heart base from a dog with concurrent valvar pulmonary stenosis. White arrowhead: thickened, redundant, and tethered pulmonary valve leaflets. Note the post-stenotic dilation of the main pulmonary artery. (D) Spectral Doppler from dog (C) showing a transvalvular gradient of approximately 4 m/s (~64 mmHg). (E) Oblique right parasternal short axis view highlighting a dilated coronary sinus *. (F) Right parasternal short axis view from a dog with concurrent severe tricuspid valve dysplasia and tricuspid stenosis. White arrowhead: thickened, tethered septal tricuspid valve leaflet. A: atrial chamber; Ao: aorta; LA: left atrium; LV: left ventricle; MPA: main pulmonary artery; RA: right atrium; RV: right ventricle; ECG: elctrocardiogram.

ovariohysterectomy 204 days after intervention for CTD, as well as an arteriovenous malformation (esophageal varices from the celiac artery) in the caudal thorax by computed tomography angiography performed 218 days after intervention for CTD. A second dog was diagnosed with a ductal diverticulum on angiography.

All seven dogs initially underwent balloon dilation of the CTD membrane, preceded by a cutting balloon membranostomy in 5 of 7 cases. The techniques for CTD balloon dilation [11,12,19] and cutting balloon membranostomy [15] have been previously described. Approaches were via the left femoral vein in two cases, right jugular vein in three cases, and right femoral vein in one case. All dogs that underwent pulmonary balloon valvuloplasty concurrently had a jugular vein approach. Four of these dogs had perforate CTD membranes

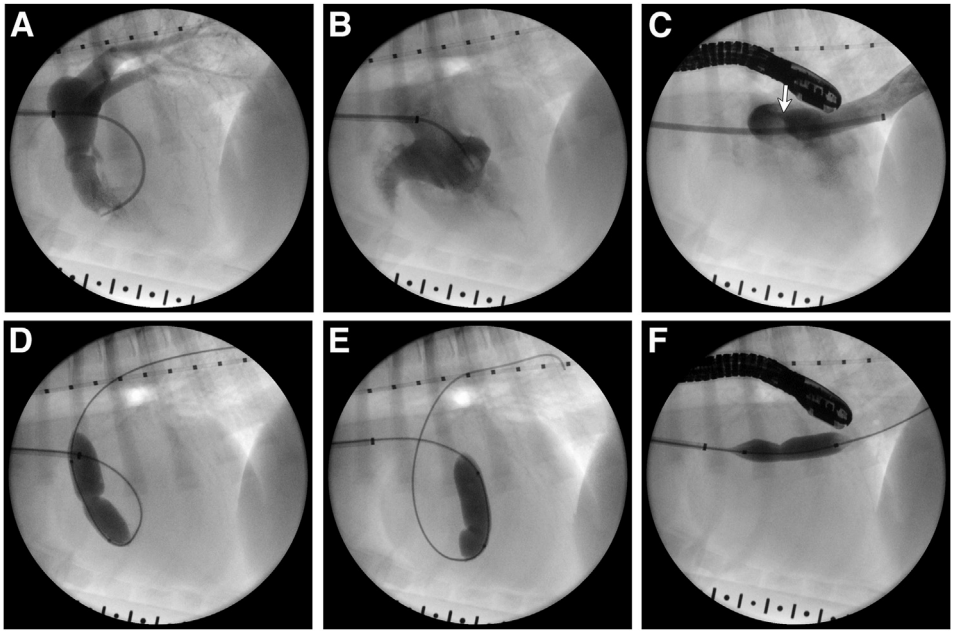

Fig. 4 Angiography and intervention: Fluoroscopic images during cardiac catheterization and intervention from case 5, a pit bull terrier with pulmonary valve stenosis, tricuspid valve stenosis, imperforate cor triatriatum dexter, and a right-to-left shunting patent foramen ovale. Angiography in the right ventricle (A), right atrium (B), and caudal vena cava after puncture of the right atrial membrane (C) demonstrates the three obstructive lesions in the right heart of this dog. The right-to-left shunt at the atrial level before intervention can also be seen (arrow) in (C). Balloon dilation of all three lesions — pulmonary valve (D), tricuspid valve (E), and right atrial membrane (F) — resulted in improved hemodynamics throughout the right heart. In all images, a marker catheter is present in the esophagus for calibration, and in (C) and (F), a transesophageal echocardiography probe can be seen.

with preliminary pressure gradients ranging from 2 to 7 mmHg (median, 6.5 mmHg). Post-procedural pressure gradients in these dogs ranged from 1 to 4 mmHg (median 3.5 mmHg). In two cases, concurrent severe PS was treated by balloon pulmonary valvuloplasty performed during the same catheterization. All seven cases had post-procedural angiography performed with the initial interventions. One case required a second procedure, and angiography was repeated at that time, both before and after stent implantation. In all cases, post-interventional caudal contrast injections showed improved, more rapid filling of the cranial RA chamber through a larger orifice in the intra-atrial membrane.

Two of seven dogs (29%) required two procedures to relieve the clinical signs associated with their CTD obstruction. In both cases, PE re-occurred after the initial procedure. These dogs were both initially treated with a combined cutting balloon membranostomy followed by balloon dilation. In the first of these cases, PE initially resolved but had re-occurred at the one-month recheck, and the second procedure, balloon-expandable stent placement, placed as described previously [20], was performed four months after the initial treatment. After stent placement, the patient's clinical signs resolved completely with no reoccurrence of PE at subsequent rechecks.

In the second case, the PE re-occurred the day after balloon dilation. This dog was subsequently taken to surgery for an intra-atrial membrane resection under right-sided venous inflow occlusion [13,17,22]. Severe arrhythmias developed during surgery, initially consisting of a supraventricular tachycardia, ventricular premature complexes, and ventricular tachycardia that were medically treated intra-operatively. The patient then went into sinus arrest (presumed to be due to intra-operative manipulation of the sinus node) with a ventricular escape rhythm, and an epicardial pacemaker was emergently placed during the same procedure. Persistent arrhythmias, development of a thrombus at the RA incision site resulting in cranial caval syndrome, inflammatory pleural effusion thought to be due to the presence of a thoracostomy tube, and pain prolonged the postoperative care of this dog. The dog was discharged after nine days in the hospital receiving pimobendan, enalapril, and spironolactone; recurrent PE has not been noted since one-month after procedure (follow-up period: 27 months).

Outcomes

Outcome information was available for the majority of cases and is summarized in supplemental Table B. All seven cases that underwent interventional procedures (catheterization or surgical) for treatment of the CTD were alive at the time of last contact and had no recurrence of previous PE. The median [range] time from diagnosis to last contact for these seven dogs was 330 days [45—1440 days].

In seven of seventeen cases (41%), the membrane was perforate and considered to be incidental or minimally contributory to clinical signs. These dogs were managed for their concurrent cardiac disease, if necessary, or left untreated. In these dogs, time from diagnosis to last follow-up was 210 days [31—450 days] days. One dog with severe PS in which intervention was declined by the owner was prescribed atenolol. The dog with DCRV was initially untreated but eventually was prescribed sotalol because of exercise-induced collapse episodes. Seventeen months after diagnosis, this dog was presented with pleural and peritoneal effusion, secondary to right-sided congestive heart failure. Spironolactone and furosemide were added to the therapy and resulted in clinical improvement. Additional diagnostics and intervention were declined. The adult dog with right-to-left shunting PDA, severe PH, and pleural effusion was treated with sildenafil, benazepril, and spironolactone and was doing well clinically with no recurrent effusion at last follow-up, two months after starting treatment. Finally, the adult dog with generalized myocardial dysfunction and ventricular ectopy was treated with pimobendan, sotalol, and benazepril and was doing well at the last recheck, two months after starting medications. Muscular dystrophy was the suspected as the etiology of this dog's myocardial dysfunction and systemic abnormalities.

Two dogs were euthanized at the time of presentation, and a third was euthanized 11 weeks later because of clinical signs unrelated to the CTD. One dog was lost to follow-up. The two dogs that were euthanized at presentation were young dogs (aged three and four months, respectively) that were evaluated for PE and had concurrent congenital disease. The remaining dog that underwent euthanasia was a nine-year-old bulldog with severe, recurrent PE suspected to be secondary to severe PH and degenerative valvular disease that was managed medically. This dog was treated with sildenafil, pimobendan, and furosemide and the quality of life improved initially, but this dog was euthanized 11 weeks after initial presentation because of persistent pulmonary infiltrates and recurrent ascites.

Gross pathology

Three dogs that were euthanized had full necropsies performed. In two cases, the CTD membrane was identified on necropsy. The CTD membrane was not identified in the adult dog euthanized because of persistent PE and pulmonary infiltrates. On necropsy examination, this dog was found to have a cholangiocarcinoma with lymph node metastasis and abdominal lymph node obstruction, suspected to be contributing to the recurrent PE. Moderate cardiomegaly was identified, with myxomatous changes to the mitral (moderate) and tricuspid (mild). No CTD membrane was identified, although this dog had a confirmatory agitated saline contrast study before euthanasia. The possibility of a dilated RA aneurysm cannot be excluded in this dog, although the failure to identify a clear CTD membrane may have been due to necropsy error.

The remaining two cases of CTD were confirmed on necropsy. In one, a perforate CTD was noted with the caudal vena cava and coronary sinus entering the caudal atrial chamber, as well as global RA dilation, severe hepatic congestion, and severe PE. This dog also had moderate TVD with the CTD membrane in fibrous continuity with the septal cusp of the tricuspid valve leaflet. In the other case, severe RA dilation, PFO, and the CTD membrane were observed, with the caudal vena cava and coronary sinus entering the caudal chamber (Fig. 5). This dog also had TVD with fused leaflets and a stenotic orifice, a dysplastic pulmonary valve, and dysplastic/short chordae tendineae on the mitral apparatus consistent with mitral valve dysplasia.

Discussion

This case series describes the clinical findings of 17 dogs with CTD. In this referral patient population, CTD was a solitary cardiac abnormality in only three dogs (18%). Most cases in this study (82%) had concurrent congenital disease, with right-sided defects predominating. The possible relationship between congenital right-sided cardiac defects in dogs has been discussed previously [27,28], with PS and TVD often seen concurrently. Single case reports of dogs with CTD have also shown that a number of these dogs have concurrent congenital disease affecting the right heart, with TVD [13,16,20], PS [19], and DCRV [11] reported.

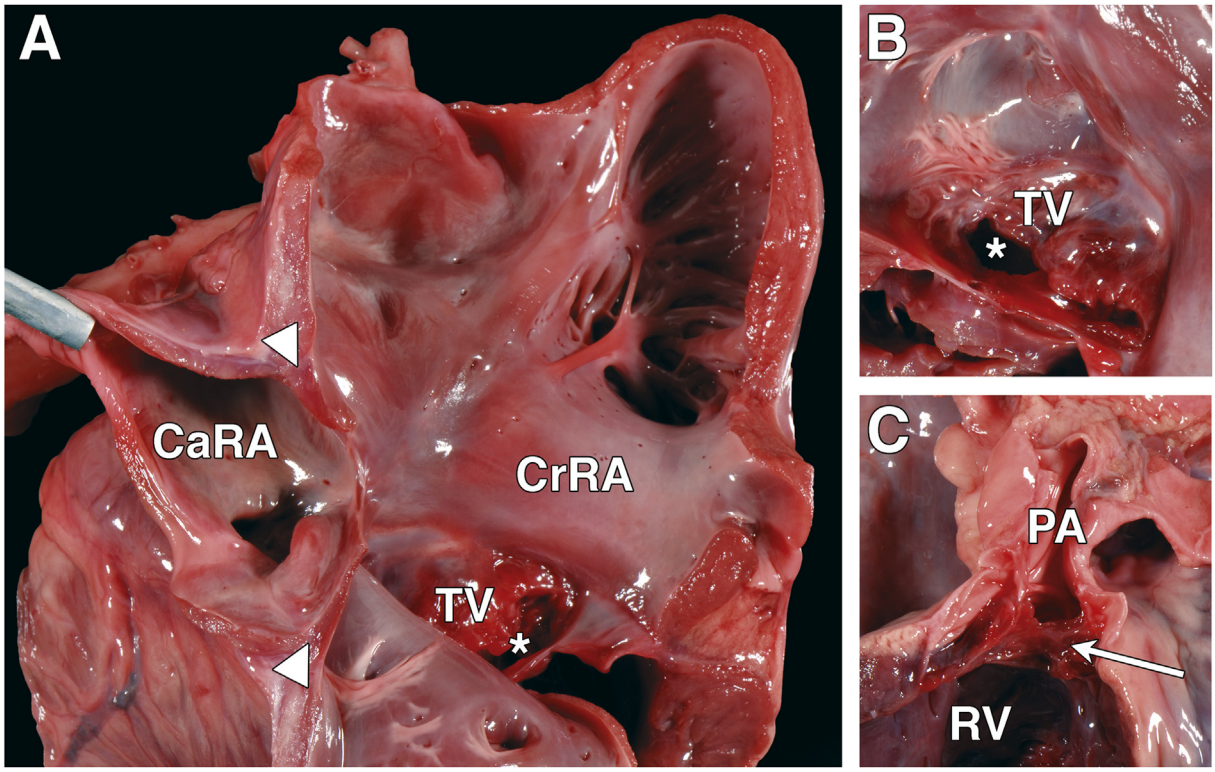

Fig. 5 Postmortem images: photographs of case 3 showing multiple right-sided congenital defects. Panel (A) demonstrates the muscular division (between arrowheads) that divides the right atrium into caudal (CaRA) and cranial (CrRA) portions, as well as showing a thickened tricuspid valve (TV) with a stenotic central orifice *, and right ventricular hypertrophy. Panel (B) represents an en face or dorsal view of the tricuspid valve (TV) showing malformed and thickened leaflets with a stenotic central orifice *. Panel (C) shows the pulmonary valve (arrow) from this same patient which is thickened and dysplastic with evidence of right ventricular (RV) hypertrophy and minimal post-stenotic dilation of the pulmonary artery (PA).

Two of the dogs in this study also had suspicion for accessory pathways, one with ventricular pre-excitation suggestive of atrioventricular fibers (Kent bundle) and paroxysmal re-entrant tachycardia, and one with shortened P-Q interval and no evidence of ventricular pre-excitation, suggestive of accelerated atrioventricular nodal conduction or an atrionodal bypass accessory pathway [29]. Both these dogs also had TVD. An association between tricuspid valve abnormalities and accessory pathway conduction in dogs has been previously suggested [28,30] because malformation of the tricuspid valve apparatus may be mechanistically associated with accessory pathway formation. Of note, most accessory pathways in dogs are located in the right posterior wall [30], an area that is likely to be affected by malformation of the tricuspid valve apparatus. The relative frequency of atrioventricular conduction abnormalities in our study population emphasizes the need for diagnostic electrocardiography as part of the initial evaluation in these patients.

Failure of apoptosis has also been suggested as a mechanism for tricuspid valve malformation in dogs, potentially contributing to the incomplete separation of the tricuspid valve leaflet from the right ventricular wall (tethering) [31,32]. Although there appears to be a frequent association of multiple right-sided cardiac congenital abnormalities in dogs with CTD, the exact embryologic mechanism has not been elucidated. Cor triatriatum dexter remains an uncommon congenital disease in this species, and where it fits into the constellation of right-sided malformations is not known. Cor triatriatum dexter results from persistence of the embryologic right sinus venosus valve. It is possible that defective apoptosis could contribute to persistence of this valve. In people, atrial septation and the loss of the sinus venosus valve should occur in the first four to seven weeks of gestation, before formation of the atrioventricular or semilunar valves [33]. It is possible that alterations in apoptotic mechanisms link these temporally unassociated defects. It is also possible that there are related genetic mutations causing this pattern of right-sided anomalies.

Additional studies would be necessary to determine if there is a pattern of inheritance to CTD and other congenital diseases in dogs.

Previous case reports of dogs with CTD have focused on animals with clinical signs caused by caudal vena cava inflow obstruction. Most of these reports detailed interventional procedures for treatment of symptomatic patients. Seven of the 17 patients (41%) included in this study had CTD that was suspected to be incidental or minimally contributory to the patient's clinical signs. In two of these cases, PE was present at initial presentation but potentially unrelated to the CTD. In one dog, PE resolved after balloon pulmonary valvuloplasty with no treatment of the CTD, and in the second dog, the PE was suspected to be due to lymphatic obstruction from a cholangiocarcinoma that was diagnosed on necropsy. Increased RA filling pressures might have contributed to accumulation of PE in these two cases. Five of the seven dogs had no evidence of clinically significant PE, despite concurrent cardiac disease. Whether or how the presence of a perforate CTD could impact outcome in these dogs is not known. It is possible that chronic, mildly elevated RA filling pressure could potentiate development of PE in these patients, even if their coexisting diseases were the predominant factor for PE formation.

Most dogs in this study had an extensive evaluation with multiple diagnostic modalities used. Radiographic and ECG findings were typically nonspecific and were not diagnostic for CTD in any case. Radiographic evidence of caudal vena cava dilation, a hallmark feature of CTD that is suggestive of elevated RA filling pressure, was noted in only two cases. Most dogs in this study had concurrent cardiac abnormalities, however, and radiographic findings often suggested the presence of these diseases and may have helped rule out other possible causes for the clinical signs.

In all cases, diagnosis of CTD on echocardiography was relatively straightforward, although when a membrane had a large perforation, agitated saline contrast was necessary to differentiate CTD from aneurysmal dilation of the RA. Pulsed-wave Doppler interrogation of peak flow across the membrane (occurring at ventricular systole) was used to establish pressure gradients between the cranial and caudal CTD chambers in most of the cases with a perforate CTD. This gradient is discussed in numerous reported cases of dogs with CTD [11—13,15,21,22,25]. The prognostic value of measuring this pressure gradient is not known, however, and this measurement may be affected by the presence of concurrent disease. The mean pressure gradient across a venous obstruction may be a more useful measure of severity, but was not evaluated in this study. In a dog with CTD and no other abnormalities, the peak diastolic velocity of the transmembrane flow is likely to reflect the severity of the obstruction. The presence of tricuspid valve regurgitation, right ventricular outflow obstruction (PS or DCRV), or PH, however, might increase the pressure in the cranial RA chamber during ventricular systole and minimize this gradient. Ultimately, the change in this gradient in an individual dog (e.g. before and after procedure or due to worsening concurrent disease) might be more meaningful than an isolated measurement compared between dogs.

Aside from dogs that were euthanized before initiation of treatment, most of the dogs in this study survived and were still alive at the time of writing (up to 48 months after diagnosis). Interventional procedures, when performed, were typically successful in alleviating clinical signs on the first attempt, and no serious complications were reported with catheter-based interventions. When balloon membranostomy fails, stent implantation or surgical resection may be considered. In the dogs with large-diameter perforations and no clinical signs, no treatment was recommended and the dogs remained without clinical signs associated with RA inflow obstruction through the period of follow-up, suggesting that CTD can exist incidentally and that treatment is not required in the absence of PE.

Limitations

This is a retrospective study and, as such, has limitations. The dogs described were evaluated in referral institutions, so no conclusions regarding relative prevalence of CTD in the general canine population can be drawn. Diagnostic evaluations and initial therapeutics were not standardized and varied significantly between dogs. In addition, because cases were recruited from multiple referral institutions, different approaches to initial diagnosis and management were noted; comparing outcomes or utility of diagnostic tests is not advisable with the available data. Follow-up for some cases is limited because dogs with no recurrence of clinical signs were not consistently brought back for recheck evaluations. Despite the number of dogs, which was greater than that in previous reports, it remains likely that the spectrum of clinical presentations for dogs with CTD is not represented completely in this case series. This report is not intended to provide recommendations for

Video table

Video	Title	Description
1	Two-dimensional transthoracic echocardiographic cine of an agitated saline contrast study — saphenous injection	Left parasternal long axis view. The cine loop shows the agitated saline contrast entering the accessory chamber, passing into the main right atrial chamber, and then filling the right atrium. A small number of bubbles are also observed in the left atrium, consistent with a right-to-left shunting patent foramen ovale.
2	Two-dimensional transthoracic echocardiographic cine of an agitated saline contrast study — cephalic injection	Oblique right parasternal long axis view. The cine loop shows the agitated saline contrast entering the main right atrial chamber and subsequently passing through the tricuspid valve and into the right ventricle. No contrast is observed in the accessory chamber.

treatment or prognostic information for individual animals because the spectrum of concurrent disease and clinical presentations was vast and will impact those decisions.

Conclusions

Cor triatriatum dexter is a rare congenital anomaly in dogs that, when present, is often associated with other congenital malformations of the right heart. Dogs with widely perforate CTD membranes may be asymptomatic into adulthood, although this condition may exacerbate clinical signs associated with other right-sided diseases. Dogs with symptomatic CTD can have long survival times with intervention. Echocardiography appears to be an appropriate modality for diagnosis of CTD.

Conflicts of Interest Statement

The authors do not have any conflicts of interest to disclose.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvc.2019.03.002.

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