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Cardiovascular Images

A pictorial view of the three-dimensional representation and comparative two-dimensional image orientation derived from computed tomography angiography in a dog with a patent ductus arteriosus☆

A.B. Saunders, DVM [a,*], K.R. Doocy, DVM [a], S.A. Birch, BA [b]

[a] *Department of Small Animal Clinical Sciences, Texas A&M University, College Station, TX, USA*
[b] *PixelBeaker, Chattanooga, TN, USA*

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Abstract Patent ductus arteriosus (PDA) occlusion is one of the more common cardiovascular procedures performed in dogs. Two-dimensional imaging has been the primary method of visualizing the PDA and is the basis of its morphologic description. Transesophageal echocardiographic imaging has further characterized the three-dimensional (3D) variation in ductal morphology and shape (circle, oval). An accurate assessment of the shape and dimensions of a PDA in an individual dog is important when making decisions about definitive closure. Ductal measurements from angiography and echocardiography have not been found to be interchangeable, likely related in part to the static two-dimensional measurement of a 3D structure. We describe the use of computed tomography angiography (CTA) images imported into three software programs as a tool to provide 3D information about PDA anatomy

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☆ A unique aspect of the Journal of Veterinary Cardiology is the emphasis of additional web-based images permitting the detailing of procedures and diagnostics. These images can be viewed (by those readers with subscription access) by going to http://www.sciencedirect.com/science/journal/17602734. The issue to be viewed is clicked and the available PDF and image downloading is available via the Summary Plus link. The supplementary material for a given article appears at the end of the page. Downloading the videos may take several minutes. Readers will require at least Quicktime 7 (available free at http://www.apple.com/quicktime/download/) to enjoy the content. Another means to view the material is to go to http://www.doi.org and enter the doi number unique to this paper which is indicated at the end of the manuscript.

* Corresponding author.
E-mail address: asaunders@cvm.tamu.edu (A.B. Saunders).

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including a comparison to images obtained from classic two-dimensional imaging modalities. These images provide an example of thorax and heart position related to transducer position and the orientation of image acquisition to demonstrate why measurements do not always compare. Additionally, 3D images are useful as a training tool and in the development of devices and training opportunities. Multidimensional imaging provides a unique representation of the 3D anatomical structure of the ductus arteriosus as displayed in these images from a dog with a PDA.

Abbreviations

CTA	computed tomography angiography
PDA	patent ductus arteriosus
3D	three-dimensional

A 6-month-old, 6 kg, female miniature schnauzer was evaluated for an asymptomatic grade 4/6 continuous left basilar murmur and diagnosed via echocardiography with a left-to-right shunting patent ductus arteriosus (PDA) with mild secondary left-sided heart enlargement. As part of an institutionally approved study and with consent from the owner, computed tomography angiography (CTA) of the thorax was performed under anesthesia prior to PDA occlusion. Briefly, the dog was premedicated (butorphanol 0.2 mg/kg IV followed by midazolam 0.2 mg/kg IV) then induced with propofol (4 mg/kg IV). Anesthesia was maintained with sevoflurane inhalant and a fentanyl constant rate infusion (10 mcg/kg/min IV). Images were acquired with a 40-slice computed tomography scanner[c] (scan parameters 120 kVP, 450 mA, 0.6 mm slice thickness per rotation). A 13 ml bolus of iodinated contrast[d] was administered into the left cephalic vein using a power injector. A region of interest was placed in the cranial vena cava for automatic trigger scanning when the region of interest reached 80 Hounsfield units within the vessel. The postcontrast series include three-phase angiography without timed delays between scans with a scan time for each phase of 10 s. Transverse plane images were reconstructed with a soft tissue algorithm on a dedicated workstation with 50% overlap. The Digital Imaging and Communications in Medicine data set from the CTA was imported into three software imaging programs for further analysis.

Image interpretation

In Fig. 1, a custom volume-rendered three-dimensional (3D) reconstruction algorithm was applied using an open source imaging software program.[e] The panels on the left display the two-dimensional images of the PDA acquired with standard imaging including lateral angiography, transthoracic echocardiography[f] from the right parasternal short axis view at the level of the main pulmonary artery, transthoracic echocardiography from the left parasternal cranial short axis view, and transesophageal echocardiography. The PDA morphology is type II based on angiography [1]. Images in the panels on the right display the correlative volume rendered images of the heart and thorax acquired from the CTA to show angle of acquisition and ultrasound transducer position (when applicable for echocardiographic images) in relation to the PDA to approximate the corresponding angiographic or echocardiographic imaging modality (shown in sequence in Video 1). In Fig. 2, the area immediately surrounding the PDA was isolated from the remainder of the thorax using a 3D modeling software[g] to display the blood pool and surrounding tissue. The blood pool is displayed as a 3D geometric mesh using a series of triangles to depict a topographical surface view as a map of the PDA structure (Fig. 2A). A 3D point cloud provides a view beyond the surface allowing visualization of the PDA and surrounding structures maintaining the relationship of the tissue and blood pool in multiple dimensions (Fig. 2B). In Fig. 3, a 3D representation of the anatomy was rendered in an interactive virtual reality 'true 3D' system,[h] and custom transfer functions (color maps based on Hounsfield units) were applied to depict the heart and blood vessels in a variety of ways to display cardiovascular tissue or blood pool. The 3D image was freely rotated in real time to view the

[c] SOMATOM Definition AS, Siemens AG, Muenchen, Germany.
[d] Omnipaque, GE Healthcare Inc., Oslo, Norway.
[e] OsiriX v.6.5.1, Pixmeo SARL, Bernex, Switzerland.
[f] GE Vivid E9, GE Vingmed Ultrasound, Horton, Norway.
[g] 3-matic, Materialise, Leuven, Belgium.
[h] EchoPixel True 3D, EchoPixel Inc., Mountain View, CA, USA.

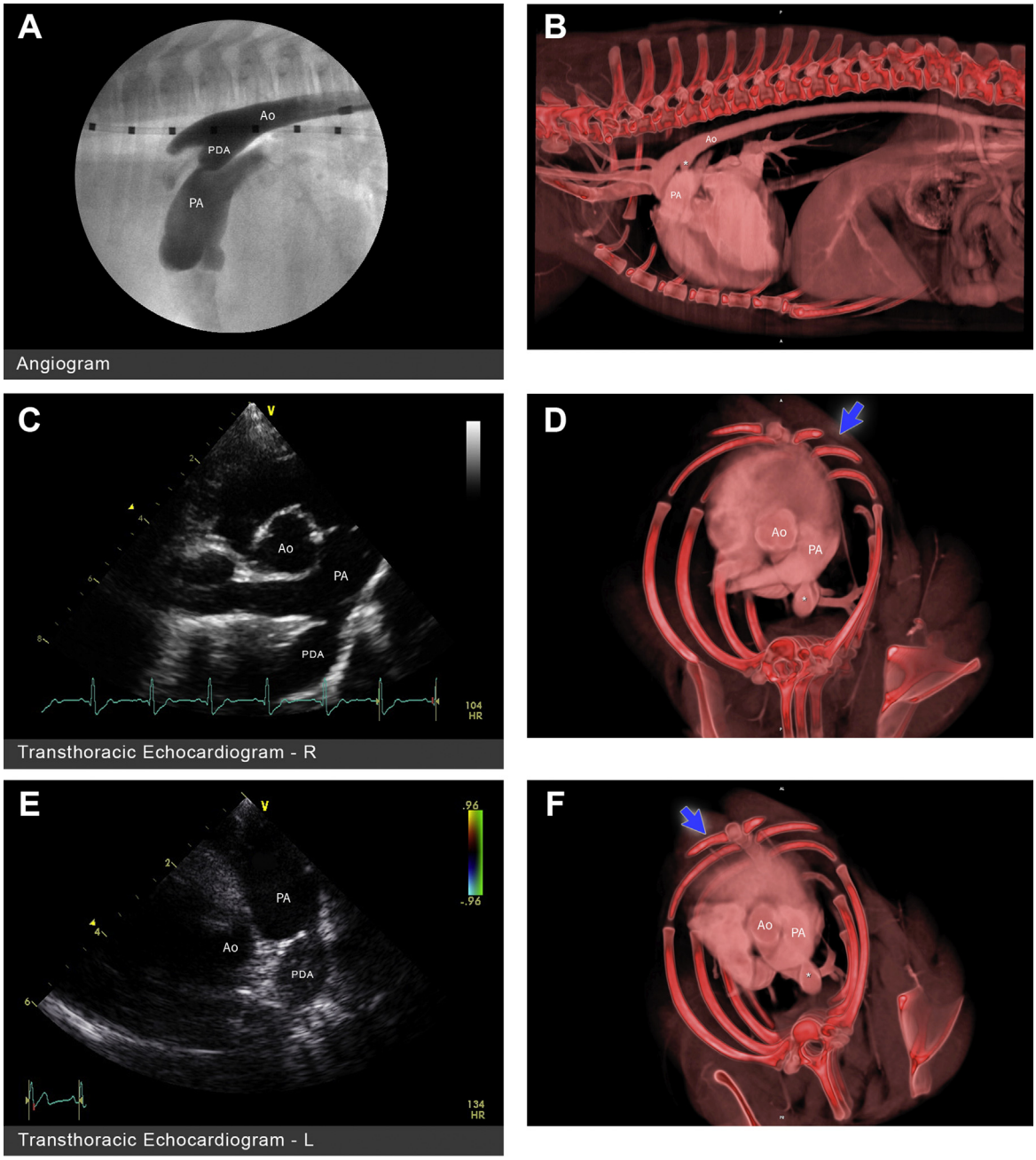

Fig. 1 Pictorial consisting of images obtained from standard imaging modalities of a patent ductus arteriosus (PDA) in a dog that are compared to computed tomography angiography derived volume-rendered images of the thorax rotated to display the PDA to match the angiographic and echocardiographic images. Panels A and B display the PDA (denoted by an * in the volume rendered views) from a right lateral angiogram and a volume-rendered view with the thorax positioned to match the angiogram. In panels C and D, the PDA is displayed with transthoracic echocardiography obtained from a right parasternal short axis view at the level of the main pulmonary artery, and the volume-rendered image of the thorax was rotated to display the PDA in a similar view. In panels E and F, the PDA is displayed with transthoracic echocardiography obtained from a left parasternal cranial short axis view, and the volume-rendered image of the thorax was rotated to display the PDA in a similar view. In panels G and H, the PDA is displayed with transesophageal echocardiography, and the volume-rendered image was rotated to display the PDA in a similar orientation. Transesophageal echocardiography maintains the PDA in the near field compared to transthoracic echocardiographic images. The location and angle of the ultrasound transducer for each of the transthoracic and transesophageal echocardiographic images is denoted by a blue arrow on the corresponding volume-rendered images of the thorax. Ao: aorta; PA: pulmonary artery.

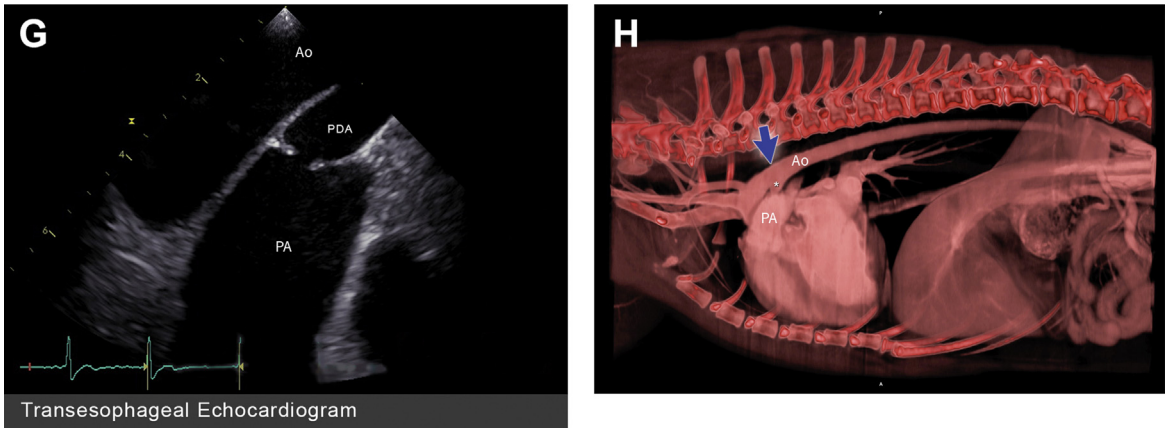

Fig. 1 (Continued).

heart and thorax in a dorsoventral position (Fig. 3A), and a cut plane applied to remove the dorsal wall of the aorta to show the pulmonary ostium of the PDA in an end on view as if peering down the ampulla into the pulmonary artery (Video 2) or rotated into a lateral position (Fig. 3B and C), and a cut plane applied to remove the lateral thorax including ribs with transfer functions applied to display the blood pool (B) or cardiovascular tissue (C).

Discussion

Multiple studies have compared angiographic and echocardiographic measurements of PDA and reported that measurements between imaging modalities are not generally comparable [2—4]. Reconstructed 3D images provide unique views of the PDA to show the orientation in which two-dimensional images obtained may not always display the PDA in a similar position. Additionally, PDA shape can range from circular to oval, and orientation of the image could affect measurements if they were obtained from different locations within the oval shape (long, short, and oblique) [4]. Device sizing guidelines have been based primarily on angiography with more recent studies including echocardiographic measurements of the pulmonary ostium and ampulla; however, differences in image orientation between imaging modalities and poor image quality can lead to erroneous PDA measurements and impede successful closure [2,5—7]. Oversized and undersized devices are cited as a potential reason for procedural complications [6,8], highlighting the necessity of having an awareness of the anatomic characteristics of the PDA and acquiring good quality images for measuring prior to selecting a device [2,4]. In a recent survey of veterinary cardiologists, device embolization was the most common complication reported, and the most common topics of interest reported were related to resolving or minimizing complications, methods of measuring the PDA, and device selection and sizing.[i]

With transesophageal echocardiography, the ultrasound transducer is positioned directly above the PDA and therefore displays the PDA in the near field and in a similar long axis orientation to angiography (Fig. 1B and H). As previously described, imaging with 3D transesophageal echocardiography can provide end-on and cross-sectional views of the PDA similar to the 3D representation of the CTA down the ampulla toward the pulmonary artery [9]. Three-dimensional transesophageal echocardiography has the added value of providing continuous imaging in real time. Compared to transesophageal echocardiography, the transthoracic echocardiographic transducer is positioned on the thorax, not directly above the PDA, thus the PDA is displayed in a far field position and at various angles depending on the orientation of the heart (Fig. 1D and F). An example of ductal measurements has been previously published, and in that study, recommendations were made to use measurements from the images that most clearly depict the PDA [4].

A high-quality CTA study with minimal motion artifact produces the best 3D images. In all three software programs described here, the Digital Imaging and Communications in Medicine files are imported and the 3D images that are generated can be rotated to display the PDA from multiple views. Unique aspects of each software program are related to how fast the image can be generated, ease of use, and how the images can be manipulated. Additionally, it is important to consider the operator's level of expertise. OsiriX is a

[i] Patent ductus arteriosus in review: more than 10 years with the Amplatz canine duct occluder and PDA survey results. American College of Veterinary Internal Medicine Forum session, June 2018, Seattle, WA, USA.

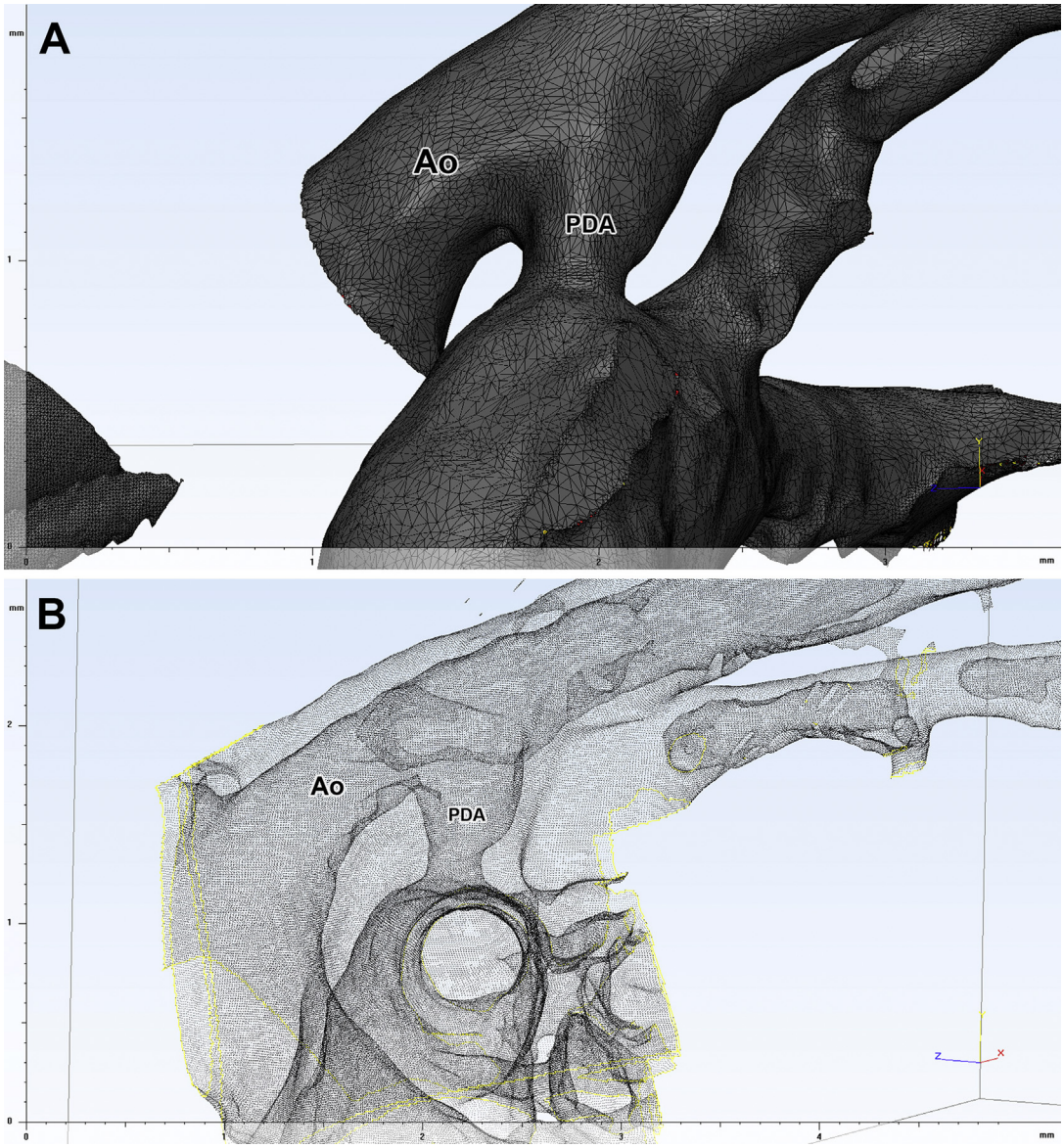

Fig. 2 Patent ductus arteriosus (PDA) and surrounding vasculature isolated from the remainder of the thorax and displayed as (A) a three-dimensional (3D) geometric mesh that represents the blood pool and (B) a 3D point cloud that allows visualization of the tissue and internal blood pool. Both can be rotated to view the 3D structure of the PDA from various angles and allow for measurements to be obtained. Note the difference in the appearance between images is related to the position of the aorta compared to the PDA which is slightly different (aorta behind the PDA in A and in front in B). Ao: aorta.

widely used medical imaging viewer with post-processing and video output capabilities that is reasonably user friendly but requires more expertise for advanced functionality. Materialise 3-matic belongs to a suite of highly technical software programs focused on taking medical image studies through segmentation to 3D printing that requires technical expertise and training. EchoPixel renders a true 3D model viewed with 3D glasses in a matter of minutes without requiring segmentation. Models can be rotated freely in 360° with transfer functions applied that allow the user to toggle between blood volume and tissue display with ease and brief instruction.

Although routine use of CTA is not required for closure of PDA in dogs, in addition to enhancing our understanding of ductal anatomy, there are additional benefits provided by the software packages and 3D modeling. The stereolithography files created in Materialise 3-matic can be used to 3D print the PDA and surrounding structures for biomedical engineering of custom training models for practicing ductal occlusion [10]. Measurements of the pulmonary ostium and ampulla as well as volume calculations of the PDA can be obtained from the 3D geometric mesh models to provide additional anatomic characteristics to influence future device development [11]. As a

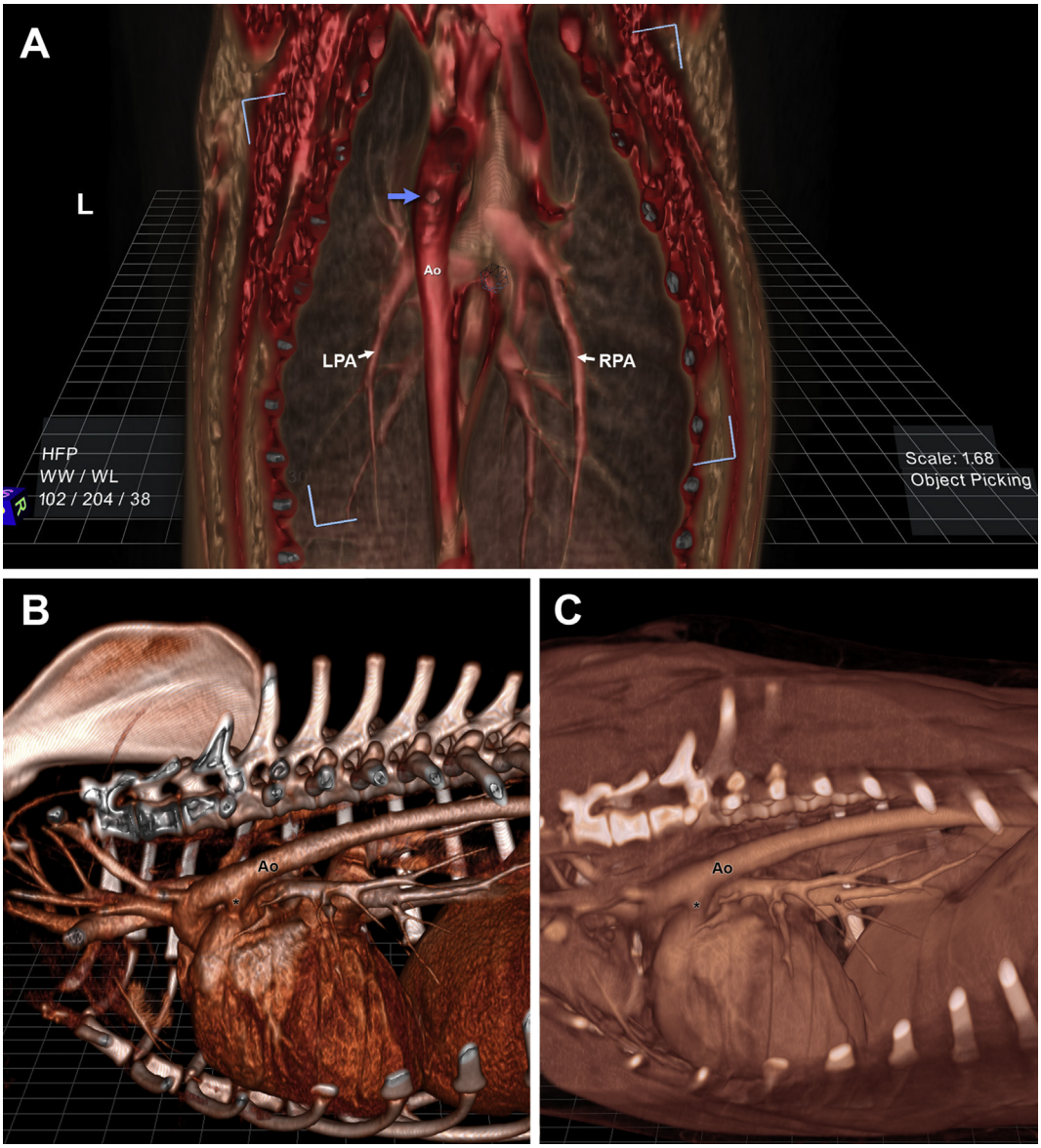

Fig. 3 Images of the thorax in a dog with a patent ductus arteriosus (PDA) portrayed as still image screen captures from an interactive virtual reality system. In panel A, the thorax is displayed in a dorsoventral position with the blood pool removed and a cut plane applied to remove the dorsal wall of the descending aorta to show the pulmonary ostium of the PDA (*) in an end on view peering down the ampulla (blue arrow). In panels B and C, the image was rotated to display the thorax in a lateral view to display blood pool or cardiovascular tissue respectively. Ao: aorta; L: left; LPA: left pulmonary artery; RPA: right pulmonary artery.

supplementary training tool, surgery residents can manipulate the 3D images to position the thorax and use transfer functions and cutting planes to remove tissues revealing the location of the PDA and surrounding structures. At our institution, advanced imaging is a useful tool. Here we report visualization of a basic congenital defect to show how we use advanced imaging to lead to a better understanding of PDA morphology. We have also found it useful in complex cases to assist with device selection and to allow surgeons to visualize the surgical plane prior to hybrid procedures. It is our hope that making these images available will be helpful and perhaps serve as a stimulus for the continued advancement of imaging and interventional cardiology in our field.

In summary, reconstructed data sets from the CTA study provide a 3D representation of the anatomy to enhance the understanding of spatial relationships useful to those performing PDA closure and in development of techniques, devices, and training opportunities to maximize successful closure and minimize complications.

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Conflicts of Interest Statement

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvc.2018.09.004.

Video table

Video 1	Computed tomography angiography derived volume-rendered image of the thorax from a dog with a PDA. The thorax is rotated to match the orientation of standard imaging modalities beginning with angiography and followed by transthoracic echocardiography from the right parasternal short axis view at the level of the main pulmonary artery, transthoracic echocardiography obtained from a left parasternal cranial short axis view, and transesophageal echocardiography.
Video 2	Manipulation of a 3D image of the thorax in an interactive virtual reality system from two viewpoints to show manipulation of the model and how it appears in 3D demonstrating the use of transfer functions to display different tissue characteristics and rotation of the thorax with application of a cut plane to the aorta to display the PDA from a dorsal view peering down the ampulla at the pulmonary ostium.

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