ESCOLA UNIVERSITÁRIA VASCO DA GAMA

Ciclo de Estudos Integrado Conducente ao Grau de Mestre em Medicina Veterinária

Artigo de revisão

MULTIMODALITY IMAGING IN THE ASSESSMENT OF DOGS WITH PERICARDIAL EFFUSION

Zoé Clélie Nehla Isnard

Coimbra, julho 2024

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LIST OF ABREVIATIONS

BUN: Blood urea nitrogen

cCT: Cardiac tamponade

cTnI: Cardiac troponin I

CT: Computed tomography

CaCT: Cardiac computed tomography

DV: Dorso-ventral

ECG: Electrocardiographic

FCU: Focused cardiac ultrasound

HU: Hounsfield Unit

HSA: Hemangiosarcoma

MDCT: Multi-detector computed tomography

MRI: Magnetic Resonance Imaging

cMRI: Cardiac magnetic resonance imaging

PCV: Packed cell volume

TTE: Trans Thoracic Echocardiography

VD: ventro-dorsal

VPCs: Ventricular premature contractions

RA: Right atrium

RV: Right ventricle

LA: left atrium

LV: left ventricle

PE: Pericardial effusion

PPDH: Peritoneopericardial diaphragmatic hernia

R-CHF: Right-sided congestive heart failure

2DE: Two-dimensional echocardiography

M-Mode: Time-motion echocardiography

CDI: 2D color Doppler imaging

PWD: Pulsed Doppler

CWD: Continuous Doppler (CWD)

IVS: Interventricular septum

SSFP: Steady-state free precession

MULTIMODALITY IMAGING IN THE ASSESSMENT OF DOGS WITH PERICARDIAL EFFUSION

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ABSTRACT

This review aims to comprehensively evaluate the utility and efficacy of multimodality imaging techniques in the assessment of dogs with pericardial effusion. By analyzing existing literature, this study seeks to provide insights into the strengths and limitations of various imaging modalities, including echocardiography, radiography, computed tomography, and contrast-enhanced multidetector computed tomography in diagnosing, characterizing, and managing pericardial effusion in dogs. Ultimately, this contributes to improved diagnostic accuracy and treatment outcomes in veterinary cardiology. Pericardial effusion poses a significant threat due to its potential progression to life-threatening states, underscoring the importance of accurate and timely diagnosis for prompt intervention. Pericardiocentesis serves as a vital first-line treatment, highlighting the necessity of a thorough diagnostic approach to provide prognostic information crucial for treatment decisions. Imaging techniques play a crucial role in managing pericardial effusions in dogs, offering unique perspectives that allow veterinarians to establish accurate diagnoses and determine appropriate therapeutic interventions. Transthoracic echocardiography and focused cardiac ultrasound emerge as primary imaging methods, with transthoracic echocardiography providing detailed non-invasive cardiac evaluations, including confirmation of diagnosis, identification of potential causes, and guidance for pericardiocentesis. Radiography serves as a valuable, cost-effective option, particularly for chronic or slowly progressing cases. However, ultrasound and radiography alone may be insufficient for precise diagnosis due to variable sensitivity and inability to evaluate associated abnormalities. Advanced imaging techniques like computed tomography, multi-detector computed tomography and cardiac magnetic resonance imaging offer heightened sensitivity in detecting pericardial effusion cases and assessing associated abnormalities. Integration of advanced imaging techniques as complementary tools to traditional methods could significantly enhance the diagnostic armamentarium for pericardial effusion assessment in dogs. Future research should focus on addressing gaps between human and veterinary medicine to refine treatment approaches and improve outcomes for dogs with this condition.

Key words: dogs, pericardial effusion, diagnosis, multimodality imaging

RESUMO

Esta revisão bibliográfica tem como objetivo avaliar a utilidade e eficácia das técnicas de imagem multimodalidade na avaliação de cães com efusão pericárdica. Ao analisar a literatura existente, este estudo busca fornecer *insights* sobre as ventagens e limitações de várias modalidades de imagem, incluindo ecocardiografia, radiografia, tomografia computadorizada e tomografia computadorizada multidetetores com contraste na diagnóstico, caracterização e maneio da efusão pericárdica em cães. Isso contribui para uma melhor precisão diagnóstica e resultados de tratamento em cardiologia veterinária. A efusão pericárdica representa uma ameaça significativa devido à sua potencial progressão para estados que ameaçam a vida, destacando a importância de um diagnóstico preciso e oportuno para intervenção rápida. A pericardiocentese serve como um tratamento vital de primeira linha, destacando a necessidade de uma abordagem diagnóstica completa para fornecer informações prognósticas cruciais para decisões de tratamento. Técnicas de imagem desempenham um papel crucial no maneio de efusões pericárdicas em cães, oferecendo perspetivas únicas que permitem aos veterinários estabelecer diagnósticos precisos e determinar intervenções terapêuticas apropriadas. A ecocardiografia transtorácica e o ultrassom cardíaco focalizado surgem como métodos de imagem primários, com a ecocardiografia transtorácica fornecendo avaliações cardíacas detalhadas não invasivas, incluindo confirmação de diagnóstico, identificação de causas potenciais e orientação para pericardiocentese. A radiografia serve como uma opção valiosa e económica, especialmente para casos crónicos ou de progressão lenta. No entanto, o ultrassom e a radiografia isoladamente podem ser insuficientes para diagnóstico preciso devido à sensibilidade variável e incapacidade de avaliar anormalidades associadas. Técnicas de imagem avançadas como tomografia computadorizada, tomografia computadorizada multidetetores e ressonância magnética cardíaca oferecem sensibilidade aumentada na detecão de casos de efusão pericárdica e avaliação de anormalidades associadas. A integração de técnicas de imagem avançadas como ferramentas complementares aos métodos tradicionais poderia melhorar significativamente o arsenal diagnóstico para avaliação de efusão pericárdica em cães. Pesquisas futuras devem se concentrar em abordar lacunas entre medicina humana e veterinária para refinar abordagens de tratamento e melhorar resultados para cães com esta condição.

Palavras-chave: cães, efusão pericárdica, diagnóstico, imagem multimodal

INTRODUCTION

Throughout this thesis we will review and summarize the literature exploring the existing imaging techniques used in veterinary cardiology for evaluating PE in dogs. We will be including the key imaging modalities used in this context such as echocardiography, radiography, CT. We will also address the use MDCT and MRI as imaging techniques for this condition.

In the first part of this work, we will explain briefly the pathofisiological and clinical aspect of pericardial effusion in dogs. Then we will discuss the principles, advantages, and limitations of each in the context of PE in dogs. Then, we will summarize previous research and studies highlighting the diagnostic and prognostic value of multimodality imaging in dogs with PE in order to address our research question « How do different imaging modalities contribute to the assessment and management of PE in dogs? »

To select relevant literature about Multimodality Imaging in the Assessment of Dogs with PE, we have established specific criteria and employed effective search strategies and methodologies.

Firstly, we have ensured that the literature selected was directly related to imaging techniques used for assessing PE specifically in dogs excluding all literature relating other species. We have also limited our selection to recent studies with a date range from 1999 to 2023. We have included older ones only in order to establish a historical context and to have comprehensive assessment of PE in dogs during the first part of this presentation. Considering the type of literature, our focus was mainly on peer-reviewed literature but we have also included original research articles, case studies, review articles and clinical guidelines. We have also incorporated scientific articles from human medicine in order to discuss potential future approaches in veterinary medicine for addressing this pathology. In terms of search strategy, we have begun by including relevant keywords and phrases such as "pericardial effusion diagnosis" "multimodality imaging" “dogs/canine“ “radiography“ "echocardiography," "computed tomography," "contrast-enhanced MDCT’’. We’ve used academic databases such as PubMed, Google Scholar, Web of Science, veterinary-specific databases like VetMed Resource and CAB Abstracts and scientific books linked in the bibliography.

ANATOMY AND GENESIS OF PERICARDIAL EFFUSION IN DOGS

Pericardial diseases are frequently encountered in veterinary practice, representing 8% of all cardiac referrals in dogs and 6% of feline cases in referral institutions (Ettinger et al., 2016). Various forms of pericardial diseases exist including congenital, acquired primary and acquired secondary conditions (French, 2010). The majority of pericardial diseases involve the abnormal accumulation of fluid within the pericardial sac referred to as pericardial effusion (PE) (French, 2010). When the quantity of fluid becomes excessive, the pericardial sac can no longer distend, and the pressure exerted on the heart becomes higher than the diastolic filling pressure, particularly on the right side, resulting in circulatory insufficiency (on the right side). This phenomenon known as cardiac tamponade (cCT) is an emergency (Nelson & Couto, 2019). PE in dogs exhibits a total incidence rate of 0.43% and medium to giant breeds are predisposed (Ettinger et al., 2016). Idiopathic pericarditis and cardiac tumors are the most prevalente causes of PE in dogs (Kittleson, Jan 2023), among other numerous etiologies evoked later.

1.1 ANATOMY OF THE CARDIOVASCULAR SYSTEM

A healthy heart has a conical shape and is located in the chest, specifically within the mediastinum. It is positioned obliquely, with the base or hilum at the cranial end and the apex in a caudoventral location (Adams, 2003). The septum divides the heart into two distinct sections: the cranioventral part commonly referred to as the "right heart," and the caudodorsal part known as the "left heart" (Bahr, 2018).

The right heart comprises the right atrium (RA) and the right ventricle (RV), along with an additional extension called the auricle projected cranioventrally from the atrium (Adams, 2003). The cranial and caudal vena cava, along with the coronary sinus, drain into the RA (Bahr, 2018). Blood moves from the RA to the RV through the atrioventricular orifice, hindered from regurgitation by the right atrioventricular (tricuspid) valve. Subsequently, the RV propels the blood into the pulmonary circulation through the pulmonary arterial trunk and the pulmonary valve guarantees that there is no backward flow of blood (Bonagura & Fuentes, 2021).

The left heart comprises the left atrium (LA) and the left ventricle (LV). The LA constitutes the dorsocaudal part of the heart's base and has an auricular pocket (Adams, 2003). It receives blood from the pulmonary veins (Bahr, 2018). Blood moves from the LA into the LV, with the left atrioventricular

valve, also known as the mitral valve. The LV then propels blood to most parts of the body through aortic valve then the aorta (Bonagura & Fuentes, 2021).

The pulmonary arterial trunk, coming out of the arterial cone of the RV, bifurcates into two distinct pulmonary arteries: the right and the left (Adams, 2003) to supply, after further bifurcations, blood to each one of the pulmonary lobes (Bonagura & Fuentes, 2021). The pulmonary veins from each lung independently drain into the left atrium (Bahr, 2018).

The ascending aorta originates from the left ventricle then curves forming the aortic arch then the descending aorta (Adams, 2003). In the chest, the aorta is termed the thoracic aorta, while in the abdominal region, it is referred to as the abdominal aorta (Bahr, 2018). Within the cranial mediastinum, the aorta bifurcates into two main branches known as the brachiocephalic arterial trunk and the left subclavian artery (Adams, 2003).

On radiographies, the caudal vena cava is usually visible between the cardiac silhouette and the diaphragm. It joins with the cardiac silhouette near the region of the LA (Adams, 2003). When measured at the same intercostal space, the diameter of the caudal vena cava should be smaller than that of the aorta (Bonagura & Fuentes, 2021).

The pericardium is a robust fibroserous sac that surrounds the heart. In younger animals, it comes into contact with the cranial thymus (Adams, 2003). The pericardium is intricately connected with the major blood vessels entering or exiting the heart. It is not visible in standard X-rays unless there is pericardial fat to provide contrast (Bonagura & Fuentes, 2021).

The pericardium comprises two layers: the tough external layer termed the fibrous pericardium, and a thin, internal layer known as the serous pericardium. The fibrous pericardium is a connective tissue that exhibits limited distensibility. Nevertheless, it can stretch up to a certain limit when pressure is gradually applied. Situated within the fibrous pericardium, the serous pericardium consists of two layers: the outer parietal layer lining the internal fibrous pericardium and the internal visceral layer constituting the outermost layer of the heart (known as the epicardium). Each layer consists of a monolayer of epithelial cells referred to as mesothelium. (Miller & Gal, 2017).

The pericardial cavity, situated between the outer and inner serous layers, typically holds 1 to 15 mL of a plasma ultrafiltrate acting as a lubricant to minimize friction generated by cardiac contraction (Scott P Shaw & John E Rush, 2007a). Although animals can survive and function normally without an intact pericardium, the pericardium serves various crucial functions (Adams, 2003).

1.2 ETIOLOGY

The causes of PE are numerous and include tumoral, infectious, metabolic, toxic, cardiovascular, traumatic and idiopathic conditions (Scott P Shaw & John E Rush, 2007a).

The main cause of PE is of tumoral origin, accounting for over two-thirds of cases. Hemangiosarcomas (HSA) are by far the most common tumors, representing 60% of cases, followed by tumors at the base of the heart (chemodectoma, paraganglioma) (6%) and mesotheliomas (5%). Lymphosarcomas represent only 1% of the causes of effusion. Metastasis of tumors from other sites to the heart or pericardium is a possibility. "Idiopathic" effusions account for 20% of cases and are diagnosed by exclusion (Scott P Shaw & John E Rush, 2007a).

Cardiac conditions other than tumors frequently lead to PE (14% of cases), but they are mostly moderate and do not cause tamponade (Ware, 2007). In rare cases, atrial rupture is possible (severe mitral insufficiency). Metabolic (uremia, hypercholesterolemia in hypothyroidism) and toxic (anticoagulant poisoning) origins are rare causes of pericardial effusion. Lastly, trauma and infectious causes (bacterial, due to foreign body migration - 1% of cases - or fungal) are rarely described causes (Scott P Shaw & John E Rush, 2007a). Congenital pericardial diseases (such as peritoneopericardial diaphragmatic hernia (PPDH), benign intrapericardial cysts and pericardial defects) are uncommon (Ware, 2007).

1.3 PATHOPHYSIOLOGY OF PERICARDIAL EFFUSION

Pathogenesis of PE depends on the specific cause (Haritha, 2019b). In diseases involving tumors, nephrotic syndrome or toxins, the pericardium is prone to irritation leading to inflammation and buildup of fluid (Ware, 2007). In systemic inflammatory diseases or infections, inflammatory cells specifically target the pericardium causing effusion. Atrial or ventricular rupture result in the direct introduction of blood into the pericardial space. In congestive heart failure, the accumulation of fluid in the pericardium is attributed to elevated capillary hydrostatic pressure and changes in Starling forces (Scott P Shaw & John E Rush, 2007a).

Irrelevant of the cause, the pace at which fluid builds up in the pericardium is crucial in determining its hemodynamic impact (Miller & Gal, 2017). When fluid accumulates slowly, it leads to the expansion of the pericardium up to a certain limit (Haritha, 2019b). Over time, the accumulation of fluid is greater

than the stretching capacity of the pericardium leading to an increase in intrapericardial pressure, which hinders diastolic filling and reduces venous return (Miller & Gal, 2017). The elevated venous pressures, reduced preload and diminished stroke volume limit the heart's ability to efficiently pump blood, resulting in the observed clinical signs (Scislowicz, 2015b). When the intrapericardial pressure surpasses the pressure of the right atrium and ventricle (normally 4–8 mm Hg) cCT develop accompanied by varying degrees of hemodynamic collapse (Scott P Shaw & John E Rush, 2007a).

The amount of fluid needed to induce cCT varies significantly depending on the rate of fluid accumulation. In experimental canine models, as little as 25–100 mL of fluid rapidly injected into the pericardium can elevate intrapericardial pressure sufficiently to cause tamponade. In contrast, PE that gradually increases in volume can reach up to 2L in a large-breed dog before cCT becomes clinically apparent (Haritha, 2019b).

Effusion liquid can appear as transudate (hydropericardium), exudate, pus (pyopericardium) or most frequently blood (hemopericardium). Quilopericardium are very rare in canine specie (Hébert et al., 2010).

2 CLINICAL PRESENTATION AND DIAGNOSIS OF CANINE PERICARDIAL EFFUSION

2.1 EPIDEMIOLOGY

The epidemiology of this condition underscores different contributing factors and predispositions, which vary based on breed, age, the health status and sex. The prevalence of each etiology of PE in dogs varies significantly based on the age and of the breed of the animal (Nelson & Couto, 2019).

In younger dogs, it is crucial to consider congenital malformations, bacterial and fungal infections, and foreign bodies (Nelson & Couto, 2019). Except in regions where coccidiomycosis is endemic, in most young dogs PE is caused by idiopathic pericardial bleeding (Scott P Shaw & John E Rush, 2007a). This condition has been referred to by various names, such as chronic proliferative pericarditis, idiopathic hemorrhagic PE or idiopathic pericardial hemorrhage (Ware, 2007). Despite continuous research, the exact cause remains unknown and studies have not found evidence of a viral or immune-related origin (Zini et al., 2009).

Idiopathic PE is more prevalent in middle-aged dogs (7 years old), mostly males of medium to large breeds, including the German Shepherd, Golden Retriever, Great Dane and Saint Bernard (Nelson & Couto, 2019).

Dogs with non-idiopathic effusions had a median age of 9 years (Mellanby & Herrtage, 2005). Higher occurrence appears in specific breeds predisposed to developing cardiac anomalities notably the Cavalier King Charles Spaniel (Reineke et al., 2008). Effusions in older dogs are also often dues to a heart tumors (Treggiari et al., 2017) that seem to follow a breed predisposition pattern such as mesothelioma, a specific PE form, with all cases belonging to small/medium breeds (Choi, 2023). German Shepherd often develop HSA in the right atrium (Griffin et al., 2021). Chemodectomas are more commonly observed in older Boxers (Noszczyk-Nowak et al., 2010).

These observations underscore a correlation between breed size and PE type, suggesting diverse pathological mechanisms or distinct genetic predispositions based on the dog's size (Stepien et al., 2000).

2.2 CLINICAL PRESENTATION

The intensity of clinical manifestations in dogs with PE hinges on the speed of fluid buildup in the pericardium (whether rapidly with low volumes or slowly with high volumes) and the root cause of the condition (Stafford Johnson et al., 2004). Clinical signs might be nonspecific until the onset of cCT and related cardiovascular decompensation (S. P. Shaw & J. E. Rush, 2007).

In the initial phases of chronic PE potential nonspecific symptoms may include lethargy, weakness, decreased exercise tolerance, and loss of appetite (Nelson & Couto, 2019). In more advanced stages of chronic PE cases, the clinical history may involve abdominal distension, tachypnea or dyspnea, collapse, and occasionally coughing or vomiting (Stafford Johnson et al., 2004). Due to its lower parietal thickness compared to the left heart, the right heart is the first to be affected in cases of chronic effusion (Miller & Gal, 2017). As a result, clinical manifestations previously cited of right heart failure are predominant, with ascites being the most common sign. Large volumes of PE can also exert pressure on the lungs and trachea, leading to respiratory difficulties and coughing (Nelson & Couto, 2019). Excessive fluid accumulation compressing the esophagus may cause dysphagia, regurgitation, or even progressive vomiting (Fahey et al., 2017). Dogs with neoplastic diseases may have a history of collapse, and chronic cases may exhibit a noticeable loss of lean body mass (Nelson & Couto, 2019). In

cases of chronic accumulation of pericardial fluid, the pericardial sac's ability to stretch or enlarge delays the onset of clinical signs of right heart failure until significant PE is present. These signs may gradually appear as the pericardium's stretching capacity is exceeded (Nelson & Couto, 2019).

On the other hand, acute PE rapidly elevates intrapericardial pressure resulting in reduced cardiac filling and sudden decline in cardiac output (Nelson & Couto, 2019). Consequently, acute effusion leads to sudden collapse or weakness and syncope, often triggered by physical exertion (Haritha, 2019b).

2.3 PHYSICAL EXAMINATION

In cases of subacute or prolonged PE, the development of right-sided congestive heart failure (R-CHF) leads to characteristic physical examination findings. These include distension of the jugular veins and/or positive hepatojugular reflux, hepatomegaly, ascites, dispneia and weakened femoral pulses (S. P. Shaw & J. E. Rush, 2007). Jugular venous distention arises from increased RA filling pressures and is consistently present in dogs with cCT (S. P. Shaw & J. E. Rush, 2007). In cases with moderate to large PE, indistinct or muted heart sounds are frequently encountered (Nelson & Couto, 2019), but normal heart sounds can also occur (Saunders & Gordon, 2020). Although PE itself does not cause a murmur, concurrent cardiac disease may contribute to one (Ware, 2007). Some dogs with cCT present a pulsus paradoxus (weak femoral pulse during inspiration and a stronger pulse during expiration) (Nelson & Couto, 2019). Sinus tachycardia, pale mucous membranes, and prolonged capillary refill time are common reflecting high sympathetic tone due to reduced cardiac output (Stafford Johnson et al., 2004).

The occurrence of simultaneous pleural effusion can result in respiratory distress, muted lung sounds and additional muffled heart sounds over the ventral thorax (Saunders & Gordon, 2020).

When fluid accumulates rapidly, acute cCT can result in shock and death without obvious clinical signs. In these cases, jugular venous distention and hypotension may be observable (Nelson & Couto, 2019).

Patients with infectious pericarditis may exhibit fever and, rarely, a pericardial friction rub may be audible (Nelson & Couto, 2019).

2.4 DIAGNOSIS

Physical examination, clinical manifestations, imaging and estimation of pericardial fluid help in diagnosing the condition (S. P. Shaw & J. E. Rush, 2007).

Imaging methods are essential instruments for diagnosing PE in dogs. While this subsequent section is dedicated to diagnosis, characterization, and management of PE in dogs, the second section of this thesis will focus on how multimodality imaging techniques are employed to diagnose, characterize, and manage PE in dogs. Thus, imaging techniques diagnosis will be treated further in the second section.

Although no single physical examination finding is definitive for diagnosing PE, a combination of classic signs evoked earlier especially in middle-aged or older large-breed dogs, tends to raise suspicion (S. P. Shaw & J. E. Rush, 2007).

Electrocardiographic (ECG) findings in dogs with PE commonly reveal sinus tachycardia. Ventricular premature contractions (VPCs) are less common but may occur, especially during or after pericardiocentesis (S. P. Shaw & J. E. Rush, 2007). About 50% of dogs with PE exhibit low-voltage QRS complexes (measuring less than 1 millivolt) (Figure 1) (Bonagura & Fuentes, 2021) but this finding is not specific. Additionally, in some cases, there may be a phenomenon called electrical alternans (Figure 1) attributed to the motion of the heart within the pericardial sac. This refers to a variation in the height of the QRS complexes with alternate beats, with cyclic changes in R-wave amplitude (e.g., 1:1, 2:1). However, normal ECG does not necessarily rule out the presence of PE (Berg R, 1984).

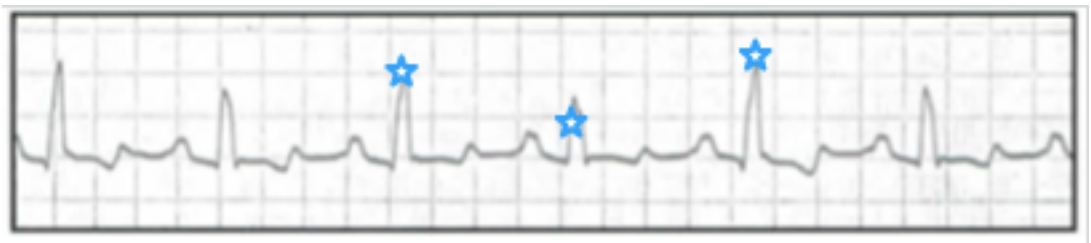

Figure 1: ECG trace (lead II) of a dog with pericardial effusion and electrical alternans. The QRS complexes are smaller than normal and there is a cyclical change in the QRS complex height (blues stars). Paper speed 50 mm/s; gain 10 mm/mV (French, 2010).

Blood tests such as hematology and serology, are generally not highly informative for diagnosing PE as any changes observed may only indicate the underlying disease (Haritha, 2019b). An increased leukocyte count, thrombocytopenia and atypical red blood cells (schistocytes, acanthocytes) may be noted, particularly in cases of HSA (S. P. Shaw & J. E. Rush, 2007). Some cases may show non-regenerative or poorly regenerative anemia probably related to be anaemia of chronic disease. In areas where Coccidioides immitis is endemic testing is advisable and positive titers may suggest a fungal cause (S. P. Shaw & J. E. Rush, 2007). A study investigated vector-borne pathogen infections in dogs with PE in a Mediterranean area. Vector-borne pathogens were more frequently found in dogs with PE warranting further investigation, particularly in idiopathic cases, with PCR offering valuable insights in endemic areas (Tabar et al., 2018).

Serum biochemistry typically shows normals results, although there may be slight elevations in blood urea nitrogen (BUN) and creatinine levels due to reduced cardiac output (prerenal azotemia) (Saunders & Gordon, 2020) but also in cases of uremic pericarditis (Berg R, 1984). Mild hyponatremia, hypochloremia, and hyperkalemia may also be observed. Liver enzymes may show elevation if there is moderate to severe hepatic congestion (Nelson & Couto, 2019).

Pericardial fluid can manifest as an exudate, transudate, modified transudate, hemorrhagic or neoplastic (Hébert et al., 2010). Distinguishing the type of effusion based solely on clinical appearance can be challenging so further analysis is always recommended (Hébert et al., 2010). This procedure needs previous pericardocentesis followed by effusion analysis including total and differential white blood cell count, packed cell volume, cytology, bacterial culture and sensitivity. Hemorrhagic effusions are common in dogs and transudates are moderately common. Exudative effusions, on the other hand, are relatively uncommon in small animals (Scislowicz, 2015a).

Hemorrhagic effusions present as dark red fluids (Table 1). These are characterized by a packed cell volume (PCV) > 7%, specific gravity > 1.015 and protein concentration > 3 g/dL (Nelson & Couto, 2019). Commonly, hemorrhagic PE in dogs is attributed to HSA (Scott P Shaw & John E Rush, 2007b). It is crucial to note that blood from a hemopericardium does not clot due to a swift deficiency of thrombocytes and clotting factors (Nelson & Couto, 2019).

Pure transudative fluids are typically clear (Table 1), with a specific gravity < 1.012 and protein concentration < 2.5 g/dL. Modified transudates often appear slightly cloudy or have a pink tinge, with a specific gravity ranging from 1.015 to 1.030 and protein concentration of 2.5 to 5 g/dL (De Laforcade

et al., 2005). Causes of transudative effusions include conditions such as congestive heart failure, hypoalbuminemia, peritoneopericardial diaphragmatic hernia, pericardial cysts and certain toxemias. (Hébert et al., 2010).

Exudative effusions present as cloudy to opaque (Table 1), with a protein concentration exceeding 3 g/dL and a specific gravity > 1.015 (Scislowicz, 2015a). While not prevalent in small animals, sterile exudative effusions have been observed in dogs with conditions such as leptospirosis, distemper, bacterial pericarditis, and idiopathic PE (Ware, 2007).

Though it is crucial to recognize the types of PE associated with specific conditions, many experts consider cytology to have limited value in distinguishing between neoplastic and idiopathic causes of PE (Sisson et al., 1984). However, several studies have evaluated its diagnostic effectiveness in identifying infectious agents or lymphoma as the root causes, ultimately affirming its reliability and conclusiveness (Cagle et al., 2014). Neoplastic conditions other than lymphoma seldom exfoliate, making cytology alone insufficient for their diagnosis (Cagle et al., 2014) and additional diagnostic tests on fluid or blood samples exhibit limited ability to differentiate from non-neoplastic causes (S. P. Shaw & J. E. Rush, 2007). While neoplastic mesothelial cells may exfoliate and contribute to a definitive diagnosis, caution is necessary as reactive mesothelial cells can resemble neoplastic cells (Cagle et al., 2014).

Various diagnostic methods based on fluid analysis from pericardiocentesis have been explored to distinguish between neoplastic and non-neoplastic causes, but none have reliably achieved this goal (De Laforcade et al., 2005).

PE shows notable variations in lactate, hematocrit and urea nitrogen levels between neoplastic and non-neoplastic cases (Cagle et al., 2014) nevertheless, the diagnostic utility of these markers for malignancy is limited due to considerable overlap between the two groups and lack consistent accuracy (Nelson & Couto, 2019). A study has shown that the difference in glucose values between peripheral and pericardial samples is more pronounced in dogs with neoplasia compared to those without (De Laforcade et al., 2005). While some studies suggest that troponin elevation doesn't reliably differentiate among various causes of effusion (Nelson & Couto, 2019), others indicate increased serum troponin I levels in dogs with pericardial disease compared to normal controls (Porter et al., 2016). A study has found that, in dogs with PE, a plasma cardiac troponin I (cTnI) concentration greater

than 0.25 ng/mL identified cardiac HSA with a sensitivity of 81% and specificity of 100%, prompting the need for further studies to confirm and establish diagnostic thresholds (Chun et al., 2010).

Surgical procedures like thoracotomy or thoracoscopy provide the opportunity to obtain pericardial biopsies, aiding in the diagnosis of conditions such as mesothelioma and other cardiac tumors for which fluid analysis can lead to inconclusive results (Nelson & Couto, 2019).

Table 1: Comparison of physico-chemical, cytological and bacteriological criteria of various pericardial fluid effusions of dogs. Adapted from (Hébert et al., 2010).

	Hemopericardi-um	**Transudate**	**Chylopericardium**	**Modified transudate**	**Exudate**
Macroscopical appearance	Bloody appearance	Clear or transparent	Milky or strawberry milk	Sero-hemorrhagic	Thick yellow to brown appea-rance
Cells	(hematocrit > 7%) Red blood cells, macrophages with signs of erythro-phagocytosis	< 2500/µL Mesothelial cells	1600-200000/ µL Small lymphocytes, macrophages, and neutrophilic poly-morphonuclear cells	1000-7000/µL Macrophages, mesothelial cells and neutrophilic polymorphonu-clear cells, some-times tumoral cells	> 15000/ µL Polymorphonu-clear cells, ma-crophages,
Proteins	30-60g/L	< 10 g/L	35-78 g/L	25-50 g/L	> 30 g/L
Density	> 1.015	< 1.008	1.019-1.038	1.008-1.015	>1.015
Germs	Absence	Absence	Absence	Absence	Septic exudate: YES Aseptic exudate: NO

2.5 MANAGEMENT

Pericardiocentesis can be a life-saving procedure for animals with cardiogenic shock secondary to PE (Scislowicz, 2015a). This procedure aims to relieve the pressure causing R-CHF and allows for obtaining fluid samples for diagnostic evaluation (Haritha, 2019a).

Depending on the animal's cardiovascular condition and temperament, it may be advisable to administer sedation before performing pericardiocentesis (Nelson & Couto, 2019).

Performing puncture with the patient in a standing position is the preferred method (Olcott & Sleeper, 2010), although for certain dogs, lateral recumbency is more effective for restraint (Nelson & Couto, 2019). Pericardiocentesis can be performed either blindly or under ultrasound guidance (Linney, 2023). Landmarks for blind puncture is between the third to fifth intercostal space (Haritha, 2019a) just above the costochondral junction. Ultrasound-guided centesis is performed at the largest diameter of effusion (Olcott & Sleeper, 2010). The puncture should be on the cranial pole of rib to avoid damaging the neurovascular situated caudally (Linney, 2023) and can be either on the right or left side of the thorax (Jutkowitz, 2008). Since pericardiocentesis is a sterile procedure, a large area centered on the catheter insertion point should be correctly clipped and surgically disinfected (Nelson & Couto, 2019).

To drain out the fluid, the ideal catheter is a 14-gauge / 5-inch one for most medium to large-breed and a 16-gauge, 2½-inch catheter in smaller dogs (Olcott & Sleeper, 2010). The catheter is slowly introduced through the skin and thoracic wall, pass through the intercostal muscle and enter the pericardial space. A flash of pericardial fluid should be obtained (Nelson & Couto, 2019). A syringe or extension set with a stopcock and syringe (preferred) is then affixed to the catheter (Jutkowitz, 2008). It is crucial to keep the system closed to air continuously after breaching the chest wall to prevent the development of a pneumothorax (Olcott & Sleeper, 2010).

To confirm that the fluid is effusion and not blood resulting from inadvertent puncture of a vessel or cardiac chamber, a sample can be placed in a serum separator or plain tube. No clotting should occur if the fluid is effusion (Jutkowitz, 2008). Subsequently, rapid withdrawal of PE can be performed (Haritha, 2019a). However, it is important to remember that blood from an active hemorrhage (such as in the case of a left atrial tear or an actively bleeding tumor) will also not clot (Olcott & Sleeper, 2010).

While efforts should be made to remove as much pericardial fluid as possible, complete drainage may not be achievable (Linney, 2023). Once no more fluid is aspirated into the syringe, the catheter, along with the extension set, is carefully removed (Olcott & Sleeper, 2010).

Samples of the effusion should be collected in EDTA and plain tubes for analysis, and the total volume of fluid withdrawn documented (Nelson & Couto, 2019).

Following successful drainage of PE, the patient's cardiovascular parameters should exhibit immediate improvement (Nelson & Couto, 2019), because, as intrapericardial pressure decreases, there is enhancement in right heart filling, leading to increased cardiac output, improved oxygenation, strengthened pulse, and a reduction in heart rate (Haritha, 2019a).

The most frequent complication of pericardiocentesis is cardiac ventricular arrhythmia. Typically, cessation of the arrhythmias occurs upon catheter withdrawal (Nelson & Couto, 2019). In cases of severe arrhythmias, a bolus of lidocaine (2 mg/kg IV) can be administered (Jutkowitz, 2008). There is also a minimal risk of lung or coronary artery laceration (Linney, 2023). Although extremely rare, these complications can have serious consequences (Jutkowitz, 2008).

Recurrent effusions that don't improve with repeated pericardiocenteses are typically addressed through subtotal pericardiectomy. Less invasive method are thoracoscopic partial pericardiectomy (Case et al., 2013) and percutaneous balloon pericardiotomy (Sidley et al., 2002).

The medical management of PE is rarely effective (Haritha, 2019a). Diuretics are contraindicated in cases of acute cCT as they can decrease blood volume, exacerbating the decrease in cardiac output (Ojeda et al., 2015).

While the use of corticosteroids has not shown proven benefits in treating idiopathic pericarditis (Olcott & Sleeper, 2010) their use is believed to aim at avoiding fluid recurrence (Haritha, 2019a). Some authors suggest using glucocorticoids (prednisone PO at 1 mg/kg/day, tapered over 2-4 weeks) after ruling out an infectious cause through pericardial fluid culture or cytologic analysis (Nelson & Couto, 2019).

The treatment of malignant PE involves various approaches, with chemotherapy considered as a potential option in certain cases (Haritha, 2019a). Intracavitary chemotherapy has been employed for the management of malignant mesothelioma (Moberg et al., 2022), although it remains poorly documented. If chemotherapy is wanted for HSA, doxorubicin hydrochloride is considered as a

therapeutic option. Radiation treatment is also explored as a potential beneficial intervention (Jutkowitz, 2008).

If idiopathic pericarditis is suspected, the owner should be advised to monitor the animal for any recurrence of clinical signs after pericardiocentesis. If such signs emerge, a repeat pericardiocentesis is warranted (Nelson & Couto, 2019). A subtotal (partial) pericardiectomy is generally recommended after the third pericardiocentesis (Scislowicz, 2015a).

Thus primary aim in treating patients with symptomatic PE is relief of the symptoms, although secondary aims should include determination of the cause of the effusion and prevention of recurrence (Gibbs et al., 2000).

2.6 PROGNOSIS

The prognosis for dogs experiencing PE varies significantly based on the root cause (S. P. Shaw & J. E. Rush, 2007).

Congenital PE such as PPDH generally carries a favorable prognosis (S. P. Shaw & J. E. Rush, 2007). Conversely, dogs with PE secondary to HSA typically face a poor to grave prognosis in the short term, with reported average survival durations ranging from 1 to 3 months (Ware, 2007). While some dogs may initially respond to pericardiocentesis, signs often reappear shortly after the effusion returns. Moreover, a significant number of dogs with HSA have metastasis or micrometastasis, often to the lungs and not detectable on radiographs, at the time of diagnosis (Nelson & Couto, 2019). Aortic body tumors (chemodectoma) have also a dark prognostic but they typically exhibit slow growth, with survival durations of 129 days without pericardiectomy and 661 days with pericardiectomy (Vicari et al., 2001). The prognosis for PE stemming from other neoplasms is generally poor to guarded (S. P. Shaw & J. E. Rush, 2007). In cases of infectious PE, prognosis varies from guarded to good and is contingent on the response to treatment (Saunders & Gordon, 2020). PE due to CHF rarely accumulates in a volume such that pericardiocentesis is required. In these patients, prognosis is dictated by the severity of the underlying heart disease (Mellanby & Herrtage, 2005). Dogs with LA rupture, secondary to myxomatous degeneration, have a guarded long-term prognosis (S. P. Shaw & J. E. Rush, 2007). Idiopathic PE, conversely, comes with a good to excellent prognosis (S. P. Shaw & J. E. Rush, 2007). It may resolve spontaneously following one or more therapeutic pericardiocenteses.

Resistant cases could necessitate surgical pericardiectomy, employing one of the techniques discussed previously (Nelson & Couto, 2019). A study reported a 50% survival rate at 1,500 days post-diagnosis (Gibbs et al., 1982), and another study indicated a 72% survival rate after 18 months.(ARONSON & GREGORY, 1995). Considering that these animals typically present with severe left atrial dilatations, these survival rates are actually quite promising.

3. IMAGING TECHNIQUES IN THE MANAGEMENT OF DOGS WITH PERICARDIAL EFFUSION

3. 1. SIGNIFICANCE OF ACCURATE AND TIMELY DIAGNOSIS IN DOGS WITH PERICARDIAL EFFUSION

Accurate and timely diagnosis of dogs with PE holds profound significance within the realm of veterinary medicine due to several compelling reasons.

First of all, as evoked earlier, PE can swiftly progress to cCT, a life-threatening state (Hébert et al., 2010). Without prompt intervention with pericardiocentesis, cCT can result in shock and even sudden cardiac arrest (Hébert et al., 2010). Therefore, accurate and timely diagnosis of PE is paramount to initiate treatment as soon as possible, alleviate these symptoms thus relieving the suffering of the affected animal.

However, since PE can stem from various etiologies (Scott P Shaw & John E Rush, 2007b) it is crucial to identify the root cause as further additional therapies may differ significantly (Nelson & Couto, 2019).

Also, as discussed earlier, some etiologies may have a better prognosis than others. Thereby an accurate diagnosis of PE also provides valuable prognostic information with nonneoplastic causes having the best prognosis, followed by chemodectomas, and HSA having the worst prognosis, mainly due to their metastatic nature (S. P. Shaw & J. E. Rush, 2007).

In conclusion, accurate and timely diagnosis in dogs with PE is not merely a matter of medical practice; it is a matter of life and death. The rapid onset and potential severity of this condition make it imperative for veterinarians to possess the knowledge and skills necessary to recognize, diagnose, and treat PE promptly. Then, whenever possible, treatment of patients with PE should be aimed at managing the underlying cause (Scheuermann et al., 2021).

3. 2. ROLE OF MULTIMODALITY IMAGING TECHNIQUES IN ASSESSING PERICARDIAL EFFUSION IN DOGS

Multimodality imaging techniques have been playing a pivotal role in the comprehensive assessment of PE in dogs, significantly enhancing the accuracy of diagnosis and the effectiveness of treatment strategies. This advanced approach combines various imaging modalities (Misri, 2013). In this text we have chosen to review the main and most used techniques such as echocardiography, radiography, and cardiac computed tomography (caCT) which provide a thorough evaluation of the condition. We will also emphasize the role of modern imaging techniques such as Contrast-enhanced multi-detector computed tomography (MDCT) and Magnetic Resonance Imaging (MRI) that have revolutionized the assessment of PE in dogs.

Multimodality imaging in medicine refers to the use of multiple imaging techniques to gain a comprehensive understanding of a patient's condition. These techniques provide different types of information and can complement each other, leading to a more accurate diagnosis and better treatment planning (Yitbarek & Dagnaw, 2022). Multimodality imaging techniques are important in veterinary cardiology. In the context of PE, they offer a comprehensive view of the condition's characteristics and extent. Additionally, some of these techniques aid in identifying the underlying causes (Bouvard et al., 2020).

3. 3. CLASSICAL IMAGING TECHNIQUES

3. 3. 1. Echocardiography

Echocardiography, or Trans Thoracic Echocardiography (TTE) is the use of ultrasound waves to generate real-time images of the heart and its neighboring structures (Mattoon et al., 2020). Various ultrasound modes are frequently utilized in cardiology including two-dimensional echocardiography (2DE), time-motion echocardiography (M-Mode), 2D color Doppler imaging (CDI), Doppler ultrasound spectral modes, Pulsed Doppler (PWD) and Continuous Doppler (CWD) (Mattoon et al., 2020). Theses diverse modes can furnish detailed information on cardiac morphology, function and abnormalities allowing for a gold standard complete comprehensive echocardiographic examination (Linney, 2023). Interpreted accurately, they enable the clinician to establish a conclusive diagnosis and can also lead

to the identification of functional and hemodynamic consequences of cardiac pathologies in a non-invasive manner (Mattoon et al., 2020).

Probes with a frequency of 5-7.5 MHz offer sufficient image resolution and penetration depth for the majority of dogs. Larger dogs may necessitate the use of a 3.5 MHz probe (Mattoon et al., 2020).

In the context of PE, TTE is the preferred diagnostic method as it enables veterinarians to directly and precisely observe the presence and extent of effusion, assess its impact on cardiac function and detect potential complications such as caCT (S. P. Shaw & J. E. Rush, 2007). This non-invasive technique is essential not only for the initial diagnosis but also for continuous patient monitoring (MacDonald et al., 2009). It is so sensitive for detecting pericardial fluid that even small amounts of PE (10 to 15 ml) can be clearly evidenced (S. P. Shaw & J. E. Rush, 2007).

Since fluid is sonolucent, PE manifests as an echo-free space located between the bright parietal pericardium and the epicardium (Figure 2) (Nelson & Couto, 2019). The pericardium is visualized as a curved, brighter border, delineating the boundary between the pericardium and the lungs (Mattoon et al., 2020). In cases of significant PE, the heart may exhibit a swaying motion within the anechoic fluid of the pericardial sac (Nelson & Couto, 2019). If the fluid contains cells like erythrocytes, it may have an increased echogenicity. If chronic, strands of fibrin may be observed moving in the fluid or occasionally adhering to the epicardium (MacDonald et al., 2009). On the M-mode trace (Figure 2) the pericardium forms a horizontal line separated from the posterior wall by an anechoic band (the effusion) (Nelson & Couto, 2019). Sometimes, pleural effusion, a significantly enlarged left atrium (LA), a dilated coronary sinus or a persistent left cranial vena cava can be challenging and lead to confusion with PE (Nelson & Couto, 2019).

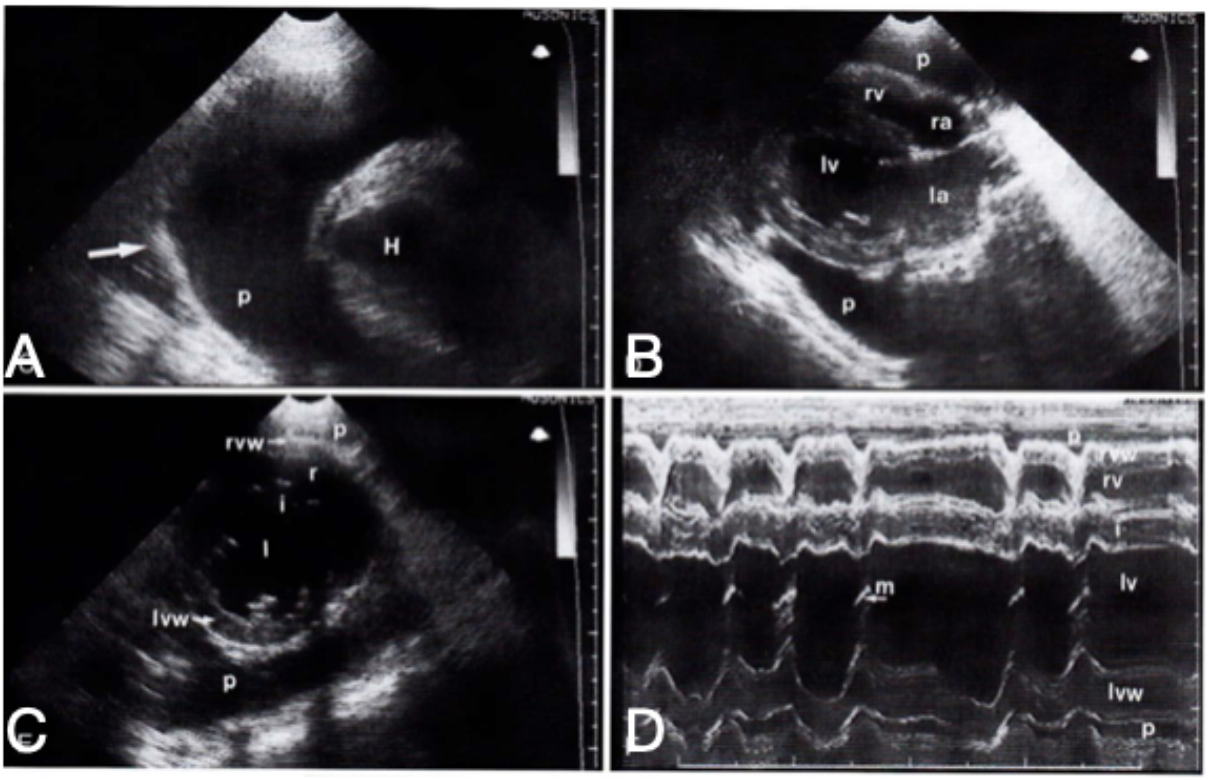

Figure 2: Left parasternal long axis (A), right parasternal long (B) and short (C)-axis view B-Mode of a dog with idiopathic pericardial effusion showing fluid surrounding the heat. (D) M-mode echocardiogram of pericardial effusion in a dog (Kealy, J. K., & Mac, A. H., 2008).

am, anterior leaflet of the mitral valve; ivs, interventricular septum; la, left atrium; lv, left ventricle; lvw, left ventricular wall; p, pericardial effusion; ra, right atrium; rv, right ventricle; rvw, right ventricular wall.

It is important to note that the intrapericardial pressure is a better factor for determining hemodynamic compromise than volume of effusion. Collapse of the RA (Figure 3) or, less frequently, the RV, during diastole is a sign of caCT (Nelson & Couto, 2019). In this scenario, there is an observable movement of the RA appendix, and during diastole, the RA wall droops towards the auricula. Increased pressure in the RV, is better characterized in M-mode where the interventricular septum (IVS) can move to the left, creating a echocardiographic phenomenon known as “paradoxical septal motion” a parallel displacement of the IVS to that of the posterior wall of the left ventricule (Mattoon et al., 2020).

The cause of PE is not always identifiable, but it is important to carefully scan the cardiac edges in all directions for hypoechoic neoplastic masses (S. P. Shaw & J. E. Rush, 2007). Improved visualization of the heart base and mass lesions is typically achieved before pericardiocentesis is undertaken (Nelson & Couto, 2019). Certain mass lesions can be challenging to visualize and the absence of a detected mass during ultrasound does not necessarily rule out a neoplastic etiology (MacDonald et al., 2009).

In a study, TTE exhibits notably good sensitivity (82%) and specificity (100%) in diagnosing cardiac masses in dogs with PE. Repeated examinations enhance the sensitivity to 88% (MacDonald et al., 2009). While TTE cannot provide a definitive diagnosis of the root cause, it often allows strong assumptions about the origin of a mass which has often important prognostic implications. For example, a cavitated mass from the RA is likely a HSA (Yamamoto et al., 2013). The aforementioned study (MacDonald et al., 2009) found comparable sensitivity and specificity for 2D TTE in distinguishing RA masses from other causes (84% and 100%, respectively) and in distinguishing heart base masses from other causes (74% and 98%, respectively). To enhance to sensitivity of TTE, some author recommends coupling it with ECG findings (Nelson & Couto, 2019).

Limitations include variable sensitivity for detecting cardiac masses (MacDonald et al., 2009) and an inability to assess associated abnormalities in nearby structures. Its application may be restricted by the small field of view, occasional poor acoustic windows and high operator dependency. Furthermore, echocardiography is not effective for evaluating associated abnormalities in the lungs, mediastinum, or adjacent structures, a crucial aspect in the assessment of concurrent metastatic disease (MacDonald et al., 2009).

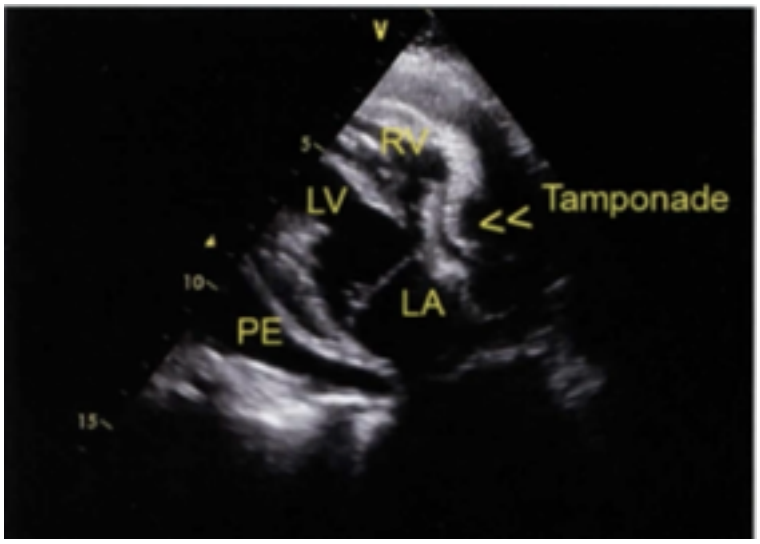

Figure 3: Right parasternal long-axis view of a dog with idiopathic pericardial effusion and cardiac tamponade. The arrowheads demonstrate the collapse of the right atrial wall (French, 2010).

3. 3. 2. Radiography

Radiography utilizes X-rays to generate static images. While it offers less detail compared to TTE, it still serves as a valuable initial screening tool (Hébert et al., 2010) providing a comprehensive diagnostic overview. It allows visualization of the entire thorax, enabling evaluation of alterations in the cardiac silhouette (size and shape) and detecting changes in heart position or effusion-related findings (Thrall, 2017b). Studies have emphasized the utility of thoracic radiographs as an economical and accessible diagnostic option in assessing chronic or slowly progressing cases of PE (Guglielmini et al., 2012).

Dorso-ventral (DV) or ventro-dorsal (VD) chest X-ray images provide valuable insights into the heart and major blood vessels condition. When taking these images, using the DV incidence is preferred over the VD incidence. For accurate results, X-rays should be captured at the end of the inspiration phase (Thrall, 2017b). It is crucial to capture X-rays that cover the entire chest with symmetrical positioning. The X-ray beam should be centered on the caudal edge of the scapula, typically near the fifth intercostal space (Ayers, 2012). In DV or VD incidences, the vertebrae should align with the sternum, and in the profile incidence, the arches of the ribs should not extend beyond the level of the vertebrae (Ayers, 2012).

Mild to severe cardiomegaly is commonly observed (S. P. Shaw & J. E. Rush, 2007). If massive, the amount of fluid can lead to a globoid-shaped heart shadow visible on both radiographic views (Nelson & Couto, 2019). The magnitude of cardiac enlargement exhibits a positive correlation with the chronicity of the effusion and the volume of accumulated fluid (S. P. Shaw & J. E. Rush, 2007). The edges of the cardiac silhouette may appear distinctly sharp. This could be is attributed to both minimized motion artifact resulting from cardiac contraction (Thrall, 2017a) and also smaller fluid volumes that enable the identification of various cardiac contours, particularly in the dorsal aspect (Nelson & Couto, 2019).

Besides the globoid-shaped, additional radiographic signs of cCT include pleural effusion, clearly defined pulmonary vascularization, distended CVC and pulmonary veins, hepatomegaly and reduced abdominal detail (attributable to ascite) (Bonagura & Fuentes, 2021). Certain heart-base tumors can lead to tracheal deviation or exhibit a soft tissue mass effect. HSA in dogs often presents with common metastatic lung lesions (Nelson & Couto, 2019). Fluoroscopy shows a large heart with apparently only small contractions. In the absence of other radiological abnormalities, caudal vena cava dilation may have no clinical significance (Bahr, 2018)

The sensitivity and specificity in identifying dogs with congestive disease due to PE using cardiac silhouette enlargement (vertebral heart score ≥ 10.7cm), were reported as 77.6% and 47.8%, respectively. The sensitivity and specificity in recognizing a globoid appearance of the cardiac silhouette to identify dogs with cCT were found to be 41.9% and 40.0%, respectively (Côté et al., 2013). Similarly, the sensitivity and specificity of assessing a convex appearance of the dorsocaudal aspect of the cardiac silhouette for detecting dogs with cCT were reported as 57.1% and 35.0%, respectively (Côté et al., 2013).

The main disadvantage of radiography is it lacks the real-time capabilities of TTE. Also, study's findings indicated that none of the evaluated radiographic variables exhibited high (> 90%) sensitivity or specificity for identifying dogs with cCT. Consequently, thoracic radiographic findings should not be deemed reliable for identifying dogs with cCT due to PE (Côté et al., 2013).

As it provides a rapid and accurate diagnosis TTE has been traditionally used as the initial imaging technique of choice for the majority of patients with suspected PE (Ware, 2007). Radiography, while less detailed than TTE, serves as a valuable initial screening tool. It aids in identifying changes in cardiac silhouette and effusion-related findings especially in chronic cases (Thrall, 2017a). As evoked,

neoplastic PE carries a poor prognosis, but benign idiopathic PE does not. Thus, definitive diagnosis is critical for prompt surgical intervention and accurate prognostic evaluation. However, in many cases, TTE, pericardial fluid cytology and/or radiography often are inconclusive.

3. 4. ADVANCED IMAGING TECHNIQUES

Radiography and ultrasonography are the most utilized techniques in veterinary clinical practice, mainly due to practical, management, and economic reasons. Nevertheless, there has been a growing adoption of advanced imaging methods such as CT and MRI in veterinary cardiology in the last few decades (Greco et al., 2023) probably because cardiac conditions, especially masses pose a common diagnostic challenge (Nelson & Couto, 2019). The progress in CT and MRI technology, enabling the acquisition of sub-second volumetric cardiac images, has provided valuable descriptive information regarding the extent of tumors, their anatomical location, and potential types (Diana & Guglielmini, 2020).

3. 4. 1. Computed Tomography

Computed tomography (CT) is a medical imaging technology that utilizes X-rays and computer processing to generate highly detailed cross-sectional images of the body (Schwarz & Saunders, 2011). During a CT scan, the patient is positioned on a scanning bed which moves through the CT gantry while an X-ray tube and an array of electronic X-ray detectors rotate around the patient (Greco et al., 2023). This rotational movement captures a series of cross-sectional images generated based on variations in tissue density (Wisner & Zwingenberger, 2015). The captured images, referred to as "slices," are later reconstructed to form detailed three-dimensional images of internals structures. Finely collimated images can be acquired as needed for specific areas of interest and the decision to use contrast-enhanced CT is made on a case-by-case basis (Schwarz & Saunders, 2011). Contrast agents used in veterinary CT are non-ionic iodinated contrast media (Schwarz & Saunders, 2011) usually injected into the cephalic or saphenous veins (jugular veins in very small animals) (Greco et al., 2023).

In cases of PE, the buildup of fluid within the pericardium has a Hounsfield Unit (HU) value which depend on the presence or not of hemorrhage. Hyperdense clots may appear in the pericardial sac (Schwarz & Saunders, 2011). On CT images, a healthy pericardium usually presents as a thin band measuring less than 2 mm in thickness (Wisner & Zwingenberger, 2015).

In a human study, it has been observed that malignant PE often shows irregular pericardial thickening and enlarged mediastinal lymph nodes on CT imaging (Sun et al., 2010). Although irregular thickening alone is not always present, it indicates potential malignancy when combined with effusion (Breen, 2001). Mediastinal lymph node enlargement is a significant finding ($p < 0.001$) of malignant PE in human medicine, with high specificity (93.5%) but has limited data in veterinary medicine (Sun et al., 2010). In a study CT and TTE demonstrated similar sensitivity in detecting cardiac masses. However, authors suggest that the primary value of CT should lay in identifying pulmonary metastasis and extra-cardiac lesions in the liver and spleen (K. Scollan et al., 2015). Veterinary medicine lacks an equivalent method to the standard prospective ECG-gated cardiac CT scan used in human medicine, which is effective in evaluating many pericardial conditions (Hoey et al., 2016).

The cross-sectional nature of CT images eliminates the challenges of anatomical superimposition, offering higher contrast resolution than thoracic X-rays (Keane et al., 2017). CT imaging provides precise characterization of PE, aiding in identifying underlying causes like tumors poorly detected by X-ray or TTE. Another notable advantage lies in its precision for planning interventions such as surgery or biopsy, surpassing the accuracy of conventional imaging techniques (Diana & Guglielmini, 2020).

However CT involves ionizing radiation and require anesthesia which is a significant limitation in veterinary practice (Diana & Guglielmini, 2020). Also, for cardiac imaging, its utility is limited by cardiac motion. Thus, other diagnostic imaging methods like TTE are often more advantageous especially in the context of PE particularly in veterinary medicine (Keane et al., 2017). Also, performing pericardiocentesis prior to CT evaluation could complicate the interpretation of CT images (K. Scollan et al., 2015).

caCT technology has experienced faster advancements compared to other imaging techniques, with scanner performance doubling approximately every two years over the past decade (Langenberger et al., 2009). One of the latest breakthroughs in CT technology is MDCT, also referred to as multislice CT (Bertolini & Prokop, 2011).

3.4.2 Multi-detector Computed Tomography and contrast enhanced multi-detector Computed Tomography

The introduction of multi-detector computed tomography (MDCT) in human medicine has been a significant advancement in CT imaging, with direct implications for imaging various body systems, especially the cardiovascular system. This technology is nowadays also commonly used in small animals and has started to revolutionize the assessment of PE in dogs as it provides exceptional advantages in terms of accuracy, detail, and diagnostic precision (Bertolini, 2017).

MDCT is an advanced medical imaging technique that integrates the principles of CT imaging technology (Burrill et al., 2007). Conventional spiral CT and MDCT differ in three key enhancements (1) higher speed, (2) larger coverage, and (3) thinner sections (Rubin, 2003). Firstly, MDCT excels in rapid acquisition speed, rotating at 0.37 seconds compared to the 1-second rotation speed of conventional CT (Rubin, 2003). Secondly, and more importantly, MDCT utilizes multiple detectors to capture volumetric data rather than individual slice data. This leads to quicker image acquisition and higher-resolution images when compared to conventional CT. MDCT obtains cross-sectional images of the thorax in less than 30 seconds (K. Scollan et al., 2015). However, the true advance with these newer scanners comes not only from the ability to obtain thinner sections faster, but by moving from a "section-by-section mode' to a 'volume mode' transforming CT from a transaxial cross-sectional technique into a truly three-dimensional imaging modality (Prokop, 2005a). Contrast enhanced MDCT involves administering a contrast agent, usually through intravenous injection as described earlier. Practitioners can enhance the visibility of the pericardial sac boundaries and differentiate fluid accumulation from surrounding tissues (K. Scollan et al., 2015). This high level of precision is extremely valuable for evaluating the size, type and distribution of the effusion (K. Scollan et al., 2015). Human studies have already demonstrated its effectiveness for the differentiation of benign and malignant causes of PE (Xu et al., 2018).

Contrast-enhanced MDCT's ability to detect even small fluid accumulations allows to diagnose the condition at an earlier stage, potentially before clinical symptoms become pronounced (K. Scollan et al., 2015). Detailed anatomical images aid in accurately identifying the underlying causes and guiding treatment decisions effectively. Three-dimensional reconstructions of the pericardial sac enable surgeons to visualize the effusion's extent and proximity to vital structures, facilitating preoperative planning significantly (Bertolini, 2017). Also, the capability to monitor changes in effusion volume and distribution is crucial for tracking the patient's response and adjusting treatment strategies as necessary (K. Scollan et al., 2015).

These specific features of contrast-enhanced MDCT make it a promising imaging technique for evaluating neoplastic PE associated with cardiac or pericardial tumors as well as screening for metastases. Various studies, mentioned later in this section, have proven its clinical advantages when compared to other imaging techniques. However, these studies have certain limitations such as a small sample size, the absence of abdominal ultrasound comparisons and a lack of histopathological confirmation (K. F. Scollan et al., 2015). Contrast-enhanced MDCT can extend from the thorax to the abdomen in a short time, making it suitable for assessing cardiac structures and screening for metastases (Kim et al., 2009) within short periods of general anesthesia (K. F. Scollan et al., 2015). This quick acquisition time offers an advantage over MRI that's currently the imaging modality of choice in human medicine to evaluate cardiac tumors (Kim et al., 2009). In cases of suspected neoplastic PE, thoracic X-ray is commonly used for detecting thoracic metastases, but MDCT is more sensitive. This is particularly important considering that a significant number of HSA metastasize early in the disease course, implying the potential presence of small pulmonary nodules at the time of diagnosis (Nelson & Couto, 2019). Two studies (Nemanic et al., 2006) and (K. Scollan et al., 2015) reported that 90% of pulmonary metastases identified on MDCT were not visible on radiographs. For screening abdominal metastases or primary neoplasms, abdominal MDCT is also superior to ultrasonography, especially in larger dogs (>25kg) (Fields et al., 2012). TTE hold a low sensitivity in detecting RA masses (63%) (see figure 4), particularly in cases with small effusions or post-pericardiocentesis (MacDonald et al., 2009). Additionally studies in human medicine have shown that the presence of the crista terminalis can lead to misinterpretation of RA mass in TTE (Akcay et al., 2007). A concern also applicable to veterinary medicine in the context of PE (K. Scollan et al., 2015) that can be solved as MDCT offers enhanced clarity in such cases (K. F. Scollan et al., 2015). While further investigations are needed to establish the sensitivity and specificity of MDCT compared to TTE, the current findings indicate its potential clinical utility as an additional method to TTE in the diagnosis and evaluation of PE as it provides valuable information regarding the extent of the disease in the thorax and abdomen (K. Scollan et al., 2015). This finding aligns with recommendations in human medicine, where MDCT serves as an essential adjunct imaging study following the diagnosis of PE with echocardiography (Klein et al., 2013).

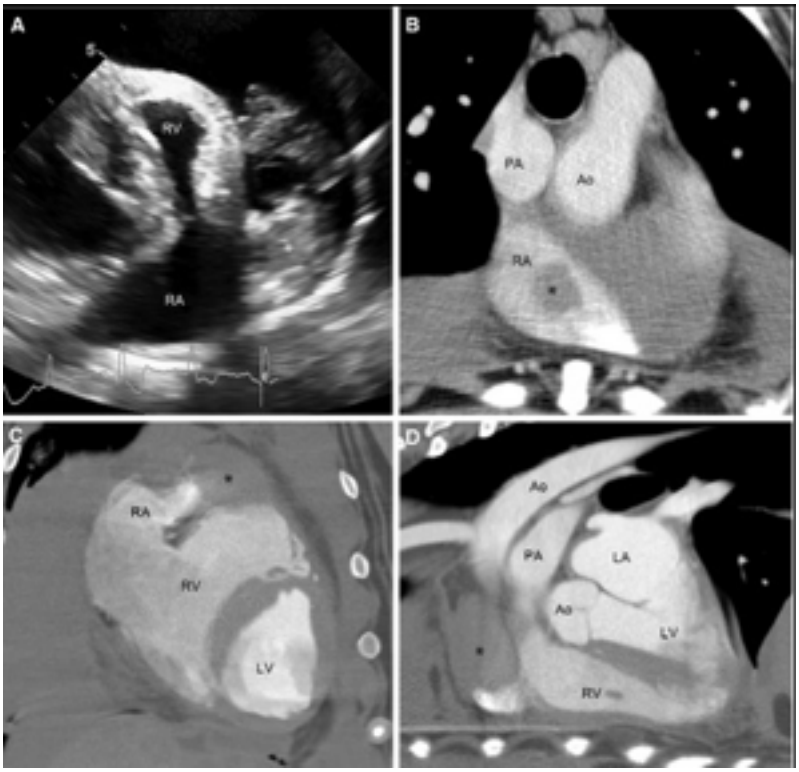

Figure 4: Two-dimensional echocardiography (A) and transverse (B), dorsal (C), and sagittal (D) contrast-enhanced multidetector computed tomography (MDCT) images of a dog with a right auricular hemangiosarcoma (K. F. Scollan et al., 2015). The mass (*) is identified by echocardiography at the right auricle from the left cranial view. The MDCT images show the mass (*) at the right auricle and extending toward the body of the RA. Ao, aorta; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle.

However, a disadvantage of MDCT in veterinary cardiology is its potential for increased radiation exposure compared to other imaging modalities such as TTE. This heightened exposure can be a concern, particularly in cases where repeated imaging or long-term monitoring is required. Additionally, MDCT require general anesthesia or deep sedation for optimal image acquisition, which can pose risks to certain patients, especially those with underlying health conditions. Furthermore,

the cost associated with MDCT equipment and procedures may limit its widespread availability and routine use in veterinary practices (Bertolini & Prokop, 2011).

Despite these constraints, MDCT imaging techniques have the potential to transform the assessment of PE in dogs by providing a more comprehensive evaluation of thoracic and abdominal structures through a single imaging modality (Bertolini, 2017).

Future advancements may enhance the widespread of this technique in veterinary practice, particularly with the integration of (ECG)-gating to MDCT offering superior imaging of cardiac morphology than non-ECG-gated MDCT (Gunther-Harrington et al., 2019). ECG-gating synchronizes imaging with the cardiac cycle to enhance visualization of cardiac morphology (Gunther-Harrington et al., 2019). The characteristics of non-ECG- and ECG-gated MDCT have not been extensively explored in veterinary clinics. However, a recent study (Kim et al., 2023) indicate its effectiveness in diagnosing cardiac masses, such as pericardial nodules, in dogs. Managing rapid heart rates, high costs, and anesthesia time still affect its clinical utility compared to non-ECG-gated MDCT CG-gated MDCT (Drees et al., 2011).

3.4.3 Magnetic resonance imaging / Cardiac magnetic resonance imaging

Cardiac magnetic resonance imaging (cMRI) is considered the gold standard for imaging suspected cardiac or pericardial masses in human medicine (Randhawa et al., 2011). In contrast, in veterinary medicine, cMRI is a relatively recent practice that has become increasingly important in cardiology field (Gilbert et al., 2010).

MRI is a non-invasive and non-ionizing medical imaging technique that relies on powerful magnetic fields and radio waves to produce detailed images of internal body structures (Wisner & Zwingenberger, 2015). cMRI specifically targets imaging of the heart and its adjacent structures using the same principle (Jeudy & White, 2008). Gadolinium-based MRI contrast agents are extensively utilized in clinical practice especially for delineating masses (Sparrow et al., 2005).

cMRI delivers highly detailed, cross-sectional images of the heart, enabling a comprehensive evaluation of cardiac morphology, function, and potential abnormalities (Constantine et al., 2004). Like CT, MRI enables imaging in any desired plane facilitating the visualization of the entire heart and adjacent structures. Also the precise differentiation between various soft tissues contrast allow distinguishing more precisely masses like thrombi, primary cardiac tumors and metastases (see Figure 5) (Grizzard & Ang, 2007). In addition to anatomical imaging, the ability to acquire images synchronized with the cardiac cycle (cardiac gating) and assess both hemodynamics and myocardial contractility allow understanding the impact of PE on cardiac performance (Gilbert et al., 2010). A study in dogs

revealed cMRI played a crucial role in confirming and better characterizing masses detected by TTE (Boddy et al., 2011). A veterinary report has highlighted the potential of cMRI in cases of hemorrhagic PE, aiding in pre-surgical determination of mass presence characterization and detecting complications related to pericardiocentesis (Gallach & Mai, 2013).

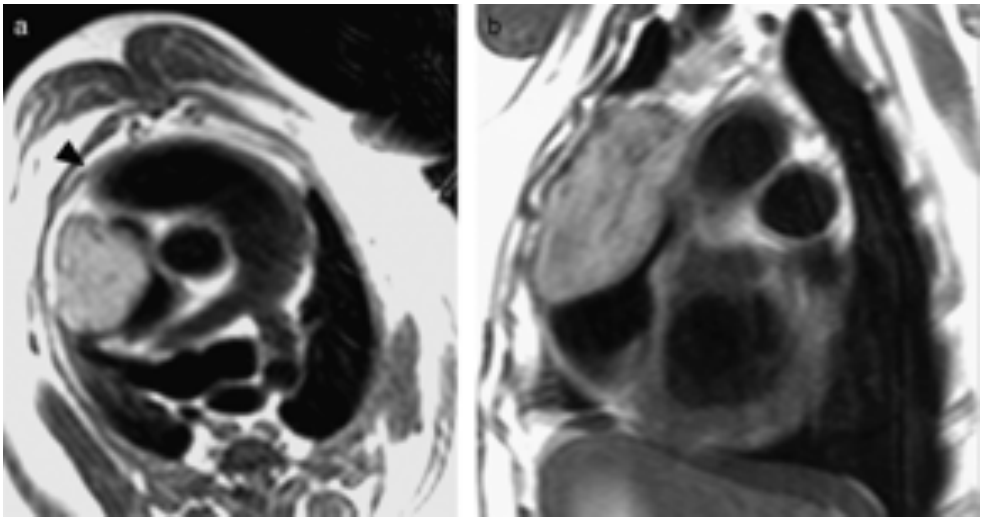

Figure 5: Dorsal T1-weighted magnetic resonance images of the heart showing a hyperintense mass located dorsal to and extending into the AV groove. There is a small amount of pericardial fluid present (arrowhead). (K. F. Scollan et al., 2015)

In human medicine, cMRI has shown potential for making a presumptive diagnosis of angiosarcoma without the need for biopsy by showing specific appearances in T1, T2-weighted images and in steady-state free precession (SSFP) imaging. Because some HSA in dogs have shown similar characteristics to human angiosarcoma further studies are needed to determine if theses cMRI characteristics can be paralleled with veterinary medicine (Sparrow et al., 2005). Challenges in diagnosing other types of cardiac tumors through MRI persist (Grizzard & Ang, 2007). For paragangliomas the ability to definitively compare findings between humans and dogs is uncertain (Boddy et al., 2011).

While MRI is highly effective and can be employed for detecting PE in dogs, it does have some limitations in cardiology field. There are few reports on its use due to infrequent applications in standard practice and existing research are based on small sample sizes and lack of histopathological verification. Clinical challenges include the need for extensive training and general anesthesia due to

long image acquisition times (20-60 minutes). MRI can double acquisition time compared to MDCT (K. F. Scollan et al., 2015) and is complicated by cardiac disease (Gilbert et al., 2010). MRI rooms restrict anesthetic and monitoring equipment to non-ferrous metals (Gilbert et al., 2010). Limited availability of MRI equipment and technical skills hinders accessibility (Boddy et al., 2011). Physiological challenges like cardiac and respiratory motion and intrapulmonary air interference limit MRI's practical use compared to more accessible alternatives (Gilbert et al., 2010).

In conclusion, despite being a reference standard in human clinical practice due to its versatility and ability to offer insights into both structural and functional aspects of the heart, its immediate prospects in veterinary practice are uncertain because of practical and economic considerations. However, it holds potential applications in veterinary specialized cardiology to rule out cardiac masses when TTE is inconclusive (Sparrow et al., 2005).

In the context of PE in dogs, CT and/or cMRI, by their ability to provide detailed anatomical and functional information are advantageous to establish an accurate diagnosis if the root cause has not been clearly identified by TTE or radiography. Overall, the use of each one is very dependent on the specific clinical scenario mandating a highly individualized approach as each technique has advantages and limitations across a range of disease processes.

3.5. FOCUSED CARDIAC ULTRASOUND, A COMPROMISE IN GENERAL PRACTICE

Focused cardiac ultrasound (FCU) serves as a valuable point-of-care diagnostic imaging tool primarily applied to symptomatic dogs. Unlike comprehensive echocardiography, FCU is a short-timed examination involving specific views to identify significant abnormalities in cardiac chamber size or systolic function in order to swiftly detect cardiovascular diseases causing life threatening clinical signs (DeFrancesco & Ward, 2021). FCU findings, combined with patient data, aid orienting the diagnostic and guiding emergency treatment (Hezzell et al., 2020).

In dogs, FCU is valuable for promptly diagnosing conditions like PE, cCT or structural heart diseases leading to congestive heart failure (Hezzell et al., 2020). FCU also helps characterize hypotensive dogs, identify severe heart diseases and aid in cardiopulmonary resuscitation by identifying underlying causes for non-shockable cardiac arrests (Gardner et al., 2017). Its enhanced diagnostic accuracy has

earned FCU the nickname "visual stethoscope of the 21st century" for point-of-care thoracic ultrasound (Gillman & Kirkpatrick, 2012).

The microconvex probe is commonly used in FCU due to its accessibility. However, for cardiac imaging, the phased-array transducer is preferred (DeFrancesco & Ward, 2021). Shaving hair is usually unnecessary if alcohol and gel are used, especially in the parasternal region. Recommended patient positions include standing or sternal for dogs in respiratory distress. Right lateral positioning is advised if lateral recumbency is better tolerated by the dog (Hezzell et al., 2020).

There are two main acoustic windows for obtaining standard heart views. The right parasternal allows for short-axis and long-axis views, aiding in evaluating cardiac chamber size. Nonstandard views can help characterize suspected cardiac masses or thrombi. The subxiphoid window is useful for imaging the caudal vena cava, apical heart regions, and PE (DeFrancesco & Ward, 2021).

The visualization of an anechoic fluid around the heart of a dog presenting evocative clinical signs allows for a prompt diagnosis of PE (Lisciandro, 2016). If no mass is detected, neoplasia should be discarded and after patient stabilization, a complete diagnostic echocardiogram coupled with cTnI levels should be assessed to confirm or dismiss suspicions of a mass lesion (Chun et al., 2010). FCU also enhances safety during pericardiocentesis by guiding (ultrasound-guided) the procedure or identifying the optimal site for centesis (ultrasound-assisted) (Tsang et al., 1998).

In summary, FCU is a quick and qualitative, point-of-care examination offering a low-stress and time-sensitive approach particularly valuable in the management of critically ill patient with PE. TTE and FCU are both crucial diagnostic tools for acute and chronic PE in dogs, each with unique advantages. FCU offers rapid, immediate insights in emergency situations, while echocardiography provides a more comprehensive understanding of PE's characteristics but requires more time and specialized facilities limiting its application in urgent scenarios. Thus, the choice between FCU and echocardiography depends on specific clinical needs, resource availability, and urgency (DeFrancesco & Ward, 2021).

CONCLUSION: COMBINATION FOR COMPREHENSIVE ASSESSMENT

The urgency associated with the swift progression of PE to life-threatening states emphasizes the crucial role of accurate and timely diagnosis allowing prompt intervention, with pericardiocentesis serving as a vital first-line treatment. The complexity of PE etiologies underscores the importance of a thorough and complete diagnostic approach, providing valuable prognostic information crucial for treatment decisions.

Imaging techniques are indispensable tools in the management of PE in dogs. Each contribute unique perspectives, allowing veterinarians to corroborate findings to establish an accurate diagnosis and ultimately determining the most appropriate therapeutic interventions improving the prognosis and well-being of the dog affected by PE. Additionally, these imaging techniques enable veterinarians to assess treatment outcomes and monitor the resolution over time.

TTE and FCU stands out as the primaries medical imaging methods for managing the most of patients with suspected PE. FCU proves invaluable in emergency situations, offering immediate perspectives on critical cardiac conditions. In contrast, comprehensive TTE provides a more detailed examination, becoming a non-invasive gold standard for thorough cardiac evaluations. TTE not only confirms the diagnosis (through direct visualization) but can also find its potential causes, such as primary heart conditions, cardiac tumors or allow conducting cytological and bacteriological analyses on US-guided samples. Moreover, it is especially useful in the treatment by enabling US-guided pericardiocentesis, an urgent therapeutic procedure often feasible in conscious patients. Radiography, while less detailed, serves as a valuable economical and accessible diagnostic option especially for assessing chronic or slowly progressing cases presenting severe PE.

However, in many cases, ultrasound and/or x-ray alone are insufficient to establish the precise diagnosis because of their variable sensitivity for detecting cardiac masses and inability to evaluate associated abnormalities in nearby structures. While advanced imaging techniques like computed CT, MDCT and cMRI are not obligatory for diagnosing PE, they offer heightened sensitivity in detecting such cases.

Thus, the integration of theses advanced imaging techniques as complimentary imaging techniques to the most traditional methods could contribute significantly to the diagnostic armamentarium for the assessment of PE in dogs knowing that tumors are the primary cause of this condition in dogs. The collaborative use of each one of these diagnostic tools not only optimizes diagnostic accuracy but also

emphasizes the flexibility required by the clinician to adapt to the diverse clinical needs of individual patients. The economical and practical implications of advanced methods represent one of the biggest restrictions in real time practice. However, their potential application in specialized area and research contexts signifies a promising avenue for future exploration and refinement in veterinary cardiology.

As advancements in veterinary medicine progress, the integration of modern diagnostic modalities becomes crucial for advancing patient care, refining treatment approaches and ultimately improving outcomes for dogs with PE. Research gaps between human and veterinary medicine highlight the necessity of additional studies to ascertain the applicability of findings in the veterinary domain. Such future research holds the promise of a future where precise diagnosis and effective management significantly contribute to the enhancement of the overall management of life-threatening conditions like PE in dogs.

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