ASSESSMENT OF LEFT ATRIAL FUNCTION IN CATS WITH ARTERIAL THROMBOEMBOLISM BY USING TWO-DIMENSIONAL SPECKLE TRACKING ECHOCARDIOGRAPHY

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จุฬาลงกรณ์มหาวิทยาลัย
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การประเมินการทำงานของหัวใจห้องบนซ้ายในแมวที่มีภาวะลิ่มเลือดอุดตันหลอดเลือดแดง โดยการตรวจคลื่นเสียงสะท้อนความถี่สูงด้วยวิธีสเป็กเกิล แทรกกิงแบบสองมิติ

น.ส.จิดาภา โตสุวรรณ

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จิดาภา โตสุวรรณ : การประเมินการทำงานของหัวใจห้องบนซ้ายในแมวที่มีภาวะลิ่มเลือดอุดตันหลอดเลือดแดง โดยการตรวจคลื่นเสียงสะท้อนความถี่สูงด้วยวิธีสเป็กเกิล แทรกกิงแบบสองมิติ . (ASSESSMENT OF LEFT ATRIAL FUNCTION IN CATS WITH ARTERIAL THROMBOEMBOLISM BY USING TWO-DIMENSIONAL SPECKLE TRACKING ECHOCARDIOGRAPHY) อ.ที่ปรึกษาหลัก : รศ. ดร. สพ.ญ.สิริลักษณ์ สุรเชษฐพงษ์

ภาวะลิ่มเลือดอุดตันเส้นเลือดแดงในแมวเป็นโรคที่เฉียบพลัน อาการแสดงรุนแรง และอัตราการเสียชีวิตสูง ภาวะนี้อาจมีสาเหตุจากความผิดปกติของหัวใจ เช่น โรคกล้ามเนื้อหัวใจผิดปกติ หรือ โรคอื่นๆที่ไม่ใช่โรคหัวใจ การตรวจคลื่นเสียงสะท้อนด้วยคลื่นความถี่สูงแบบสองมิติ หรือการอัลตราซาวน์หัวใจเป็นเครื่องมือหลักที่ใช้ในการประเมินความเปลี่ยนแปลงของโครงสร้างของหัวใจและการทำงานของกล้ามเนื้อหัวใจในแมว ในขณะที่การตรวจคลื่นเสียงสะท้อนความถี่สูงด้วยวิธีสเป็กเกิล แทรกกิง แบบสองมิติ เป็นการอัลตราซาวน์วิธีใหม่ที่ใช้ภาพที่บันทึกมาจากการอัลตราซาวน์แบบสองมิติ โดยเทคนิคใหม่นี้สามารถประเมินการเคลื่อนไหวของกล้ามเนื้อหัวใจในหลายทิศทาง ทำให้สามารถประเมินความผิดปกติของลักษณะและคุณภาพของการบีบตัวของกล้ามเนื้อหัวใจ ซึ่งได้มีการนำมาใช้ในมนุษย์ สุนัข และแมวที่มีภาวะกล้ามเนื้อหัวใจหนาตัว แต่ยังไม่มีการศึกษาเทคนิคนี้ในแมวที่มีภาวะลิ่มเลือดอุดตันเส้นเลือดแดงมาก่อน วัตถุประสงค์ของการวิจัยครั้งนี้ คือ การประเมินการทำงานของกล้ามเนื้อหัวใจห้องบนซ้ายในแมวที่มีภาวะลิ่มเลือดอุดตันเส้นเลือดแดง และแมวปกติ โดยการตรวจคลื่นเสียงสะท้อนความถี่สูงด้วยวิธีสเป็กเกิล แทรกกิง แบบสองมิติ การศึกษาครั้งนี้ประกอบด้วยแมวปกติ 23 ตัว และแมวที่ภาวะลิ่มเลือดอุดตันเส้นเลือดแดง 21 ตัว ซึ่งแบ่งออกตามสาเหตุเป็น 2 กลุ่ม เกิดจากโรคหัวใจ 15 ตัว และ ไม่ได้เกิดจากโรคหัวใจ 6 ตัว ผลการทดลองพบว่า ค่า Left atrial strain จากการใช้วิธีสเป็กเกิล แทรกกิง แบบสองมิติ ของกลุ่มแมวที่ภาวะลิ่มเลือดอุดตันเส้นเลือดแดงที่เกิดจากโรคหัวใจมีค่าลดลง เมื่อเทียบกับกลุ่มแมวปกติอย่างมีนัยสำคัญ ($p<0.001$) แต่ไม่มีความแตกต่างอย่างมีนัยสำคัญในกลุ่มแมวที่ภาวะลิ่มเลือดอุดตันเส้นเลือดแดงที่ไม่ได้เกิดจากโรคหัวใจ จากการทดสอบความสัมพันธ์พบว่า ค่า Left atrial strain ในช่วง Reservoir ของหัวใจห้องบนซ้าย (LASr) มีความสัมพันธ์กับค่าต่างๆที่ได้มาจากการใช้วิธีสเป็กเกิล แทรกกิง แบบสองมิติ ซึ่งสามารถใช้เป็นค่าตัวแทนได้ อีกทั้งจากการทดสอบสัมประสิทธิ์การแปรผันทั้งผู้วัดคนเดียวกัน และผู้วัดต่างคน ค่า LASr อยู่ในเกณฑ์ที่ยอมรับได้ จากการวิเคราะห์การถดถอยโลจิสติคพบว่า LASr ที่น้อยกว่าร้อยละ 11 มีความน่าจะเป็นของการเกิดภาวะลิ่มเลือดอุดตันเส้นเลือดแดงในแมวสูงขึ้น 189 เท่า (95%CI: 15.73-2,269.86, p-value<0.001) กล่าวโดยสรุป การตรวจคลื่นเสียงสะท้อนความถี่สูงด้วยวิธีสเป็กเกิล แทรกกิง แบบสองมิติ สามารถใช้ประเมินการทำงานของกล้ามเนื้อหัวใจห้องบนซ้ายในแมวที่มีภาวะลิ่มเลือดอุดตันเส้นเลือดแดงได้ และสามารถทำซ้ำได้โดยที่ไม่ทำให้สัตว์เจ็บปวด ด้วยวิธีดังกล่าว พบการทำงานที่ผิดปกติของหัวใจห้องบนซ้ายในแมวที่ภาวะลิ่มเลือดอุดตันเส้นเลือดแดงที่เกิดจากโรคหัวใจ แต่ไม่พบในกลุ่มแมวที่ภาวะลิ่มเลือดอุดตันเส้นเลือดแดงที่ไม่ได้เกิดจากโรคหัวใจ และค่า LASr ที่น้อยกว่าร้อยละ 11 อาจจะใช้ประเมินความน่าจะเป็นของการเกิดภาวะลิ่มเลือดอุดตันเส้นเลือดแดงในแมวได้

จุฬาลงกรณ์มหาวิทยาลัย
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สาขาวิชา	อายุรศาสตร์สัตวแพทย์	ลายมือชื่อนิสิต .....
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Jidapa Tosuwan : ASSESSMENT OF LEFT ATRIAL FUNCTION IN CATS WITH ARTERIAL THROMBOEMBOLISM BY USING TWO-DIMENSIONAL SPECKLE TRACKING ECHOCARDIOGRAPHY. Advisor: Assoc. Prof. SIRILAK SURACHETPONG, D.V.M., M.S., Ph.D., D.T.B.V.M.

Feline arterial thromboembolism (ATE) is an acute and distressing clinical presentation with high mortality and poor prognosis. ATE may be related to cardiogenic causes such as the underlying myocardial disease or non-cardiogenic causes. Echocardiography is the routine diagnostic tool to evaluate cardiac structural changes and myocardial function in cats. Two-dimensional speckle tracking echocardiography (2D-STE) is a novel ultrasound modality based on 2D echocardiographic images, that allows multidirectional active deformation assessment and provides comprehensive information on myocardial contractile properties and function. 2D-STE echocardiography has been used to estimate the strain and strain rate of left atrial myocardial deformation in humans, dogs and cats with HCM, but there has been no study in cats with ATE. The objective of this study was to investigate left atrial myocardial deformation in cats with ATE and normal cats using 2D-STE. This study included twenty-three normal cats and twenty-one ATE cats diagnosed with fifteen cardiogenic ATE and six non-cardiogenic ATE. The left atrial stain and stain rate were significantly decreased in cats with cardiogenic ATE compared with the normal group ($p<0.001$), but no significant difference between the non-cardiogenic ATE and normal groups. From the correlation test, the use of left atrial stain during the reservoir phase assessed by 2D-STE could represent the overall LA deformation. In addition, the intra- and inter-observer coefficient of variation was acceptable for LASr. From the logistic regression, the LASr value of less than 11% was a significant factor for the occurrence of ATE, with a crude odds ratio of 189.0 (95%CI: 15.73-2,269.86, p-value<0.001). In conclusion, the left atrial longitudinal strain of reservoir phase derived by 2D-STE is a repeatable and non-invasive technique to assess LA myocardial deformation in cats with ATE. By 2D-STE, impaired LA function was detected in cats with cardiogenic ATE, but not in cats with non-cardiogenic ATE. LASr <11% could predict the risk of occurrence of ATE in the cat population.

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Chulalongkorn University

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จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Jidapa Tosuwan

TABLE OF CONTENTS

Page

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

LIST OF TABLES

Page

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

LIST OF FIGURES

Page

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

CHAPTER I

INTRODUCTION

Feline arterial thromboembolism (ATE) is acute and distressing clinical presentation with poor prognosis and high mortality. The most common clinical sign is hindlimb paralysis, with the following notable signs: pulselessness, poikilothermia, pallor and pain of the extremities. The thrombotic material that usually forms in the cardiac chamber and is associated with underlying myocardial diseases, can be classified as cardiogenic arterial thromboembolism (CATE). ATE may be related to non-cardiogenic causes such as hyperthyroidism and neoplasms, particularly pulmonary carcinoma (Smith et al., 2003; Luis Fuentes, 2012). A previous study has shown that ATE occurs mostly in cats with hypertrophic cardiomyopathy (HCM) and is also found in cats with other cardiomyopathies such as dilated cardiomyopathy (DCM), restrictive cardiomyopathy (RCM) and non-specific myocardial disease (Rush et al., 2002). The prevalence of thromboembolism on postmortem examination has been found in up to 48% of cats with HCM (Fox et al., 1999). Factors associated with CATE include left atrial (LA) enlargement, LA systolic dysfunction, increased left ventricular (LV) wall thickness and diameter, left atrial appendage (LAA) flow velocities and spontaneous echocardiographic contrast (SEC) (Rush et al., 2002; Payne et al., 2015; Schober and Maerz, 2006). The SEC and cardiac thrombi are commonly seen in LA and the LAA in cats with cardiomyopathy; however, thrombi can also occur in LV and the ascending aorta (Black, 2000). The pathogenesis of LA thrombus formation is still unclear (Schober and Maerz, 2006; Peck et al., 2016). Thrombus formation is thought to be associated with Virchow's triad, i.e., local blood stasis, endothelial damage, and hypercoagulability. Left atrial dysfunction may be one of the causes of thrombus formation in LA. Therefore, assessment of left atrial function may be useful to identify cats at risk for developing ATE.

Echocardiography is the most important diagnostic tool for myocardial diseases in cats that can detect structural changes and functional abnormalities of the myocardium in a non-invasive manner. Conventional echocardiography (two-dimensional, M-mode, and Doppler echocardiography) is routinely used to diagnose cardiomyopathy in cats (Payne et al., 2013). Previous studies of HCM in humans have used techniques to assess myocardial strain, including tissue Doppler imaging (TDI) and two-dimensional speckle tracking echocardiography (2D-STE) to examine myocardial function. Both TDI and 2D-STE are more sensitive than conventional echocardiography (Sitia et al., 2010; Hensel et al., 2014). TDI depends on surrounded tethering of myocardial motion, cardiac translation and Doppler angle, but 2D-STE is independent of these factors (Amundsen et al., 2006; Lim et al., 2009; Tidholm et al., 2009). 2D-STE echocardiography, an ultrasound modality based on 2D echocardiographic images, allows multidirectional active deformation assessment and provides comprehensive information on myocardial contractile properties and function. 2D-STE echocardiography is used to estimate strain and strain rate (SR) of radial, longitudinal, and circumferential myocardial deformation.

2D-STE is recognised as an accurate technique for assessing myocardial function and has been used in many studies in humans with HCM and other cardiac diseases (Gersh et al., 2011; Kauer et al., 2013). 2D-STE has also been used in dogs, horses, pigs, sheep, calves, and goats (Lecoq et al., 2018; Leroux et al., 2020). This technique is recommended for assessing myocardial function in dogs with several cardiac diseases, such as myxomatous mitral valve disease and patent ductus arteriosus (Zois et al., 2012; Spalla et al., 2016; Caivano et al., 2018). In cats with HCM, 2D-STE has been used in many studies to assess left ventricular dysfunction and can assess contractile function in more details (Sugimoto et al., 2015; Spalla et al., 2019; Suzuki et al., 2019).

Preventing ATE is better than trying to treat it. If we can identify the abnormal myocardial function associated with ATE, it may lead to ways to prevent ATE. To our knowledge, evaluation of the left atrial function by 2D-STE in cats with ATE has not been reported previously. Therefore, the aim of this study is to evaluate the left atrial deformation in cats with ATE and normal cats using two-dimensional speckle tracking echocardiography (2D-STE).

Objectives of Study

To evaluate the left atrial myocardial deformation in cats with ATE and normal cats using two-dimensional speckle tracking echocardiography (2D-STE).

Hypothesis

Two-dimensional speckle tracking echocardiography (2D-STE) can be used to evaluate the difference of left atrial myocardial deformation between cats with ATE and normal cats.

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Keywords (Thai): ภาวะลิ่มเลือดอุดตันในหลอดเลือดแดง แมว หัวใจห้องบนซ้าย สเป็กเกิล-แทรกกิง

Keywords (English): Arterial thromboembolism, Feline, Left atrium, Speckle tracking

Advantages of the study

1. Establishing 2D-STE as a repeatable, non-invasive method for assessing myocardial deformation assessment method of LA in cats with ATE.
2. Serving as a fundamental knowledge of the LA global longitudinal strain measurement in cats with ATE.

CHAPTER II

LITERATURE REVIEW

Feline arterial thromboembolism (ATE) is acute and distressing clinical presentation with high mortality and poor prognosis. Several retrospective studies suggest euthanasia cats with ATE at presentation; therefore, natural mortality rates (28%–40%) are comparable to euthanasia rates (25%–35%) (Laste and Harpster, 1995; Moore et al., 2000; Smith et al., 2003; Schoeman, 1999). The most common clinical sign is hindlimb paralysis with the following notable signs: pulselessness, pain, poikilothermia and pallor of the extremities. Arterial thromboembolism in cats can be caused by many underlying diseases such as hyperthyroidism, cardiomyopathy, neoplasia, and other hypercoagulable diseases (Smith et al., 2003; Luis Fuentes, 2012). These thrombotic materials usually form in the cardiac chamber associated with underlying myocardial diseases, including hypertrophic (HCM), restrictive (RCM), dilated (DCM), and unclassified/ischemic cardiomyopathy (UCM/ICM), which can be classified as cardiogenic ATE (CATE). 17% of CATE cases have been reported as complications of feline hypertrophic cardiomyopathy (HCM) (Atkins et al., 1992). An analysis of the Veterinary Medical Data Base (VMDB) revealed that CATE occurred secondary to HCM (6%), DCM (5%), RCM (6%), and UCM (7%) of all ATE cases. (Atkins et al., 1992; Rush et al., 2002). Smith et al. (2003) reported that 1/175 (0.006%, n=22,178) of the cat population in their hospital developed ATE. Similarly, Buchanan et al. (1966) reported the prevalence of 1/142 cats (0.007%) from another center. The most common breeds with CATE are domestic short hair (84.3%). Some breeds have an increased risk of developing ATE, such as Ragdoll (0.63%, OR=8.23), Birman (1.25%, OR=5.08), Tonkinese (0.31%, OR=2.28), Abyssinian (1.57%, OR=2.12), and Maine Coon (0.94%, OR=1.21) (Smith et al., 2003). Rush et al. (2002) showed that the most frequent cause of cardiac death was ATE, followed by heart failure and sudden death. The prevalence of thromboembolism at postmortem examinations was up to 48% of patients with HCM (Fox et al., 1999). HCM cats with ATE had shorter survival time and were predicted to die within two years of diagnosis (OR=28.58, $p<0.001$) (Payne et al., 2015).

Normally, there is a balance between thrombus formation and dissolution that allows continuous repair of endothelial injury and prevents uncontrolled thrombus development. Several signaling pathways are involved in thrombogenesis, coordinating interactions between platelets, clotting factors, and the endothelium. Pathological thrombus formation is thought to be related to Virchow's triad: local blood stasis, endothelial injury, and hypercoagulable state. Blood stasis may be associated with dilated cardiac chambers or restricted blood flow. Endothelial injury may result from an enlarged left atrium, damage to the endothelial layer, or invading tumors. However, the hypercoagulable state is difficult to diagnose in pets. Clinical thrombosis in cats is usually associated with increased platelet hypersensitivity, elevation of factor II, V, VII, VIII, IX, X, XII, and fibrinogen, and decreased activity of the antithrombotic proteins antithrombin and protein C. Cats were likely to form intracardiac thrombus more than dogs. In general, intracardiac thrombi commonly form in the left auricle and are then transported through the bloodstream as emboli. These pieces of thrombus can cause embolism, particularly the classic 'saddle thrombus' that blocks at the aortic trifurcation, resulting in loss of blood flow to the pelvic limbs and causing ischemic neuropathy (Hogan, 2017).

Previous studies using conventional echocardiography revealed factors associated with ATE including LA enlargement, a low percentage of fractional shortening of the left atrium (LA-FS%), low LAA velocities, increased LV diastolic dysfunction, and spontaneous contrast (Rush et al., 2002; Schober and Maerz, 2006). Payne et al. (2015) showed that ATE is associated with all LA variables, including left atrium to aorta ratio (LA/Ao), left atrial diameter (LAD), LA-FS%, percentage of ejection fraction (LA-EF%), LV wall thickness and diameter, and spontaneous contrast, but not with regional wall motion abnormalities or LV systolic dysfunction. Spontaneous echocardiographic contrast (SEC), an ultrasound backscatter pattern with a dynamic, semiorganized, swirling pattern, indicates increased echogenicity of blood due to aggregation of red blood cell. In cats with HCM, SEC and cardiac

thrombi are commonly seen in LA and the LAA, but they can also occur in LV and the ascending aorta (Black, 2000). Stokol et al. (2008) found concurrent LA SEC in 46% of cats with ATE. LAA flow velocity, as determined by pulsed-wave Doppler echocardiography, was useful in predicting SEC related to a risk of thromboembolism in cats with cardiomyopathy. A low LAA flow velocity may be referred to blood stasis in the LAA. Cats with an LAA flow velocity of ≥0.25 m/s are at low risk of developing SEC (Schober and Maerz, 2006).

Echocardiography is the most important diagnostic tool for myocardial diseases in cats detecting myocardial structural and functional changes in the myocardium in a noninvasive manner. Conventional echocardiography (two-dimensional, M-mode, and classical Doppler imaging as continuous-wave, pulsed-wave and color-flow) is routinely used as a diagnostic method for cardiomyopathy in cats (Payne et al., 2013). Previous studies of HCM in humans have used strain rate assessment methods, including tissue Doppler imaging (TDI) and two-dimensional speckle tracking echocardiography (2D-STE), to assess myocardial function. Both TDI and 2D-STE have been indicated for higher sensitivity than conventional echocardiography (Sitia et al., 2010; Hensel et al., 2014). Moreover, some studies found that 2D-STE is better at myocardial function than TDI and conventional echocardiography (Zois et al., 2012; Spalla et al., 2016; Caivano et al., 2018). TDI is dependent on surrounded tethering of myocardial motion, cardiac translation, and Doppler angle, whereas 2D-STE is more independent of these factors (Amundsen et al., 2006; Tidholm et al., 2009; Lim et al., 2009). In cats with subclinical HCM, the 2D-STE technique was more sensitive in detecting early myocardial diastolic dysfunction compared with TDI (Sugimoto et al., 2015).

2D-STE, an ultrasound modality based on 2D echocardiographic images, allows multidirectional active deformation assessment and provides comprehensive information about the contractile properties and function of the myocardium. The

2D-STE technique analyzes the myocardial motion by frame-by-frame image tracking of natural acoustic markers referred as speckles. Speckles are generated from interactions between myocardium and ultrasound within a region of interest represented by the software on normal two-dimensional images, specifically in the left apical four- chamber view. Estimates of myocardial deformation along radial, longitudinal, and circumferential axes independent of angulation.

The LA mechanism acts as a (1) reservoir that receives blood return during LV systole; (2) conduit that passively directs blood to the left ventricle during early diastole; (3) contract that LA actively contracts during late diastole. Strain and strain rate from 2D-STE allow assessment of all three LA phases. 2D-STE has been a widely used and accepted method for non-invasive assessment of LA function in humans. Strain is a partial change in the length of a myocardial segment, represented as myocardial deformation. The strain rate is the rate at which the myocardial deformation occurs. Therefore, the LA strain curves show the physiological function of the atrium and are exactly relevant to LV functions.

In many human studies, 2D-STE is an accurate method to assess myocardial function and has been used to evaluate LA function in several cardiac diseases such as left atrial fibrosis, atrial fibrillation, primary mitral regurgitation and aortic stenosis (Yoon et al., 2005; Motoki et al., 2012; Cameli et al., 2013; Pagola et al., 2014; Yang et al., 2015; Galli et al., 2015). 2D-STE can detect early left atrial dysfunction before structural changes. (Todaro et al., 2012 and Tigen et al., 2015). 2D-STE has also been used in other animals such as dogs, sheep, pigs, calves, horses and goats to assess myocardial function (Lecoq et al., 2018; Leroux et al., 2020). This technique has been recommended for use in dogs with various cardiac diseases, such as myxomatous mitral valve disease (MMVD) and patent ductus arteriosus (Suzuki et al., 2013 and Spalla et al., 2016). Recently, 2D-STE has been performed to assess right ventricular myocardial function in dogs with pulmonary hypertension (Caivano, 2020) and MMVD

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(Yuchi et al., 2021) and myocardial function in dogs with parvoviral enteritis (de Abreu et al., 2021). In addition, the 2D-STE technique allowed automatic analysis of time to LA area or volume curve during the LA function cycle, which is beneficial in humans (Li et al., 2014) and dogs (Dermlim et al., 2019).

The study by Sugimoto et al. (2015) showed that 2D-STE could detect diastolic myocardial dysfunction in LV myocardial segments that were not yet hypertrophied in cats. 2D-STE has also been used to investigate multidirectional myocardial deformities in cats with HCM. Although systolic function was still normal on conventional echocardiography, STE was able to detect a decrease in longitudinal, radial, and circumferential deformation in cats with HCM (Suzuki et al., 2017). Asymptomatic cats with obstructive HCM had different layer-specific myocardial function assessed by 2D-STE compared to healthy cats. (Suzuki et al., 2019). 2D-STE has been used in many studies to evaluate left ventricular dysfunction and can assess contractile function in more details in cats with subclinical and clinical HCM (Sugimoto et al. 2015; Suzuki et al., 2017; Suzuki et al., 2019). 2D-STE can detect LV dysfunction even without the LA enlargement in cats with restrictive cardiomyopathy (Saito et al., 2021). In particular, the study by Kiatsilapanan and Surachetpong (2020) showed that LA dysfunction can be detected earlier than LA enlargement in cats with HCM using 2D-STE.

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The investigation of left atrial function in cats with ATE compared to normal cats using two-dimensional speckle-tracking echocardiography (2D-STE) may be useful to indicate the severity of left atrial dysfunction related to the occurrence of ATE.

CHAPTER III

MATERIALS AND METHODS

Conceptual framework

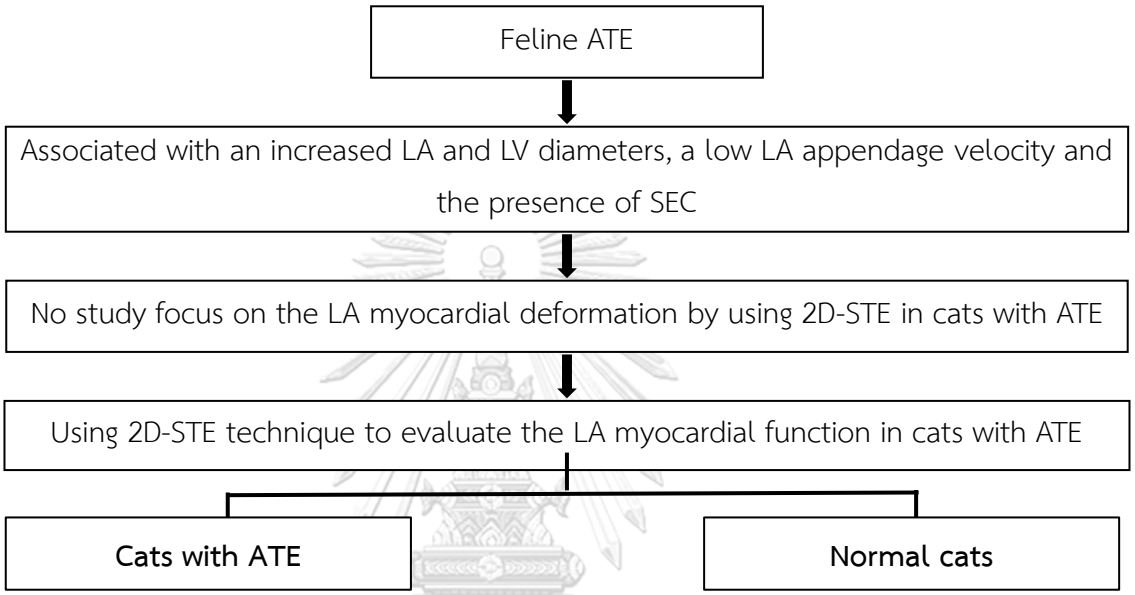

Figure 1 Conceptual framework of this study

Animals

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Adult cats, age more than one-year-old, with a bodyweight between 2-7 kilograms, any breeds and sex were recruited to the study. The population included client-owned cats with ATE and normal cats presented to the Small Animal Teaching Hospital, Faculty of Veterinary Science, Chulalongkorn University during 2019-2021. This project was reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of Faculty of Veterinary Science, Chulalongkorn University with ethical approval number 2031033 on August 1, 2020.

Data from all cats including age, sex, breed, body weight, body condition score (BCS), disease history, and clinical findings were collected. A complete physical

examination, thoracic radiography, conventional electrocardiography, systolic blood pressure and blood collection were performed in all cats. Complete blood count, blood chemistry, electrolytes, and total T4 were measured. Cardiac structure and function were examined by echocardiography. After diagnosis by conventional echocardiography, ATE cats with cardiomyopathy were defined as cardiogenic ATE (CATE) and ATE cats without cardiomyopathy were defined as non-cardiogenic ATE (non-CATE).

Inclusion and exclusion criteria for cats with ATE

Cats with ATE had to have signs of limb paralysis with pulselessness, pain, poikilothermia and pallor of the extremities. Recruited cats may have concurrent congestive heart failure or cardiac arrhythmia. Suspected cats with ATE, that were unstable and could not undergo echocardiographic examination were excluded.

Inclusion and exclusion criteria for normal cats

Normal cats included adult cats older than 1 year (Quimby et al., 2021), regardless of breed or sex. Cats were required to have a normal physical examination, specifically normal heart and lung sounds and no previously diagnosed disease. All tests including conventional echocardiography, ECG, thoracic radiography, blood pressure measurement, and blood tests (complete blood count, blood chemistry and total T4) results had to be within the normal range. Cats with systemic and cardiovascular diseases were excluded.

Sample size calculation

The sample size calculation was estimated from the study by Schober and Maerz (2006) using the median change in left atrial fractional area change between HCM cats with LA SEC and HCM without LA SEC, which was approximately 21% (p=0.01). The calculation was performed using a freeware program (GPower 3.1). For the calculation, the estimated SD was set to 13, the power was set to 0.95, and **α**

(confidence level or type I error rate) was set to 0.05. The result for the sample size calculation was 42 cats (i.e., 21 cats with ATE and 21 normal cats). The calculated sample sizes are similar to those of previous studies (Sugimoto et al., 2015; Suzuki et al., 2017; Suzuki et al., 2019).

Study protocols

Conventional echocardiography

The conventional echocardiography was performed with an ultrasound machine (Mindray, M9, Shenzhen, P.R. China) by an investigator. The M-mode echocardiography was performed to measure the wall thickness and chamber size in the right parasternal long-axis four-chamber view. M-mode parameters including the left ventricular internal diameter at the end-diastole and systole (LVIDd, LVIDs), interventricular septum at the end-diastole and systole (IVSd, IVSs), and left ventricular posterior wall thickness at the end-diastole and systole (LVPWd, LVPWs) were measured. The percentage of fractional shortening of the left ventricle (LV FS) was calculated. Using the Teichholz method, ejection fraction (EF) and LV volumes were calculated as end-diastolic volume (EDV) and end-systolic volume (ESV) using the standard formula: LV volume = $(7 \times LVID^3) / (2.4 + LVID)$ (Boon J, 2011). The maximum and minimum dimensions of the left atrium were measured on M-mode echocardiography in the right parasternal outflow tract view. The percentage of fractional shortening of the left atrium (LA FS) was calculated using the formula (LADmax-LADmin/LADmax) x 100 (Abbott and MacLean, 2006).

In the right parasternal short-axis view at the level of the left atrium during early diastole, the dimensions of the left atrium and aorta were measured according to the Swedish method (Hansson et al., 2002). The ratio of the left atrial to aorta dimensions (LA/AO) was calculated. The ejection fraction of the left atrium (LA-EF%) was calculated from the maximum and minimum LA volumes measured in the left apical four-chamber view (Blume et al., 2011). Two-dimensional echocardiographic

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images of the left apical four-chamber view with three cardiac cycles were recorded with maximum 1,000 frames per second (FPS) for 2D-STE offline analysis.

Pulsed-wave Doppler echocardiography was performed to measure isovolumic relaxation time (IVRT), transmitral flow velocity, aortic flow velocity, pulmonic flow velocity and pulmonary vein flow velocities. IVRT was measured as the time interval between aortic valve closure and the onset of the pulsed wave transmitral flow retrieved at an intermediate position between LV inflow and outflow tract in the left apical 5-chamber view (Schober and Chetboul, 2015). For transmitral flow velocity measurements, the pulsed wave sample gate was placed at the tip of the opened mitral valve leaflets in the left apical 4-chamber view (Boon J, 2011). The required indices were the peak velocity of the early diastolic wave (E wave), the peak velocity of the late diastolic wave (A wave), and the ratio between the peak velocity of the E wave and the peak velocity of the A wave (E/A ratio). Aortic flow was measured in the left apical 5-chamber view with the sample gate was placed directly below the aortic valve. In the right parasternal short-axis view, pulmonic flow was measured with the sample gate placed below the pulmonic valve and pulmonary venous flow was measured with the sample gate at the pulmonary vein opening.

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Tissue Doppler imaging was performed with the gate placed at the septal mitral annulus on the left apical 4-chamber view (Boon J, 2011). The peak velocity of the systolic wave (Sa wave), the peak velocity of the early diastolic wave (Ea wave), and the peak velocity of the late diastolic wave (Aa wave) were determined. In addition, the ratio of the peak velocity of the Ea wave to the peak velocity of the Aa wave and the ratio of the peak velocity of the E wave to the peak velocity of the Ea wave were calculated.

Two-dimensional speckle tracking echocardiography (2D-STE)

2D-STE was performed offline in the left apical four-chamber view to analyze the left atrial function by only one operator. Three sets of two-dimensional echocardiographic images that stored in DICOM format (Mindray, M9, Shenzhen, P.R. China) were analyzed. The complete myocardial region of interest (ROI) of the LA was defined by the endocardial border and the epicardial border. Using the left apical four-chamber view, ROI tracing started at the mitral annulus, along the endocardial border, extrapolated across the pulmonary veins and/or the LA appendage orifice, and ended on the opposite side of the mitral annulus using the point-and-click method. An adjustable ROI with a width of 2 mm was used. The size and shape of ROI were then manually adjusted by the operator to account for the LA wall thickness. The strain was analyzed from three consecutive cardiac cycles. The strain curve, LA volume including LA EDV, LA ESV and LA EF were automatically computed by the offline software of the ultrasound machine.

Global longitudinal strain was used to assess LA myocardial deformation as left atrial longitudinal strain (LAS) and strain rate (LASR) (Badano et al., 2018). LA deformation can be divided into 3 phases including reservoir, conduit, and contract phases. LAS and LASR were reported separately for each phase by calculating the difference between two measurement points on the strain curve. The left ventricular end-diastole was set as the reference for zero strain. LAS result was expressed as a percentage, whereas LASR was expressed as 1/s.

Definitions of LAS in each LA deformation phases (Badano et al., 2018)

1. LASr = strain during the reservoir phase, measured as the difference in strain values at ventricular end-diastole and at mitral valve opening (positive value)
2. LAScd = strain during conduit phase, measured as the difference of the strain values at mitral valve opening and at the onset of atrial contraction (negative value)

3. LASct = strain during the contraction phase, measured as the difference of the strain values at the beginning of atrial contraction and at ventricular end-diastole (negative value)

Definitions of the peaks in the LASR curve in each LA deformation phases (Badano et al., 2018)

1. pLASRr = peak strain rate during the reservoir phase (positive value)
2. pLASRcd = peak strain rate during the conduit phase (negative value)
3. pLASRct = peak strain rate during the contraction phase (negative value)

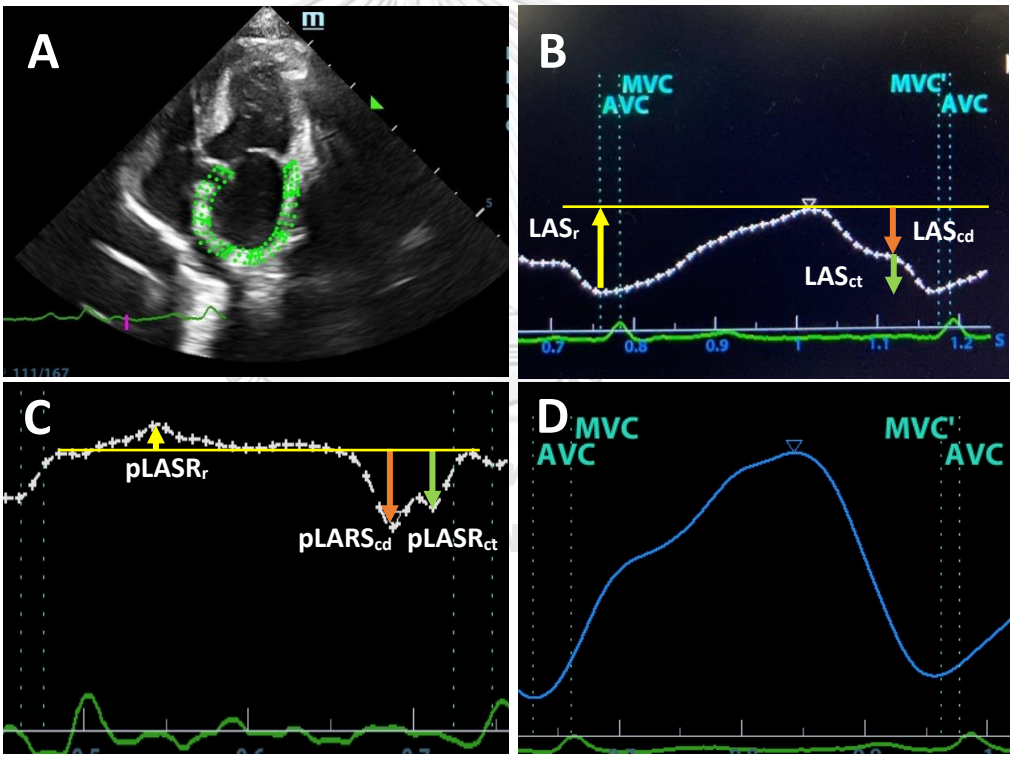

Figure 2 Using two-dimensional speckle tracking echocardiography (A) The complete myocardial region of interest of the left atrium (B) Left atrial longitudinal strain curve (C) Left atrial longitudinal strain rate (D) Left atrial volume measurement

Statistical Analysis

The commercial software SPSS version 22 (Inc, Chicago, IL, USA.) was used for statistical analysis. Descriptive statistical analysis was performed for cat characteristics including breed and sex as percentage (%). Continuous data were tested for normality using the Kolmogorov-Smirnov test. Initial descriptive statistics included mean ± standard deviation (SD) for normally distributed data and median and interquartile range (IQR) for non-normally distributed data. Differences between the cardiogenic ATE, non-cardiogenic ATE and normal groups were compared using the Kruskal-Wallis test. Spearman's rho (r_s) was used to test the correlation coefficients of the association between LASr and other continuous data of entire samples. The degree of the Spearman's rho correlation coefficient was determined as follows: r_s >0.80 means very strong correlation, r=0.60-0.79 means strong correlation; r=0.40-0.59 means moderate correlation; r <0.40 means weak correlation (Shevlyakov and Oja, 2016).

Logistic regression was conducted to develop the predictive model for the occurrence of ATE in the cat population. All categorical factors with a p-value > 0.2 assessed by the univariate logistic regression were submitted. Multicollinearity and interaction between parameters were assessed. As the multicollinearity increases, standard errors increase and the likelihood of model convergence decreases. Parameters with high multicollinearity were excluded. The backward Wald elimination method was used to generate the final model.

Goodness-of-fit statistics were performed to determine whether the model adequately described the data. The overall percentage from the classification table, the Hosmer-Lemeshow test, and the area under the Receiver Operating Characteristic Curve were used. The Hosmer-Lemeshow statistic indicates poor fit when the p-value is less than 0.05.

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The area under the Receiver Operating Characteristic Curve of 0.5 indicates no discrimination, 0.7 to 0.8 is considered acceptable, 0.8 to 0.9 is considered excellent, and more than 0.9 is considered outstanding.

The model had to meet the majority of the statistical model assumption with the largest Nagelkerke r^2. The goodness of the statistical model assumption for this study was (1) the overall percentage from the classification table >70%, (2) the Hosmer-Lemeshow test was not significant ($p > 0.05$), and (3) the area under the Receiver Operating Characteristic Curve was > 0.80 (21). A p-value <0.05 was considered significant. For clinical applicability, we converted LASr to categorical data to obtain the best cut-off value for LASr.

Reliability of measurements was determined by using data from six randomly selected cats. The LAS and LASR were used to evaluate the intra- and inter-observer coefficient of variation (CV = standard deviation/mean). The intra-observer coefficient of variation was calculated from 3 repeated examinations of each cat on different days (at least 3 days apart) by the same examiner. The inter-observer coefficient of variation was calculated from measurements performed by two different investigators with different levels of experience. The percent CV < 15% was accepted in this study (Indrayan, 2016).

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Experimental design

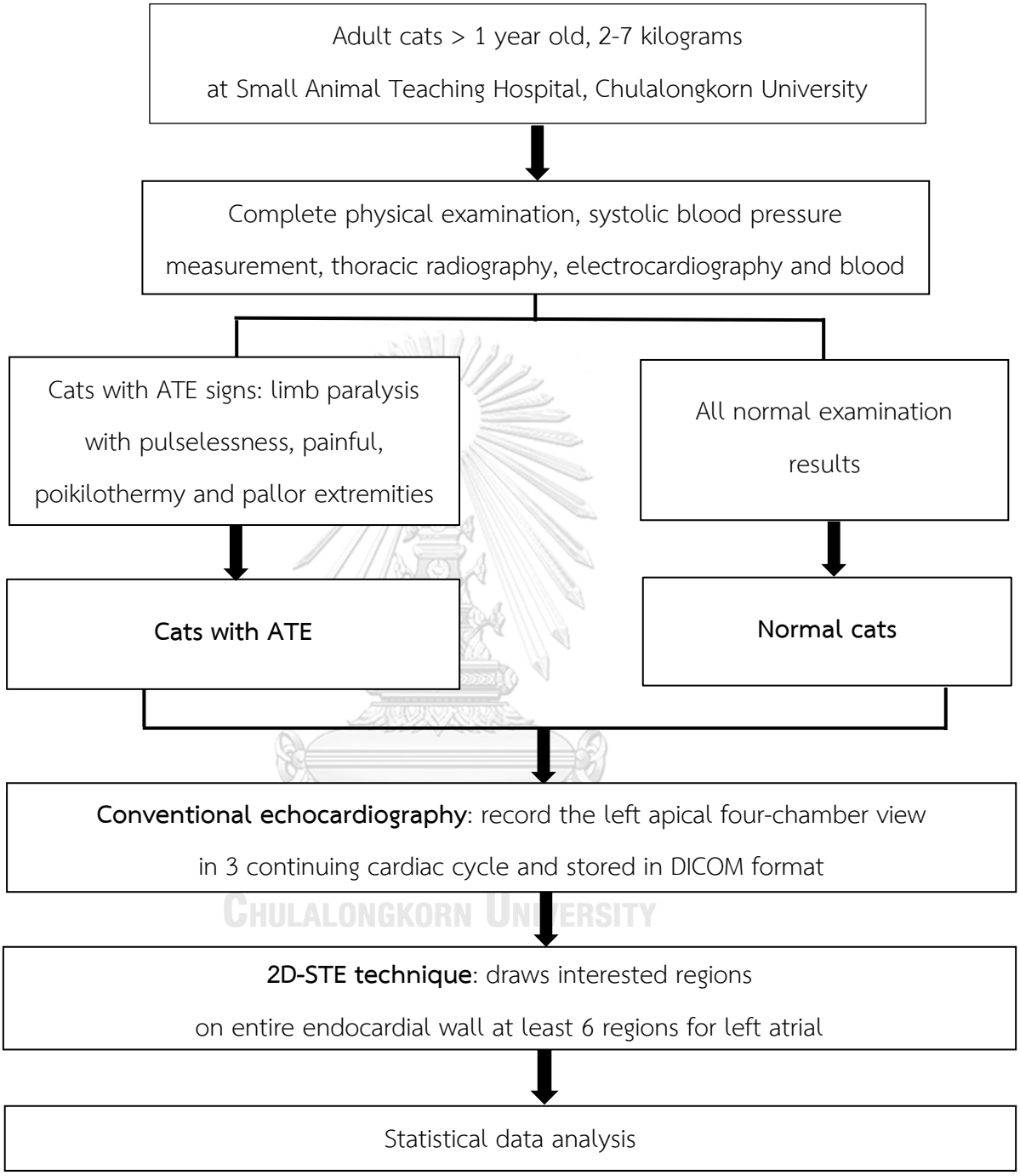

Figure 3 Experimental design of this study

CHAPTER IV

RESULTS

Part I: General Information

1.1 Signalment and physical examination findings

Forty-four cats participated in this study, including 21 cats with ATE, classified as 15 (76.43%) CATE and 6 (23.57%) non-CATE, and 23 normal cats. The general characteristics of the CATE, non-CATE and normal cats were analyzed descriptively and presented in Table 1 and Table 2. The CATE group included mainly male (80%) and DSH (73.3%). The most common cardiomyopathy in the CATE group was HCM (80%). The body weight of the CATE group was significantly different from that of the non-CATE group. The vertebral heart score (VHS) of the CATE group was significantly different from that of the normal group. The heart rate (HR) of the non-CATE group was significantly higher than that of the normal group. However, age and systolic blood pressure (SBP) were not different among the three groups. Ten cats (66.7%) of in the CATE group had congestive heart failure, 7 cats (46.7%) had pulmonary edema and 3 cats (20%) had pleural effusion. None of the non-CATE cats had SEC and thrombus. In non-CATE group, 1 cat (16.7%) had pleural effusion. Two cats in the CATE group had cardiac arrhythmias, one cat with atrial fibrillation and one cat with ventricular premature complex. SEC was found in 9 cats (60%) and thrombus within LA were found in 3 cats (20%) of in the CATE group. Two cats (13.3%) of in the CATE group and 5 cats (83.3%) of in the non-CATE group were alive for more than 7 days.

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Table 1 Descriptive analysis of general characteristics of cardiogenic arterial thromboembolism (CATE), non-cardiogenic arterial thromboembolism (non-CATE) and normal groups

Criteria	CATE (n=15)	Non-CATE (n=6)	Normal (n=23)
Sex			
Male	12 (80%)	3 (50%)	15 (65.2%)
Female	3 (20%)	3 (50%)	8 (34.8%)
Breed			
DSH	11 (73.3%)	4 (66.8%)	6 (26.09%)
Persian	1 (6.7%)	1 (16.6%)	3 (13.04%)
Mixed	2 (13.3%)	-	-
Maine coon	1 (6.7%)	-	1 (4.35%)
Scottish	-	1 (16.6%)	10 (43.48%)
Himalayan	-	-	1 (4.35%)
Bengal	-	-	1 (4.35%)
American shorthair	-	-	1 (4.35%)
Heart disease			
HCM	12 (80%)	Normal cardiac structure	Normal cardiac structure
RCM	2 (13.3%)		
UCM	1 (6.7%)		

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Abbreviations: DSH: domestic shorthair; HCM: hypertrophic cardiomyopathy; RCM: restrictive cardiomyopathy; UCM: unclassified cardiomyopathy

Table 2 Medians of general characteristics of cardiogenic arterial thromboembolism (CATE), non-cardiogenic arterial thromboembolism (non-CATE) and normal groups

Criteria	Cardiogenic ATE (n=15)	Non cardiogenic ATE (n=6)	Normal (n=23)	p-value
Age (years)	5 (4, 8)	3.0 (1.75, 4.0)	4 (1, 6)	0.08
Weight (kg)	4.65 (4.16, 5.09) [c]	2.5 (3.5, 3.75)	4.2 (3.4, 5.6)	0.031*
VHS	8.45 (7.88, 9,12) [a]	7.4 (7.0, 7.5)	7.5 (6.8, 8.2)	0.009*
SBP (mmHg)	120 (112.5, 148.75)	100 (96.25, 140.5)	130 (119, 137)	0.404
HR (bpm)	203 (181, 230)	226.5 (209.0, 251.0) [b]	196 (185, 208)	0.025*

Abbreviations: bpm: beats per minute; HR: heart rate; kg: kilograms; SBP: systolic blood pressure; VHS: vertebral heart score

All measurements were expressed as median (Q1, Q3) and compared with the Kruskal Willis test

*The p-value <0.05 represent the significant difference between these 3 groups

[a] indicates the statistically significant difference of pairwise comparison between the CATE groups and the normal group.

[b] indicates the statistically significant difference of pairwise comparison between the non-CATE group and the normal group.

[c] indicates the significant difference of the pairwise comparison between the CATE group and the non-CATE group.

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1.2 Complete blood count and blood chemistry profile values

The medians of the complete blood counts of the CATE, non-CATE and normal groups are presented in Table 3. The white blood cell count (WBC), platelet count and total T4 of the CATE group were significantly different from the normal group. The red blood cell count (RBC), hematocrit (HCT) and total protein (TP) of the non-CATE group were significantly lower than those of the normal group. In addition, alanine aminotransferase (ALT) and blood urea nitrogen (BUN) were significantly increased in both CATE and non-CATE groups compared with the normal group.

Table 3 Blood results of cardiogenic arterial thromboembolism (CATE), non-cardiogenic arterial thromboembolism (non-CATE) and normal groups

Criteria	CATE (n=15)	Non-CATE (n=6)	Normal (n=23)	p-value
Complete blood count				
RBC (x10^6 cell/mm^3)	8.2 (7.32, 9.72)	6.23 (4.98, 6.99) [b]	9.33 (8.81, 10.36)	<0.001*
HCT (%)	35.1 (29.7, 39.2)	26.35 (23.68, 28.63) [b]	36.5 (33, 39.1)	0.003*
WBC (x10^3 cell/µL)	16.81 (9.62, 17.84) [a]	12.17 (5.3, 32.94)	7.46 (5.82, 10.17)	0.002*
Platelet (x10^3 cell/µL)	111 (87.5, 129.5) [a]	102.5 (48.5, 258.5)	143 (108, 226)	0.034*
Blood chemistry				
ALT (U/L)	289.5 (129.25, 704.25) [a]	312.0 (223.25, 443.25) [b]	59 (47, 71)	<0.001*
ALP (U/L)	37 (26.5, 55.75)	58.50 (17.75, 69.25)	26 (22, 46)	0.336
Creatinine (mg/dl)	1.3 (1.15, 1.75)	1.05 (0.90, 1.73)	1.1 (1.1, 1.3)	0.113
BUN (mg/dl)	31.3 (25.9, 48.25) [a]	59.65 (23.53, 112.43) [b]	22.2(18.5, 25.5)	<0.001*
TP (g/dl)	8.4 (6.8, 8.8)	6.40 (5.63, 6.55) [b]	7.5 (7.3, 7.8)	0.002*
Albumin (g/dl)	2.95 (2.78, 3.5)	2.80 (2.40, 3.10)	2.9 (2.8, 3.1)	0.487
Total T4 (µg/dl)	1.2 (0.95, 1.95) [a]	1.30 (1.00, 3.18)	2.2 (1.8, 3)	0.023*

Abbreviations: RBC: red blood cell; HCT: hematocrit; WBC: white blood cell; ALT: alanine aminotransferase; ALP: alkaline phosphatase; BUN: blood urea nitrogen

All measurements were expressed as median (Q1, Q3) and compared with the Kruskal Willis test.

*The p-value <0.05 represents the significant difference between these 3 groups.

[a] indicates the significant difference of the pairwise comparison between the CATE and normal groups.

[b] indicates the significant difference of the pairwise comparison between the non-CATE and normal groups.

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Part II: Echocardiography

2.1 Conventional echocardiography

The measurements of conventional echocardiography including M-mode, Doppler and tissue Doppler imaging of CATE, non-CATE, and normal groups are summarized in Table 4. LA diameter, LA/Ao, LVPWd, MV E/A, PV A dur, LAD, LAS, and MV E/Ea were significantly increased in the CATE group compared with the normal group. Ao diameter, LVPW%, LV FS, LV EF, MV A vel, MV A PG, Pvein S vel, Pvein D vel, LA FS, LAA PG, LAA FLOW assessed by conventional echocardiography, and Sa, Ea, and Aa assessed by TDI technique were significantly decreased in the CATE group compared with the normal group. Whereas LA diameter, IVSs and LVPWs were significantly higher in the CATE group than in the non-CATE group. LAA flow, LAA PG and Aa were significantly lower in the CATE group than those in the non-CATE group ($p<0.05$). MV Ea/Aa was decreased and MV E/Ea was significantly increased in the non-CATE group compared to the normal group.

Table 4 Conventional echocardiography results of cardiogenic arterial thromboembolism (CATE), non-cardiogenic arterial thromboembolism (non-CATE) and normal groups

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Criteria	CATE (n=15)	Non-CATE (n=6)	Normal (n=23)	p-value
Two-dimensional measurement				
LA diameter (cm)	1.52 (1.38, 2.07) [a, c]	1.18 (1.02, 1.27)	1.12 (1.02, 1.21)	<0.001*
Ao diameter (cm)	0.72 (0.65, 0.79) [a]	0.72 (0.64, 0.94)	0.85 (0.76, 0.97)	0.019*
LA/AO	2.29 (1.90, 3.15) [a]	1.52 (1.30, 1.76)	1.25 (1.15, 1.44)	<0.001*

Criteria	CATE (n=15)	Non-CATE (n=6)	Normal (n=23)	p-value
M-mode measurement				
IVSd (cm)	0.53 (0.41, 0.69)	0.45 (0.41, 0.52)	0.45 (0.4, 0.5)	0.162
IVSs (cm)	0.88 (0.63, 0.96) [c]	0.63 (0.53, 0.66)	0.69 (0.63, 0.77)	0.012*
LVIDd (cm)	1.37 (1.25, 1.59)	1.34 (1.26, 1.37)	1.41 (1.31, 1.46)	0.474
LVIDs (cm)	0.78 (0.43, 0.93)	0.66 (0.57, 0.73)	0.57 (0.44, 0.7)	0.206
LVPWd (cm)	0.62 (0.51, 0.67) [a]	0.44 (0.36, 0.5)	0.43 (0.39,0.46)	0.001*
LVPWs (cm)	0.78 (0.75, 0.91) [c]	0.65 (0.61, 0.78)	0.71 (0.63, 0.8)	0.042*
IVS%	43.17 (27.65, 73.78)	37.84 (32.25, 57.48)	53.27 (43.48, 71.87)	0.38
LVPW%	43.33 (24.49, 50.0) [a]	53.26 (40.01, 79.01)	74.23 (59.72, 84.38)	<0.001*
LV FS (%)	46.25 (39.29, 53.5) [a]	49.89 (46.14, 56.91)	60.59 (50.83, 66.46)	0.012*
LV EDV (ml)	4.99 (3.74, 7.00)	4.45 (3.87, 4.78)	5.13 (4.23, 5.67)	0.466
LV ESV (ml)	1.06 (0.2, 1.71)	0.67 (0.43, 0.86)	0.45 (0.21, 0.78)	0.218
LV SV (ml)	4.37 (2.97, 5.88)	3.79 (3.26, 4.09)	4.78 (3.73, 5.17)	0.221
LV EF (%)	81.49 (73.56, 88.41) [a]	84.65 (81.25, 89.96)	91.4 (85.41, 95.07)	0.017*
Doppler Measurement				
MV E vel (cm/s)	74.34 (47.57, 94.21)	92.16 (71.66, 105.48)	75.38 (65.33, 86.39)	0.197
MV E PG (mmHg)	2.21 (0.91, 3.58)	3.4 (2.1, 4.5)	2.27 (1.71, 2.99)	0.197
MV A vel (cm/s)	36.41 (30.7, 50.46) [a]	40.80 (8.76, 64.89)	59.62 (52.31, 68.38)	0.001*
MV A PG (mmHg)	0.58 (0.39, 1.04) [a]	1.17 (0.55, 1.79)	1.42 (1.09, 1.87)	0.001*
MV E/A	1.67 (1.35, 2.68) [a]	1.81 (1.41, 2.04)	1.19 (1.1, 1.38)	0.011*
IVRT (s)	0.05 (0.04, 0.06)	0.05 (0.04, 0.05)	0.043 (0.04, 0.049)	0.225
AV vel (cm/s)	81.04 (63.72, 105.48)	77.11 (66.04, 101.66)	90.14 (81.59, 97.67)	0.629
AV PG (mmHg)	2.62 (1.62,4.46)	2.38 (1.79, 4.14)	3.25 (2.67, 3.81)	0.629
PV vel (cm/s)	82.44 (56.94, 95.67)	89.38 (83.89, 103.89)	86.45 (75.69, 92.68)	0.352
PV PG (mmHg)	2.72 (1.29, 3.66)	3.2 (2.82, 4.32)	2.99 (2.29, 3.44)	0.352
Pvein S vel (cm/s)	35.7 (23.25, 42.84) [a]	34.98 (28.74, 46.19)	53.19 (42.84, 59.97)	0.001*
Pvein D vel (cm/s)	28.7 (23.28, 37.13) [a]	32.68 (22.31, 39.85)	41.05 (37.84, 47.37)	0.01*
Pvein A vel (cm/s)	14.82 (13.15, 21.69)	12.14 (9.36, 22.51)	16.58 (13.57, 19.99)	0.472
Pvein A dur (s)	0.06 (0.05, 0.08) [a]	0.05 (0.04, 0.07)	0.045 (0.043, 0.057)	0.03*
Pvein S/D	1.19 (0.87, 1.54)	1.22 (1.00, 1.42)	1.32 (1.17, 1.46)	0.823

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Criteria	CATE (n=15)	Non-CATE (n=6)	Normal (n=23)	p-value
Left atrial measurement				
LAD (mm)	18.7 (15.05, 22.95) [a, c]	11.45 (10.63, 14.75)	12.2 (10.9, 14)	<0.001*
LAS (mm)	16.7 (13.4, 21.3) [a, c]	9.00 (8.10, 9.90)	8.5 (7.7, 9.5)	<0.001*
LA FS (%)	9.73 (8.24, 13.89) [a]	21.79 (20.20, 23.23)	27.17 (25.23, 34.23)	<0.001*
LAA FLOW (cm/s)	18.26 (13.75, 21.25) [a, c]	52.86 (42.16, 56.25)	35.88 (31.18, 43.13)	0.001*
LAA PG (mmHg)	0.135 (0.082, 0.188) [a, c]	1.12 (0.71, 1.26)	0.53 (0.39, 0.75)	0.001*
Tissue Doppler Imaging				
Sa (cm/s)	5.46 (5.07, 6.86) [a]	7.75 (6.96, 8.55)	8.92 (7.75, 10.33)	<0.001*
Ea (cm/s)	6.96 (6.26, 8.45) [a]	10.63 (8.0, 12.57)	11.78 (10.76, 13.81)	<0.001*
Aa (cm/s)	5.51 (4.65, 7.6) [a, c]	10.33 (6.63, 13.37)	7.95 (6.56, 9.04)	0.005*
MV Ea/Aa	1.36 (0.69, 1.63)	1.09 (0.70, 1.31) [b]	1.47 (1.35, 1.78)	0.043*
MV E/Ea	9.01 (6.63, 17.04) [a]	8.95 (8.26, 11.09) [b]	6.05 (5.07, 7.31)	<0.001*

Abbreviations: Aa: myocardial velocity associated with atrial contraction; Ao: aorta; AV: atrial valve; dur: duration; E/A: mitral inflow peak E-to-A wave velocities ratio; Ea: early diastolic myocardial relaxation velocity; EDV: LV end-diastolic volume; EF: ejection fraction; ESV: LV end-systolic volume; FS: fractional shortening; HR: heart rate; IVRT: isovolumic relaxation time; IVSd: interventricular septum in diastole; IVSs: interventricular septum in systole; IVS%: percentage of fractional thickening of interventricular septum; LA: left atrial; LA FS: left atrial fractional shortening; LAA FLOW: left atrial appendage flow velocity; LAA PG: left atrial appendage maximal pressure gradient; LAD: left atrial diameter in LA diastole; LAS: left atrial diameter in LA systole; LA/Ao: left atrium to aorta ratio; LV: left ventricle; LVIDd: left ventricular internal diameter in diastole; LVIDs: left ventricular internal diameter in systole; LVPWd: left ventricular posterior wall in end-diastole; LVPWs: left ventricular posterior wall in systole; LVPW%: percentage of fractional thickening of left ventricular posterior wall; SV: stroke volume; MV A: mitral valve peak A wave, MV E: mitral valve peak E wave; MV Ea/Aa: mitral inflow Ea wave-to-Aa wave of tissue doppler; MV E/Ea: mitral inflow E wave-to-tissue doppler Ea wave; PG: maximal pressure gradient; PV: pulmonic valve; Pvein A: pulmonary venous A wave; Pvein D: pulmonary venous diastolic wave; Pvein S: pulmonary venous systolic wave; Pvein S/D: pulmonary venous peak systolic-to-diastolic ratio; Sa: systolic myocardial velocity; vel: peak velocity; Vmax: maximal velocity

All measurements were expressed as median (Q1, Q3) and compared with the Kruskal Willis test.

*The p-value <0.05 represents the significant difference between these 3 groups.

[a] indicates the statistically significant difference of pairwise comparison between the CATE groups and the normal group.

[b] indicates the statistically significant difference of pairwise comparison between the non-CATE group and the normal group.

[c] indicates the significant difference of the pairwise comparison between the CATE group and the non-CATE group.

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2.2 Two-dimensional speckle tracking echocardiography

Values derived from two-dimensional speckle-tracking echocardiography for left atrial strain, strain rate, and volume values in the CATE, non-CATE and normal groups are shown in Table 5. LASr and pLASRr of the CATE group were significantly less positive than those of the normal group. In addition, LAScd and pLASRcd were significantly less negative than those in the normal group. While LASct and pLASRct in the CATE group were significantly less negative than those in the CATE group compared to the non-CATE and normal groups. LA EDV and LA ESV of the CATE group were also significantly greater than those of the normal group. Moreover, LA EF in the CATE group was significantly lower than that in the normal group.

Table 6 also shows the values for left atrial strain, strain rate, and volume in the HCM cats with ATE, non-CATE and normal groups. These results were quite similar to the results of the CATE group compared with the non-CATE and normal groups except that the pLASRcd of the HCM with ATE was significantly less negative than that the non-CATE group, and LA EDV was not significantly different from that of the HCM with ATE and the non-CATE group.

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Table 5 Left atrial strain, strain rate and volume derived from two-dimensional speckle tracking echocardiography in cardiogenic arterial thromboembolism (CATE), non-cardiogenic arterial thromboembolism (non-CATE) and normal groups

Criteria	CATE (n=15)	Non-CATE (n=6)	Normal (n=23)	p-value
LASr %	3.30 (2.23, 4.86) [a]	16.10 (3.95, 25.09)	20.72 (18.68, 25.06)	<0.001*
LAScd %	-1.57 (-3.63, -1.32) [a]	-6.19 (-9.08, -1.46)	-12.92 (-15.08, -10.73)	<0.001*
LASct %	-1.49 (-2.99, -0.89) [a, c]	-7.86 (-14.43, -2.54)	-8.62 (-12.92, -6.30)	<0.001*
pLASRr (1/s)	0.6 (0.48, 1.21) [a]	1.78 (0.63, 2.53)	2.04 (1.76, 2.64)	<0.001*
pLASRcd (1/s)	-0.49 (-0.97, -0.30) [a]	-1.85 (-10.57, -0.73)	-4.25 (-6.26, -3.35)	<0.001*
pLASRct (1/s)	-0.19 (-0.61, -0.08) [a, c]	-2.49 (-5.60, -0.65)	-2.48 (-3.07, -1.66)	<0.001*
GS %	0.89 (-1.02, 2.71)	15.30 (1.64, 20.97)	10.94 (-5.18, 21.18)	0.082
LA EDV avg (ml)	7.56 (4.29, 13.27) [a, C]	2.28 (1.55, 3.81)	2.04 (1.28, 2.50)	<0.001*
LA ESV avg (ml)	7.02 (3.7, 12.81) [a]	1.66 (1.24, 3.30)	1.30 (0.84, 1.47)	<0.001*
LA EF avg %	7.6 (4.0, 9.91) [a]	19.16 (12.40, 34.72)	35.99 (32.99, 41.04)	<0.001*
TPSD (s)	12.74, (3.16, 49.21)	32.29 (9.29, 49.25)	25.99 (8.05, 43.93)	0.751

Abbreviations: avg: average; cd: during LA conduit phase; ct: during LA contraction phase; EDV: end-diastolic volume; EF: ejection fraction; ESV: end-systolic volume; GS%: global strain; TPSD: total peak systolic dispenser; LAS: left atrial global longitudinal strain; pLASR: peak of left atrial strain rate; r: during LA reservoir phase

*The p-value <0.05 represent the significant difference between these 3 groups

[a] indicates the statistically significant difference of pairwise comparison between CATE and normal group

[c] indicates the significant difference of the pairwise comparison between the CATE group and the non-CATE group.

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Table 6 Left atrial strain, strain rate and volume derived from two-dimensional speckle tracking echocardiography in hypertrophic cardiomyopathy (HCM) cats with arterial thromboembolism (ATE), non-cardiogenic arterial thromboembolism (non-CATE) and normal groups

Criteria	HCM with ATE (n=12)	Non-CATE (n=6)	Normal (n=23)	p-value
LASr %	3.18 (2.07, 4.77) [a]	16.10 (3.95, 25.09)	20.72 (18.68, 25.06)	<0.001*
LAScd %	-1.49 (-1.81, -0.91) [a]	-6.19 (-9.08, -1.46)	-12.92 (-15.08, -10.73)	<0.001*
LASct %	-1.52 (-2.87, -0.91) [a, c]	-7.86 (-14.43, -2.54)	-8.62 (-12.92, -6.30)	<0.001*
pLASRr (1/s)	0.58 (0.35, 1.13) [a]	1.78 (0.63, 2.53)	2.04 (1.76, 2.64)	<0.001*
pLASRcd (1/s)	-0.43 (-0.63, -0.22) [a, c]	-1.85 (-10.57, -0.73)	-4.25 (-6.26, -3.35)	<0.001*
pLASRct (1/s)	-0.20 (-0.31, -0.09) [a, c]	-2.49 (-5.60, -0.65)	-2.48 (-3.07, -1.66)	<0.001*
GS %	0.32 (-1.34, 1.81)	15.30 (1.64, 20.97)	10.94 (-5.18, 21.18)	0.082
LA EDV avg (ml)	8.02 (4.59, 12.55) [a]	2.28 (1.55, 3.81)	2.04 (1.28, 2.50)	<0.001*
LA ESV avg (ml)	7.33 (4.04, 12.12) [a]	1.66 (1.24, 3.30)	1.30 (0.84, 1.47)	<0.001*
LA EF avg %	6.77 (3.61, 12.73) [a]	19.16 (12.40, 34.72)	35.99 (32.99, 41.04)	<0.001*
TPSD (s)	12.06, (2.89, 47.54)	32.29 (9.29, 49.25)	25.99 (8.05, 43.93)	0.685

Abbreviations: avg: average; cd: during LA conduit phase; ct: during LA contraction phase; EDV: end-diastolic volume; EF: ejection fraction; ESV: end-systolic volume; GS%: global strain; TPSD: total peak systolic dispenser; LAS: left atrial global longitudinal strain; pLASR: peak of left atrial strain rate; r: during LA reservoir phase

*The p-value <0.05 represent the significant difference between these 3 groups

[a] indicates the statistically significant difference of pairwise comparison between CATE and normal group

[c] indicates the significant difference of the pairwise comparison between the CATE group and the non-CATE group.

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Part III: Correlation

The correlations between LASr and echocardiographic values assessed by conventional echocardiography and 2D-STE in entire population are shown in the Table 7. The correlation analysis of LASr in all cats showed a very strong negative correlation with LAScd, LASct and pLASRcd ($p< 0.01$). LASr had a strong positive correlation with Sa, LA FS, pLASRr and LA EF; conversely, it had a strong negative correlation with pLASRct, LA diameter, LA/Ao, LAS, LA EDV and LA ESV. LASr showed a moderate negative correlation with LVPWd, LAD and ALT and a positive moderate correlation with FS, EF, LVPW%, A wave velocity and pressure gradient, pulmonary venous S wave and D wave velocities, pulmonary venous A wave duration, Ea, Aa, LAA flow velocity and pressure gradient. LASr had a weak negative correlation with age, LVIDs, LVPWs, LV ESV, MV E/Ea and WBC, and also a weak positive correlation with PV Vmax, PV PGmax and %GS.

Table 7 Correlation between LASr and and echocardiographic values assessed by conventional echocardiography and 2D-STE in entire population (n=44)

Parameters	LASr	
	r_s	p-value
Signalment		
Age	-0.310*	0.041
Weight	-0.238	0.124
Conventional Echocardiography		
LA diameter	-0.714**	<0.001
AO diameter	0.257	0.119
LA/Ao	-0.682**	<0.001
IVSd	-0.28	0.065
IVSs	-0.25	0.101
LVIDd	-0.082	0.597
LVIDs	-0.304*	0.045
LVPWd	-0.574**	<0.001
LVPWs	-0.353*	0.019

Parameter	LASr	
	r_s	p-value
Conventional Echocardiography		
IVS%	0.094	0.554
LVPW%	0.570**	<0.001
FS	0.424**	0.004
HR	-0.187	0.23
LV EDV	-0.114	0.461
LV ESV	-0.305*	0.044
SV	0.018	0.909
EF	0.409**	0.006
MV E vel	0.123	0.432
MV E PG	0.124	0.427
MV A vel	0.423**	0.008
MV A PG	0.531**	0.001
MV E/A	-0.312	0.053
IVRT	-0.178	0.253
AV Vmax	0.218	0.182
AV Pgmax	0.218	0.182
PV Vmax	0.346*	0.031
PV Pgmax	0.343*	0.032
Pvein S Vel	0.515**	0.001
Pvein D Vel	0.447**	0.003
Pvein A Vel	0.105	0.517
Pvein A Dur	-0.422**	0.007
Pvein S/D	0.117	0.465
Sa	0.626**	<0.001
Ea	0.536**	<0.001
Aa	0.445**	0.004
MV Ea/Aa	0.07	0.663
MV E/Ea	-0.330*	0.033
LAD	-0.591**	<0.001
LAS	-0.622**	<0.001
LA FS	0.650**	<0.001
LAA FLOW	0.590**	0.001
LAA PG	0.585**	0.001

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Parameter	LASr	
	r_s	p-value
Complete blood count and blood chemistry		
RBC	0.297	0.056
HCT	0.049	0.759
WBC	-0.317*	0.041
PLATELET	0.272	0.081
ALT	-0.501**	0.001
ALP	-0.199	0.201
Creatinine	-0.297	0.056
BUN	-0.239	0.128
Total protein	-0.159	0.326
Albumin	-0.117	0.485
Total T4	0.231	0.204
Two-Dimentional Speckle Tracking		
LASr	1	.
LAScd	-0.873**	<0.001
LASct	-0.885**	<0.001
pLASRr	0.717**	<0.001
pLASRcd	-0.848**	<0.001
pLASRct	-0.764**	<0.001
GS %	0.359*	0.017
LA EDV avg (ml)	-0.719**	<0.001
LA ESV avg (ml)	-0.727**	<0.001
LA EF avg %	0.737**	<0.001
TPSD	0.044	0.778

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Abbreviations (Conventional echocardiography): Aa: myocardial velocity associated with atrial contraction; Ao: aorta; AV: atrial valve; dur: duration; E/A: mitral inflow peak E-to-A wave velocities ratio; Ea: early diastolic myocardial relaxation velocity; EDV: LV end-diastolic volume; EF: ejection fraction; ESV: LV end-systolic volume; FS: fractional shortening; HR: heart rate; IVRT: isovolumic relaxation time; IVSd: interventricular septum in diastole; IVSs: interventricular septum in systole; IVS%: percentage of fractional thickening of interventricular septum; LA: left atrial; LA FS: left atrial fractional shortening; LAA FLOW: left atrial appendage flow velocity; LAA PG: left atrial appendage maximal pressure gradient; LAD: left atrial diameter in LA diastole; LAS: left atrial diameter in LA systole; LA/Ao: left atrium to aorta ratio; LV: left ventricle; LVIDd: left ventricular internal diameter in diastole; LVIDs: left ventricular internal diameter in systole; LVPWd: left ventricular posterior wall in end-diastole; LVPWs: left ventricular posterior wall in systole; LVPW%: percentage of fractional thickening left ventricular posterior wall; SV: stroke volume; MV A: mitral valve peak A wave, MV E: mitral valve peak E wave; MV Ea/Aa: mitral inflow Ea

wave-to-Aa wave of tissue doppler; MV E/Ea: mitral inflow E wave-to-tissue doppler Ea wave; PG: maximal pressure gradient; PV: pulmonic valve; Pvein A: pulmonary venous A wave; Pvein D: pulmonary venous diastolic wave; Pvein S: pulmonary venous systolic wave; Pvein S/D: pulmonary venous peak systolic-to-diastolic ratio; Sa: systolic myocardial velocity; vel: peak velocity; Vmax: maximal velocity

Abbreviations (Complete blood count and blood chemistry): RBC: red blood cell; HCT: hematocrit; WBC: white blood cell; ALT: alanine aminotransferase; ALP: alkaline phosphatase; BUN: blood urea nitrogen

Abbreviations (Two-Dimentional Speckle Tracking Echocardiography): avg: average; cd: during LA conduit phase; ct: during LA contraction phase; EDV: end-diastolic volume; EF: ejection fraction; ESV: end-systolic volume; GS%: global strain; TPSD: total peak systolic dispenser; LAS: left atrial global longitudinal strain; pLASR: peak of left atrial strain rate; r: during LA reservoir phase

The significant correlation was assessed by Spearman's rho correlation coefficient.

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

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Part IV: Logistic regression

Logistic regression showed that a LASr value of less than 11% was a significant factor for the occurrence of ATE, with a crude odds ratio of 189.0 (95%CI: 15.73-2,269.86, p-value<0.001). The Hosmer-Lemeshow test showed the goodness of fit of the model to the data (p>0.05), the overall percentage of the classification table was 93.2%, the area under the ROC curve was 0.932 and Nagelkerke r^2 was 0.77 (Table 8).

The accuracy of using the 2D-STE derived LASr as a predictor of the occurrence of ATE in cats is presented in the Table 9. LASr < 11% has higher accuracy compared with other cut-off values.

Table 8 Logistic regression of LASr and arterial thromboembolism occurrence in cats (n=44)

Variables	Crude OR (95% CI) [a]	*p*-value	Overall percentage (%) [b]	AUC	Nagelkerke r^2
LASr < 4 %	42 (4.443-397.001)	0.001	84.1	0.782	0.470
LASr < 5/6/7/8/9/10 %	87.750 (11.088-649.451)	<0.001	90.9	0.899	0.686
LASr < 11 %	189.0 (15.73-2269.86)	<0.001	93.2	0.932	0.770

Abbreviations: AUC: area under the ROC curve; CI: confident interval; OD: odd ratio; LASr: left atrial global longitudinal strain during LA reservoir phase

[a] Crude odds ratio derived for Logistic Regression method with Hosmer-Lemeshow test (p > 0.05)

[b] Overall percentage from classification table

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Table 9 Accuracy of LASr from 2D-STE as diagnostic test for arterial thromboembolism occurrence in cats (n=44)

	LASr < 11 %	**LASr < 10 %**	**LASr < 4 %**
Sensitivity (%)	93.33	86.67	60.00
Specificity (%)	93.10	93.10	96.55
Prevalence (%)	36.36	34.09	22.73
Positive Predictive Value (%)	87.50	86.67	90.00
Negative Predictive Value (%)	96.43	93.10	82.35
Positive likelihood	13.53	12.57	17.40
Negative likelihood	0.07	0.14	0.41
Overall accuracy (%)	93.18	90.91	84.09

Abbreviations: LASr: left atrial global longitudinal strain during LA reservoir phase

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Part IV: The measurement variability

The intra-observer and inter-observer variability in the measurement of LASr, LAScd, LASct, pLASRr, pLASRcd and pLASRct using 2D-STE in 6 normal cats are summarized in Table 10. The intra-observer CV were acceptable for all parameters. However, only LASr was acceptable for the inter-observer CV result.

Table 10 Intra-observer and inter-observer coefficient of variation of strain and strain rate by using two-dimensional speckle tracking echocardiography (n=6)

Parameters	Intra-observer CV (%)	Inter-observer CV (%)
LASr	5.25	13.71
LAScd	4.17	21.62
LASct	10.8	23.18
pLASRr	9.47	17.08
pLASRcd	8.12	29.07
pLASRct	12.82	27.01

Abbreviations: cd: during LA conduit phase; ct: during LA contraction phase; CV: coefficient of variation; LAS: left atrial global longitudinal strain; pLASR: peak of left atrial strain rate; r: during LA reservoir phase

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CHAPTER V

DISCUSSION

Part I: General Information

1.1 Signalment and physical examination findings

Forty-four cats participated in this study. Male cats and HCM were found mainly in the CATE group, which is consistent with previous reports that HCM is the most common cardiomyopathy in cats (Luis Fuentes, 2020), including in Thailand (Surachetpong et al., 2020). Male cats are predisposed to HCM (Payne et al., 2013). In this study, domestic shorthair (DSH) cats were the majority of cats with ATE. This finding has been noted in previous studies (Smith et al., 2003, Surachetpong et al., 2020, Tosuwan and Surachetpong, 2021), which could simply be due to the large proportion of DSH in Bangkok (Hunprasit et al., 2019).

The median body weight of the CATE group was significantly higher than that of the non-CATE group. This was to the participating cat breeds such as Mainecoon, a bigger size breed, within the CATE group. The vertebral heart score (VHS) of the CATE group was significantly higher than that of the normal group. This was not surprising, as VHS measurement is a method that can be used to distinguish cardiomyopathy from non-cardiomyopathy in cats (Guglielmini et al., 2014, Guglielmini and Diana, 2015). Cats with a VHS greater than 8 are suspected of having cardiomyopathy. Echocardiography has been recommended to perform in this group of cats to confirm cardiomyopathy (Sleeper et al., 2013).

The heart rate (HR) of the non-CATE group was significantly higher than that of the normal group. This could be due to physiological changes resulting from pain, anxiety and stress (Hernandez-Avalos et al., 2019). The HR of the CATE group was also higher than that of the normal group, but did not reach the statistical significance. Age and systolic blood pressure (SBP) were not different between the

three groups. Two cats from the CATE group had cardiac arrhythmias, which may affect cardiac function and deformation. However, according to Badano (2018), LA function can be accurately measured in human patients with atrial fibrillation by using 2D-STE when left ventricular end-diastole is used as a reference for zero strain.

Approximately two-third of the CATE group had congestive heart failure, representing a much higher proportion of ATE cats with CHF in the HCM population of Payne (2015) study. In the non-CATE group, one of cats had pleural effusion secondary to cranial mediastinal mass that might be associated to FeLV infection. In addition, SEC was found in 60% of cats in the CATE group. A previous study suggested that the presence of SEC was the factor related to the occurrence of ATE in cats (Nokthong et al., 2020). None of the non-CATE group had SEC or thrombus within the heart. Source of thromboembolism in the non-CATE group was unidentified in this study. From 7 days after the onset of ATE, the non-CATE cats seemed to have a higher survival rate than the CATE cats. Previous studies have identified the presence of heart failure, SEC and increased LA/Ao as predictors of mortality in HCM cats (Payne et al, 2013; Payne et al., 2015; Peck et al., 2016).

1.2 Complete blood count and blood chemistry profile values

The white blood cell (WBC) count, platelet count and total T4 level of the CATE group were significantly different from the normal group. The WBC count was significantly higher than the normal group, but still within the normal reference values of the laboratory of the Faculty of Veterinary Science, Chulalongkorn University. The CATE group had slightly increased neutrophils with normal other lymphocytes, however the neutrophil to lymphocyte ratio (NLR) was 5.68. Related with previous study, increased NLR was supporting the association between ATE and inflammation (Fries et al., 2022). The CATE group may have more physiological responses to fear, pain, excitement or stress than normal cats. The CATE group had a lower platelet count than the normal group, which may be due to accelerated

utilization from vascular thrombosis in the CATE group (Cowell et al., 2008). Total T4 was lower in the CATE group than in the normal group, which could be due to a non-thyroidal illness syndrome causing low serum total T4 (Peterson et al., 2020).

The red blood cell count (RBC), hematocrit (HCT) and total protein (TP) of the non-CATE group were significantly lower than those of the normal group. The cats in the non-CATE group had underlying disease affecting RBC, HCT and TP including, internal bleeding due to scapular fracture, feline leukemia virus infection, Mycoplasma infection and post ovariohysterectomy. In addition, alanine aminotransferase (ALT) and blood urea nitrogen (BUN) were significantly elevated in the CATE and non-CATE groups compared with the normal group. ALT may be elevated due to liver injury caused by hepatic vascular embolism (Kang et al., 2015) and/or severe muscle damage resulting from ATE (Aroch et al., 2010). The elevated level of ALT was associated with an increased risk of death in cats with ATE (Surachetpong et al., 2020).

Part II: Echocardiography

2.1 Conventional echocardiography

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

In the comparisons of echocardiographic values between CATE, non-CATE and the normal group, differences were found only between the CATE and normal groups. The elevated LA diameter, LA/Ao, LVPWd, MV E/A, PV A dur, LAD, LAS, and MV E/Ea were increased in the CATE group compared to the normal group. Increased LA diameter, LA/Ao, LAD and LAS were associated with increased volume; in addition, decreased LA FS, LAA flow and LAA PG were also presented. This could be interpreted as impaired LA function in the CATE group compared with the normal group, which could be results of the increased LA pressure and myocardial dysfunction of cardiomyopathy (Linney et al., 2013 and Payne et al., 2013). The median LAA flow in the CATE group was 18.26 cm/s. A previous study has

demonstrated that LAA flow less than 20.0 cm/s is associated with an increased risk of SEC and ATE (Schober and Maerz, 2006). Increased LVPWd and decreased LVPW%, LV FS and LV EF are associated with myocardial thickening and impaired systolic function in cats with HCM (Wess et al., 2010). Diastolic function can be measured by LA size, mitral inflow and pulmonary vein flow with conventional echocardiography and TDI (Thomas and Weyman, 1991; Bright and Herrtage, 1999; Gavaghan et al., 1999; Schober et al., 2003; Wess et al., 2010; Linney et al., 2013). In the CATE group, MV A vel, MV A PG, Pvein S vel, Pvein D vel measured by spectral Doppler echocardiography, and Sa, Ea, and Aa measured by TDI technique were decreased with LA enlargement suggesting an impaired left ventricular diastolic function compared with the normal group.

The Increased LA diameter and decreased Aa, LAA flow and LAA PG of the CATE group demonstrated impaired LA function and increased risk of ATE occurrence (Schober and Maerz, 2006), which were not found in the non-CATE group; on other words, the non-CATE group had normal LA function as determined by conventional echocardiography. Ea/Aa was decreased in the non-CATE group compared with the normal group because Aa velocity of non-CATE was higher in the result. This related to the higher heart rate of the non-CATE group. In a previous study, it was found that Aa could be affected by heart rate. The higher the heart rate was, the higher the Aa values were (Simpson et al., 2009). The E wave can be strongly influenced by decreased preload in cats. The E wave of the non-CATE group was increased, while Ea was quite similar compared to the normal group. The increased E wave of the non-CATE could be due to increased preload from fluid supplementation during the emergency care (Sugimoto et al., 2019).

2.2 Two-dimensional speckle tracking echocardiography

In the CATE group, left atrial strain and strain rate were less positive during the reservoir phase but less negative during the conduction and contraction phases compared with the normal group. These results suggest a decrease in LA deformation in cats with CATE. These findings were similar to those of previous studies examining LA dysfunction in cats with cardiomyopathy (Abbott and MacLean, 2006; Linney et al., 2014; Kiatsilapanan and Surachetpong, 2020). However, no changes in LA deformation were detected in the non-CATE group, suggesting that the non-CATE group has normal LA deformation and the thrombus formation in the non-CATE group was not related to LA function. A decreased LA deformation derived from 2D-STE in the CATE group was associated with increased LA volume and decreased LA EF similar to previous studies (Smith and Dukes, 2012; Duler et al, 2019). Because ATE cats with HCM represented the largest sample within the CATE group, the values for left atrial strain, strain rate, and volume comparing of HCM cats with ATE to the non-CATE and normal groups were quite similar to the results of the CATE group. The pLASRcd of HCM with ATE was significantly less negative than that of the non-CATE group and normal group, suggesting a reduction of LA conduit function similar to human patients with HCM (Popa-Fotea et al., 2021).

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CHULALONGKORN UNIVERSITY

Part III: Correlation

The correlation analysis of LASr in all cats showed a very strong negative correlation with LAScd, LASct, pLASRcd, and pLASRct, revealing the relationship in all 3 LA deformation phases. The use of LASr assessed by 2D-STE could represent the overall LA deformation. In addition, LASr correlated well with conventional echocardiographic parameters to assess LA systolic function and to determine LA size, suggesting that LASr can be used as an indicator to assess LA function in cats. These results are consistent with a previous study (Kiatsilapanan and Surachetpong, 2020).

Part IV: Logistic regression

Logistic regression showed that a LASr value of less than 11% was a significant factor for the occurrence of ATE, with a crude odds ratio of 189.0 (95%CI: 15.73-2,269.86, p-value<0.001), as shown in Table 7. This was the first study in which LASr was used to predict the risk of occurrence of ATE. The accuracy of using the 2D-STE derived LASr as a diagnostic test for the occurrence of ATE in cats was presented in the Table 8. The result showed that the highest accuracy was found when use the cut-off of LASr < 11% compared with other cut-off values. on other words, LASr could predict the risk of occurrence of ATE occurrence in cat population.

Part IV: The measurement variability

Intra- and inter-observer variability in the measurement of LASr, LAScd, LASct, pLASRr, pLASRcd and pLASRct using 2D-STE in 6 normal cats was summarized in Table 9. Intra-observer CV were acceptable for all parameters. However, the inter-observer CV was acceptable only for LASr. This could be related to the tracking procedure. The variability of tracking procedure may be due to myocardial wall dropout at the pulmonary vein inlets, the nonadjustable height of the strain and strain rate curve height analyzed from the STE software and the difficulty of myocardial tracking of the STE software during rapid heart rate measurements. However, LASr may be representative of LA function in cats assessed with 2D-STE, similar to previous studies in cats (Kiatsilapanan and Surachetpong, 2020) and dogs (Caivano et al., 2016; Dermlim et al., 2019; Baron et al., 2021).

This study has some limitations. The first is the limitation of the 2D-STE software. The 2D-STE software was developed for humans, and we adapted it to be used in cats. Therefore, the curve height was sometimes very short and it was difficult to clearly distinguish the phases of strain and strain rate. In addition, there

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

are some variations of strain and strain rate measured from each software. Second, high quality images should be obtained for 2D-STE. High heart rate and breathing pattern of cats may affect the quality of images.

In conclusion, the left atrial longitudinal strain of reservoir phase derived by 2D-STE is repeatable and non-invasive technique to assess LA myocardial deformation in cats with ATE. By 2D-STE, impaired LA function was detected in cats with cardiogenic ATE, but not in cats with non-cardiogenic ATE. LASr <11% could predict the risk occurrence of ATE in the cat population.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

REFERENCES

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Abbott JA and MacLean HN. 2006. Two-Dimensional Echocardiographic Assessment of the Feline Left Atrium. J Vet Intern Med. 20(1). 111-119

Aroch I, Keidar I, Himelstein A, Schechter M, Shamir MH and Segev G. 2010. Diagnostic and prognostic value of serum creatine-kinase activity in ill cats: a retrospective study of 601 cases. J Feline Med Surg. 12(6):466-75.

Amundsen BH, Helle-Valle T, Edvardsen T, Torp H, Crosby J, Lyseggen E and Slørdahl SA. 2006. Noninvasive Myocardial Strain Measurement by Speckle Tracking Echocardiography. J Am Coll Cardiol. 47(4): 789.

Atkins CE, Gallo AM, Kurzman ID and Cowen P. 1992. Risk factors, clinical signs, and survival in cats with a clinical diagnosis of idiopathic hypertrophic cardiomyopathy: 74 cases (1985-1989). J Am Vet Med Assoc. 201(4): 613-618.

Badano LP, Kolias TJ, Muraru D, Abraham TP, Aurigemma G, Edvardsen T, D'Hooge J, Donal E, Fraser AG, Marfick T, Mertens L, Popescu BA, Sengupta PP, Lancellotti P, Thomas JD and Voigt J-U. 2018. Standardization of Left Atrial, Right Ventricular, and Right Atrial Deformation Imaging Using Two-Dimensional Speckle Tracking Echocardiography: A Consensus Document of the EACVI/ASE/Industry Task Force to Standardize Deformation Imaging. Eur Heart J Cardiovasc Imaging. 19(6): 591-600.

Black IW. 2000. Spontaneous echo contrast: where there's smoke there's fire. Echocardiography. 17(4): 373-382.

Blume GG, McLeod CJ, Barnes ME, Seward JB, Pellikka PA, Bastiansen PM and Tsang TS. 2011. Left atrial function: Physiology, assessment, and clinical implications. Eur J Echocardiogr. 12(6): 421–430.

Boon JA. 2011. Veterinary Echocardiography. 2nd ed. Ames: Wiley-Blackwell, 153–266.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Bright JM and Herrtage ME. 1999. Pulsed Doppler assessment of left ventricular diastolic function in normal and cardiomyopathic cats. J Am Anim Hosp Assoc. 35:285–291.

Buchanan JW, Baker GJ and Hill JD. 1966. Aortic embolism in cats: Prevalence, surgical treatment and electrocardiography. Vet Rec. 79(18): 496–505.

Caivano D, Rishniw M, Patata V, Giorgi ME, Birettoni F and Porciello F. 2016. Left atrial deformation and phasic function determined by 2-dimensional speckle tracking echocardiography in healthy dogs. J Vet. Cardiol. 18(2): 146-155.

Caivano D, Rishniw M, Birettoni F, Patata V, Giorgi ME and Porciello F. 2018. Left atrial deformation and phasic function determined by two-dimensional speckle-tracking echocardiography in dogs with myxomatous mitral valve disease. J Vet Cardiol. 20(2): 102-114.

Cameli M, Lisi M, Righini FM, Massoni A, Natali BM, Focardi M, Tacchini D, Geyer A, Curci V, Di Tommaso C, Lisi G, Maccherini M, Chiavarelli M, Massetti M, Tanganelli P and Mondillo S. 2013. Usefulness of atrial deformation analysis to predict left atrial fibrosis and endocardial thickness in patients undergoing mitral valve operations for severe mitral regurgitation secondary to mitral valve prolapse. Am J Cardiol. 15;111(4): 595-601.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Cowell R, Tyler RD, Meinkoth JH and DeNicola DB. 2008. Diagnostic Cytology and Hematology of the Dog and Cat. 3rd ed. St Louis: Elsevier - Health Sciences Division. 256

Barger AM. 2008. Diagnostic Cytology and Hematology of the Dog and Cat. In: Veterinary Clinical Pathology. 3rd ed. 37(2): 256

Baron Toaldo M, Bini M, Romito G, Guglielmini C, Cipone M and Contiero B. 2021. Left atrial speckle tracking echocardiography in clinically healthy dogs: Variability and prediction intervals. Vet J. 267:105577.

de Abreu CB, Muzzi RAL, de Oliveira LED, Schulien T, Coelho MR, Alves LA, Hirsch C, Dorneles EMS, Pinto AMBG, Barreto MSO, Muzzi LAL and Nogueira RB. 2021. Systolic dysfunction by two-dimensional speckle tracking echocardiography in dogs with parvoviral enteritis. J Vet Cardiol. 34:93-104.

Dermlim A, Nakamura K, Morita T, Osuga T, Nisa K, Sasaoka K, Leela-Arporn R, Sasaki N, Ohta H and Takiguchi M. 2019. The Repeatability and Left Atrial Strain Analysis Obtained via Speckle Tracking Echocardiography in healthy Dogs. J Vet Cardiol. 23:69-80.

Dermlim A, Osuga T, Nakamura K, Morita T, Nisa K, Sasaoka K, Leela-Arporn R, Nagata N, Tamura M, Sasaki N, Ohta H and Takiguchi M. 2019. Effect of acute volume loading on left atrial strain values derived from two-dimensional speckle tracking echocardiography in dogs. J Vet Med Sci. 81(7): 949-957.

Duler L, Scollan KF and LeBlanc NL. 2019. Left atrial size and volume in cats with primary cardiomyopathy with and without congestive heart failure. J Vet Cardiol. 24: 36-47.

Fries RC, Kadotani S, Stack JP, Kruckman L and Wallace G. 2022. Prognostic Value of Neutrophil-to-Lymphocyte Ratio in Cats With Hypertrophic Cardiomyopathy. Front Vet Sci. 9: 813524.

Galli E, Fournet M, Chabanne C, Lelong B, Leguerrier A, Flecher E, Mabo P and Donal E. 2016. Prognostic value of left atrial reservoir function in patients with severe aortic stenosis: a 2D speckle-tracking echocardiographic study. Eur Heart J Cardiovasc Imaging. 17(5): 533-41.

Gavaghan BJ, Kittleson MD, Fisher KJ, Kass PH and Gavaghan MA. 1999. Quantification of left ventricular diastolic wall motion by Doppler tissue imaging in healthy cats and cats with cardiomyopathy. Am J Vet Res. 60(12): 1478-86.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Gersh BJ, Maron BJ, Dearani JA, Fifer MA, Link MS, Naidu SS, Nishimura RA, Ommen SR, Rakowski H, Seidman CE, Towbin JA, Udelson JE and Yancy CW. 2011. 2011 ACCF/AHA guideline for the diagnosis and treatment of hypertrophic cardiomyopathy: a report of the American College of Cardiology Foundation/American Heart Association task force on practice guidelines. Circulation. 124(24): 783-831.

Glatz SA. 1997. Primer of Biostatistics. 4th ed. New York: McGraw-Hill Health Professions Division. 454.

Hanley JA and McNeil BJ. 1982. The meaning and use of the area under the receiver operating characteristic curve. Radiology. 143(1): 29–36.

Hansson K, Häggström J, Kvart C and Lord P. 2002. Left atrial to aortic root indices using two-dimensional and M-mode echocardiography in Cavalier King Charles spaniels with and without left atrial enlargement. Vet Radiol Ultrasound, 43(6): 568-575.

Hensel KO, Jenke A and Leischik R. 2014. Speckle-tracking and tissue-Doppler stress echocardiography in arterial hypertension: a sensitive tool for detection of subclinical LV impairment. Biomed Res Int. 2014: 472562.

Hogan DF. 2017. Arterial Thromboembolic Disease. In: Textbook of Veterinary Internal Medicine. Diseases of the Dog and Cat. 8th edition. Missouri: Elsevier. 3237-3238.

Hunprasit V, Tanrattana C and Pengpis S. 2019. Epidemiology of characteristics and risk factors for overweight in cats visiting an animal hospital in Bangkok, Thailand. TJVM. 49(2): 107-11.

Indrayan A. 2012. Medical Biostatistics, Third Edition. Third ed. In: Taylor & Francis, united state of America. 183-184.

Kang MH, Min SH, Kim SG, Lee CM and Park HM. 2015. Characteristic Clinical Features and Survival in Cats with Symptomatic Hypertrophic Cardiomyopathy. J Biomed Res. 16(4): 152-158.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Kauer F, Dalen BM, Michels M, Soliman OI, Vletter WB, Slegtenhorst M, Cate FJ and Geleijnse ML. 2013. Diastolic abnormalities in normal phenotype hypertrophic cardiomyopathy gene carriers: a study using speckle tracking echocardiography. Echocardiography. 30(5): 558–563.

Kiatsilapanan A and Surachetpong SD. 2020. Assessment of left atrial function in feline hypertrophic cardiomyopathy by using two- dimensional speckle tracking echocardiography. BMC Vet Res. 16(1): 344.

Klainbart S, Kelmer E, Vidmayer B, Bdolah-Abram T, Segev G and Aroch I. 2014. Peripheral and Central Venous Blood Glucose Concentrations in Dogs and Cats with Acute Arterial Thromboembolism. J Vet Intern Med. 28(5): 1513–1519.

Laste NJ and Harpster NK. 1995. A retrospective study of 100 cases of feline distal aortic thromboembolism: 1977-1993. J Am Anim Hosp Assoc. 31(6): 492-500.

Lecoq L, Moula N, Amory H, Rollin F and Leroux A. 2018. Two-dimensional speckle tracking echocardiography in calves: Feasibility and repeatability study. Journal of Veterinary Cardiology. 20(1): 45-54.

Leroux AA, Moonen M, Farnir F, Deleuze S, Sandersen C and Amory H. 2020. Two-dimensional speckle tracking echocardiography in goats: repeatability, variability, and validation of the technique using an exercise test and an experimentally induced acute ischemic cardiomyopathy. BMC Vet Res. 16(1): 56.

Li SY, Zhang L, Zhao BW, Yu C, Xu LL, Li P, Xu K, Pan M and Wang B. 2014. Two-dimensional tissue tracking: a novel echocardiographic technique to measure left atrial volume: comparison with biplane area length method and real time three-dimensional echocardiography. Echocardiography. 31(6): 716-26.

Lim P, Mitchell-Heggs L, Buakhamsri A, Thomas JD and Grimm RA. 2009. Impact of Left Ventricular Size on Tissue Doppler and Longitudinal Strain by

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Speckle Tracking for Assessing Wall Motion and Mechanical Dyssynchrony in Candidates for Cardiac Resynchronization Therapy. J Am Soc Echocardiogr. 22(6): 695-701.

Linney C, Dukes-McEwan J, Stephenson H, López-Alvarez J and Fonfara S. 2014. Left atrial size, atrial function and left ventricular diastolic function in cats with hypertrophic cardiomyopathy. J Small Anim Pract. 55(4): 198–206.

Luis Fuentes V. 2012. Arterial thromboembolism: risks, realities and a rational first-line approach. J Feline Med Surg. 14(7): 459-470.

Luis Fuentes V, Abbott J, Chetboul V, Côté E, Fox PR, Häggström J, Kittleson MD, Schober K and Stern JA. 2020. ACVIM consensus statement guidelines for the classification, diagnosis, and management of cardiomyopathies in cats. J Vet Intern Med. 34(3): 1062-1077.

Moore KE, Morris N, Dhupa N, Murtaugh RJ and Rush JE. 2000. Retrospective Study of Streptokinase Administration in 46 Cats with Arterial Thromboembolism. J Vet Emerg Crit Care. 10(4): 245-257.

Motoki H, Dahiya A, Bhargava M, Wazni OM, Saliba WI, Marwick TH and Klein AL. 2012. Assessment of left atrial mechanics in patients with atrial fibrillation: comparison between two-dimensional speckle-based strain and velocity vector imaging. J Am Soc Echocardiogr. 25(4): 428-35.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Nokthong N, Pongsawat P, Leurdthainarong P, Sritrirasri S and Disatian Surachetpong S. 2020. A study of factors associated with arterial thromboembolism in cats affected with hypertrophic cardiomyopathy in Thailand. TJVM. 50(2): 179-84.

Oyama MA, Sisson DD, Bulmer BJ and Constable PD. 2004. Echocardiographic estimation of mean left atrial pressure in a canine model of acute mitral valve insufficiency. J Vet Intern Med. 18(5): 667-672.

Pagola J, González-Alujas T, Flores A, Muchada M, Rodriguez-Luna D, Seró L, Rubiera M, Boned S, Ribó M, Alvarez-Sabin J, Evangelista A and Molina CA.

2014. Left atria strain is a surrogate marker for detection of atrial fibrillation in cryptogenic strokes. Stroke. 45(8):e164-6.

Payne JR, Borgeat K, Connolly DJ, Boswood A, Dennis S, Wagner T, Menaut P, Maerz I, Evans D, Simons VE, Brodbelt DC and Fruentes VL. 2013. Prognostic Indicators in Cats with Hypertrophic Cardiomyopathy. J Vet Intern Med. 27(6): 1427-1436.

Payne JR, Brodbelt DC and Fruentes VL. 2015. Cardiomyopathy prevalence in 780 apparently healthy cats in rehoming centres (the CatScan study). J Vet Cardiol. 17(Suppl 1): S244-S257.

Payne JR, Borgeat K, Brodbelt DC, Connolly DJ and Fruentes VL. 2015. Risk factors associated with sudden death vs. congestive heart failure or arterial thromboembolism in cats with hypertrophic cardiomyopathy. J Vet Cardiol. 17(Suppl 1): S318-S328.

Peck CM, Nielsen LK, Quinn RL, Laste NJ and Price LL. 2016. Retrospective evaluation of the incidence and prognostic significance of spontaneous echocardiographic contrast in relation to cardiac disease and congestive heart failure in cats: 725 cases (2006–2011). J Vet Emerg Crit Care. 26(5): 704-712.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Peterson ME, Davignon DL, Shaw N, Dougherty E, Rishniw M and Randolph JF. 2020. Serum thyroxine and thyrotropin concentrations decrease with severity of nonthyroidal illness in cats and predict 30-day survival outcome. J Vet Intern Med. 34(6): 2276-2286.

Popa-Fotea NM, Micheu MM, Oprescu N, Alexandrescu A, Greavu M, Onciul S, Onut R, Petre I, Scarlatescu A, Stoian M, Ticulescu R, Zamfir D and Dorobanţu M. 2021. The Role of Left-Atrial Mechanics Assessed by Two-Dimensional Speckle-Tracking Echocardiography to Differentiate Hypertrophic Cardiomyopathy from Hypertensive Left-Ventricular Hypertrophy. Diagnostics (Basel). 11(5): 814.

Quimby J, Gowland S, Carney HC, DePorter T, Plummer P and Westropp J. 2021. AAHA/AAFP Feline Life Stage Guidelines. J Feline Med Surg. 23(3): 211-233.

Rush JE, Freeman LM, Fenollosa NK and Brown DJ. 2002. Population and survival characteristics of cats with hypertrophic cardiomyopathy: 260 cases (1990–1999). J Am Vet Med Assoc. 220(2): 202-207.

Saito T, Suzuki R, Yuchi Y, Teshima T, Matsumoto H and Koyama H. 2021. Early detection of myocardial dysfunction in a cat that gradually progressed to endomyocardial form of restrictive cardiomyopathy. BMC Vet Res. 17, 274.

Schober KE, Fuentes VL and Bonagura JD. 2003. Comparison between invasive hemodynamic measurements and noninvasive assessment of left ventricular diastolic function by use of Doppler echocardiography in healthy anesthetized cats. Am J Vet Res. 64(1): 93-103.

Schober KE and Maerz I. 2006. Assessment of Left Atrial Appendage Flow Velocity and its Relation to Spontaneous Echocardiographic Contrast in 89 Cats with Myocardial Disease. J Vet Intern Med. 20(1): 120-130.

Schober KE and Chetboul V. 2015. Echocardiographic evaluation of left ventricular diastolic function in cats: Hemodynamic determinants and pattern recognition. J Vet Cardiol. 1: S102-33.

Schoeman JP. 1999. Feline distal aortic thromboembolism: a review of 44 cases (1990–1998). J Feline Med Surg. 1(4): 221-231.

Shevlyakov GL and Oja H. 2016. Robust Correlation: Theory and Applications. West Sussex: John Wiley and Sons Ltd. 24-29.

Simpson KE, Gunn-Moore DA, Shaw DJ, French AT, Dukes-McEwan J, Moran CM and Corcoran BM. 2009. Pulsed-wave Doppler tissue imaging velocities in normal geriatric cats and geriatric cats with primary or systemic diseases

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

linked to specific cardiomyopathies in humans, and the influence of age and heart rate upon these velocities. J Feline Med Surg. 11(4): 293-304.

Sitia S, Tomasoni L and Turiel M. 2010. Speckle tracking echocardiography: A new approach to myocardial function. World J. Cardiol. 2(1): 1-5.

Smith SA, Tobias AH, Jacob KA, Fine DM and Grumbles PL. 2003. Arterial Thromboembolism in Cats: Acute Crisis in 127 Cases (1992–2001) and Long-Term Management with Low-Dose Aspirin in 24 Cases. J Vet Intern Med. 17(1): 73-83.

Smith S and Dukes-McEwan J. 2012. Clinical signs and left atrial size in cats with cardiovascular disease in general practice. J Small Anim Pract. 53(1): 27-33.

Spalla I, Locatelli C, Zanaboni AM, Brambilla P and Bussadori C. 2016. Echocardiographic Assessment of Cardiac Function by Conventional and Speckle-Tracking Echocardiography in Dogs with Patent Ductus Arteriosus. J Vet Intern Med. 30(3): 706-13.

Spalla I, Boswood A, Connolly DJ and Luis Fuentes V. 2019. Speckle tracking echocardiography in cats with preclinical hypertrophic cardiomyopathy. Journal of Veterinary Internal Medicine. 33(3): 1232-1241.

Stokol T, Brooks M, Rush JE, Rishniw M, Erb H, Rozanski E, Kraus MS and Gelzer AL. 2008. Hypercoagulability in cats with cardiomyopathy. J Vet Intern Med. 22(3): 546–552.

Sugimoto K, Fujii Y, Sunahara H and Aoki T. 2015. Assessment of left ventricular longitudinal function in cats with subclinical hypertrophic cardiomyopathy using tissue Doppler imaging and speckle tracking echocardiography. J Vet Med Sci. 77(9): 1101-1108.

Sugimoto K, Kawase N, Aoki T and Fujii Y. 2019. Effects of dehydration on echocardiographic diastolic parameters in healthy cats. J Vet Sci. 20(3):e18.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Surachetpong SD, Pairor S, Atiptamvaree T and Mangklabruks T. 2020. Survival time and factors influencing survival time in cats with arterial thromboembolism in Thailand. TJVM. 50(2): 149-54.

Suzuki R, Matsumoto H, Teshima T and Koyama H. 2013. Clinical assessment of systolic myocardial deformations in dogs with chronic mitral valve insufficiency using two-dimensional speckle-tracking echocardiography. J Vet Cardiol. 15(1): 41-9.

Suzuki R, Mochizuki Y, Yoshimatsu H, Teshima T, Matsumoto H and Koyama H. 2017. Determination of multidirectional myocardial deformations in cats with hypertrophic cardiomyopathy by using two-dimensional speckle-tracking echocardiography. J Feline Med Surg. 19(12): 1283-1289.

Suzuki R, Mochizuki Y, Yoshimatsu H, Niina A, Teshima T, Matsumoto H and Koyama H. 2019. Layer-specific myocardial function in asymptomatic cats with obstructive hypertrophic cardiomyopathy assessed using 2-dimensional speckle-tracking echocardiography. J Vet Intern Med. 33(1): 37-45.

Thomas JD and Weyman AE. 1991. Echocardiographic Doppler evaluation of left ventricular diastolic function. Physics and physiology. Circulation. 84:978–990.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Tigen K, Sunbul M, Karaahmet T. Tasar O, Dundar C, Yalcinsoy M, Takir M and Akkaya E. 2015. Early Detection of Bi-ventricular and Atrial Mechanical Dysfunction Using Two-Dimensional Speckle Tracking Echocardiography in Patients with Sarcoidosis. Lung. 193: 669–675.

Tidholm A, Ljungvall I, Höglund K, Westling AB and Häggström J. 2009. Tissue Doppler and Strain Imaging in Dogs with Myxomatous Mitral Valve Disease in Different Stages of Congestive Heart Failure. J Vet Intern Med. 23(6): 1197-1207.

Todaro MC, Choudhuri I, Belohlavek M, Jahangir A, Carerj S, Oreto L and Khandheria BK. 2012. New echocardiographic techniques for evaluation of left atrial mechanics. Eur Heart J Cardiovasc Imaging. 13(12): 973–984.

Tosuwan J, Hunprasit V and Surachetpong SD. 2021. Usefulness of peripheral venous blood gas analyses in cats with arterial thromboembolism. Int J Vet Sci Med. 9(1): 44-51.

Wess G, Sarkar R and Hartmann K. 2010. Assessment of left ventricular systolic function by strain imaging echocardiography in various stages of feline hypertrophic cardiomyopathy. J Vet Intern Med. 24(6): 1375-82.

Yang LT, Liu YW, Shih JY, Li YH, Tsai LM, Luo CY and Tsai WC. 2015. Predictive value of left atrial deformation on prognosis in severe primary mitral regurgitation. J Am Soc Echocardiogr. 28(11): 1309-1317.

Yoon YE, Oh IY, Kim SA, Park KH, Kim SH, Park JH, Kim JE, Lee SP, Kim HK, Kim YJ, Sohn DW and Cho GY. 2015. Echocardiographic Predictors of Progression to Persistent or Permanent Atrial Fibrillation in Patients with Paroxysmal Atrial Fibrillation (E6P Study). J Am Soc Echocardiogr. 28(6): 709-17.

Yuchi Y, Suzuki R, Teshima T, Matsumoto H and Koyama H. 2021. Right ventricular systolic and diastolic function assessed by two-dimensional speckle tracking echocardiography in dogs with myxomatous mitral valve disease. J Vet Med Sci. 83(12):1918-1927.

Zois NE, Tidholm A, Nägga KM, Moesgaard SG, Rasmussen CE, Falk T, Häggström J, Pedersen HD, Åblad B, Nilsen HY and Olsen LH. 2012. Radial and longitudinal strain and strain rate assessed by speckle-tracking echocardiography in dogs with myxomatous mitral valve disease. J Vet Intern Med. 26(6): 1309-1319.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

APPENDIX

Appendix A: Data of the normal group

No.	Name	Sex	Breed	Age (year)	Weight (kg)	HR (bpm)	SBP (mmHg)	VHS
1	ไรจู	Mc	DSH	1	4.2	186	128	7.1
2	ไทเกอร์	Mc	DSH	6	4.9	192	132	7.4
3	น้ำหวาน	F	Himalayan	7	2.7	192	144	7
4	Harvard	M	Bengal	1	4.8	192	126	7.1
5	Shanon	Fs	DSH	10	7.2	196	145	7.3
6	Croissant	Mc	Persian	6	6.7	185	119	6.8
7	Kanomping	Mc	Persian	6	5.6	184	138	7.5
8	Meow	Fs	Scottish fold	1	3.7	203	141	6.6
9	Lee Minho	M	DSH	7	6.7	232	101	7.5
10	Peepo	F	Scottish fold	1	3.2	157	130	7.4
11	Brownie	F	Scottish fold	1	3.3	215	111	7.4
12	Yelly	M	Scottish fold	3	4.4	168	137	7.6
13	Den	M	DSH	2	4.5	203	104	6.9
14	Eclair	M	Scottish fold	2	4.2	205	124	7.5
15	Shabu	M	Scottish fold	5	3.5	185	132	7.1
16	Pudding	F	Scottish fold	4	2.8	215	118	7.6
17	Seenual	F	Scottish fold	4.2	4.2	208	128	7.8
18	Hilo	M	Scottish fold	3.2	3.2	198	140	7
19	Simba	Mc	Mainecoon	6.4	6.4	183	130	7.5
20	Malai	Mc	American shorthair	5.6	5.6	182	119	7.8
21	Jikchow	F	DSH	4	6.5	200	137	6.8
22	Maru	M	Persian	1	3.7	231	119	7.5
23	Tanos	M	Scottish fold	1	3.4	216	130	6.8

Abbreviations: bpm: beat per minute; DSH: domestic shorthair; F: intact female; Fs: spayed female; HR: heart rate; M: intact male; Mc: castrated male; SBP: systolic blood pressure; VHS: vertebral heart score

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CHULALONGKORN UNIVERSITY

Appendix B: Data of the ATE group

No.	Name	Sex	Breed	Age (year)	Weight (kg)	HR (bpm)	SBP (mmHg)	VHS	Pulmonary edema	Pleural effusion	SEC
Cardiogenic arterial thromboembolism											
1	มีลาภ	Mc	DSH	4	4.5	250	120	8.5	Yes	Yes	Yes
2	ข้าวปุ้น	Mc	DSH	5	4.9	254	120	9.5	Yes	No	Yes
3	Kola	Mc	Mixed breed	2	4.25	198	145	7.8	No	No	Yes
4	Mavin	Mc	DSH	5	5.7	228	150	7.8	Yes	Yes	Yes
5	Sumo	Mc	DSH	10	5.35	181	112	9.3	No	No	Yes
6	Neeno	Mc	DSH	16	4.8	225	150	8	No	No	Yes
7	เหมียว	M	DSH	4	4.65	196	152	8.6	Yes	No	No
8	วีโก้	Mc	DSH	7	6.2	238	116	8.5	Yes	No	No
9	Katty	Fs	Mainecoon	10	3.6	45	96	9	Yes	No	Yes
10	Teelek	Mc	DSH	4	4.9	181	98	9.7	No	No	Yes
11	ไจ๋	Mc	DSH	6	5	210	114	8.4	No	No	No
12	ถุงเงิน	Fs	DSH	1	4.5	207	158	7.2	No	No	No
13	กุมภา	F	DSH	2	2	210	120	7.5	No	Yes	No
14	ทั้ม	M	Mixed breed	5	4.3	179	110	9.6	Yes	No	Yes
15	Money	M	Persian	8	3.9	200	120	7.6	No	No	No
Non-cardiogenic arterial thromboembolism											
1	Aeli	Fs	Persian	3	3.9	203	92	7.5	No	No	No
2	Jibi	Mc	DSH	4	3.7	222	95	7.4	No	No	No
3	Boonchoke	M	DSH	2	2.5	248	100	7.4	No	No	No
4	Lucky	F	DSH	1	2.5	260	154	6.9	No	No	No
5	Tungtong	Mc	DSH	3	3.5	211	100	6.8	No	Yes	No
6	ชมพู่	F	Scottish fold	4	3.5	231	166	8.2	No	No	No

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Abbreviations: bpm: beat per minute; DSH: domestic shorthair; F: intact female; Fs: spayed female; HR: heart rate; M: intact male; Mc: castrated male; SBP: systolic blood pressure; SEC: spontaneous echocardiographic contrast; VHS: vertebral heart score

Appendix C: M-mode echocardiographic value of normal group

No.	Name	M-mode																
		IVSd	IVSs	LVIDd	LVIDs	LVPWd	LVPWs	IVS%	LVPW%	FS	HR	EDV	ESV	SV	EF	LA	Ao	LA/Ao
1	ไรจู	0.34	0.49	1.62	0.86	0.34	0.62	43.48	82.61	46.79	186	7.42	1.38	6.04	81.43	1.37	0.79	1.74
2	ไทเกอร์	0.45	0.79	1.4	0.62	0.46	0.79	76.67	70.97	55.32	192	5.04	0.56	4.47	88.8	1.16	0.95	1.22
3	น้ำหวาน	0.39	0.63	1.46	0.7	0.28	0.61	60.53	118.52	52.11	192	5.67	0.78	4.89	86.32	1.1	0.77	1.43
4	Harvard	0.52	0.78	1.42	0.34	0.55	0.83	51.22	50	76.11	192	5.27	0.1	5.17	98.1	1.01	0.81	1.25
5	Shanon	0.35	0.53	1.33	0.65	0.39	0.62	51.06	61.54	50.81	196	4.43	0.64	3.79	85.41	1.19	0.83	1.43
6	Croissant	0.51	0.68	1.34	0.44	0.46	0.82	32.22	77.78	67.2	185	4.57	0.21	4.36	95.28	1.35	0.77	1.74
7	Kanomping	0.49	0.85	1.3	0.57	0.37	0.63	72.73	70	56.05	184	4.18	0.45	3.73	89.39	1.35	0.82	1.65
8	Meow	0.45	0.7	1.13	0.38	0.41	0.72	55.56	75.38	66.46	203	2.84	0.14	2.7	95.07	1.12	0.72	1.56
9	Lee Minho	0.4	0.52	1.66	0.89	0.35	0.62	28.12	76.79	46.56	232	7.91	1.49	6.42	81.09	1.39	0.99	1.4
10	Peepo	0.44	0.65	1.41	0.55	0.42	0.67	46.39	60.44	60.59	157	5.2	0.43	4.78	91.4	1.3	0.91	1.44
11	Brownie	0.35	0.65	1.41	0.49	0.4	0.71	83.12	77.27	64.85	215	5.13	0.3	4.83	94.28	1.08	0.93	1.16
12	Yelly	0.41	0.77	1.41	0.55	0.44	0.81	86.67	84.38	61.17	168	5.19	0.39	4.8	92.43	1.19	1.19	1
13	Den	0.43	0.75	1.47	0.77	0.51	0.61	74.07	18.75	47.83	203	5.78	1	4.78	82.64	1.14	0.74	1.54
14	Eclair	0.5	0.8	1.39	0.4	0.47	0.88	60.76	86.67	71.44	205	4.99	0.16	4.84	96.84	1.15	0.84	1.37
15	Shabu	0.42	0.7	1.45	0.49	0.45	0.65	67.16	46.48	66.03	185	5.61	0.29	5.31	94.59	1.25	1.06	1.18
16	Pudding	0.45	0.69	1.12	0.39	0.41	0.71	53.27	74.23	65.05	215	2.83	0.18	2.64	93.7	1.16	0.97	1.19
17	Seenual	0.46	0.72	1.35	0.44	0.43	0.8	56.16	86.76	67.24	208	4.57	0.21	4.35	95.3	1.2	0.86	1.4
18	Hilo	0.4	0.69	1.18	0.35	0.35	0.72	71.87	103.57	70.21	198	3.23	0.11	3.12	96.56	1.21	0.77	1.57
19	Simba	0.53	0.62	1.92	0.95	0.43	0.86	18.18	100	50.83	183	11.5	1.77	9.74	84.64	1.44	1.11	1.3
20	Malai	0.55	0.77	1.62	0.63	0.54	0.71	40	33.33	61.02	182	7.4	0.58	6.82	92.14	1.41	1.04	1.36
21	Jikchow	0.4	0.61	1.31	0.62	0.43	0.7	51.85	62.07	52.27	200	4.23	0.56	3.67	86.67	1.28	0.7	1.83
22	Maru	0.5	0.63	1.27	0.75	0.49	0.73	26.58	48.72	41.08	231	3.92	0.93	2.98	76.13	1.01	0.87	1.16
23	Tanos	0.5	0.73	1.42	0.63	0.45	0.72	45	59.72	55.75	216	5.27	0.58	4.69	89.07	0.99	0.96	1.04

Abbreviations: Ao: aorta; EDV: LV end-diastolic volume; EF: ejection fraction; ESV: LV end-systolic volume; FS: fractional shortening; HR: heart rate; IVSd: interventricular septum in diastole; IVSs: interventricular septum in systole; IVS%: percentage of fractional thickening of interventricular septum; LA: left atrial; LA/Ao: left atrium to aorta ratio; LV: left ventricle; LVIDd: left ventricular internal diameter in diastole; LVIDs: left ventricular internal diameter in systole; LVPWd: left ventricular posterior wall in end-diastole; LVPWs: left ventricular posterior wall in systole; LVPW%: percentage of fractional thickening of left ventricular posterior wall; SV: stroke volume

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Appendix D: Two-dimentional, left atrial and TDI measurement value of normal group

No.	Name	2D measurements			Left atrial measurement					TDI Measurement				
		LA	AO	LA/Ao	LAD	LAS	LA FS	LAA FLOW V	LAA FLOW PG	Sa	Ea	Aa	MV Ea/Aa	MV E/Ea
1	ไรจู	1.12	0.69	1.62	14	9.5	31.91	33.38	0.44	8.15	9.14	6.46	1.42	8.4
2	ไทเกอร์	1.2	0.78	1.53	12.5	7.7	38.1	31.77	0.40	9.74	11.13	7.95	1.4	5.07
3	น้ำหวาน	1.16	0.81	1.44	11.4	8.5	25.23	59.31	1.41	7.65	14.11	7.75	1.82	4.83
4	Harvard	1.01	0.81	1.25	10.1	6.7	33.75	33.28	0.44	7.55	10.83	7.75	1.4	8.47
5	Shanon	0.73	0.65	1.12	12	7.7	35.8	30.09	0.36	8.64	12.12	9.24	1.31	7.31
6	Croissant	1.1	1.00	1.10	13	11.2	14.47	32.26	0.42	7.15	13.12	7.35	1.78	5.55
7	Kanomping	1.4	0.82	1.71	14	11.9	15	44.69	0.8	8.92	7.81	6.92	1.13	7.02
8	Meow	1.00	0.85	1.18	11.5	7.1	37.91	39.27	0.62	7.75	10.73	8.15	1.32	5.76
9	Lee Minho	1.31	0.86	1.52	14	9.2	34.23	39.1	0.61	10.23	12.22	8.84	1.38	5.7
10	Peepo	1.12	0.98	1.14	11.2	8.9	20.53	49.22	0.98	10.33	16	10.23	1.56	4.71
11	Brownie	1.07	0.88	1.21	10.7	8.1	24.36	33.38	0.45	10.73	16.69	10.04	1.66	5.18
12	Yelly	1.07	1.02	1.05	10.7	8	25.236	46.13	0.86	9.04	11.33	8.15	1.39	7.38
13	Den	0.86	0.63	1.35	10.9	7.8	27.94	23.92	0.23	9.94	11.53	5.56	2.07	6.05
14	Eclair	1.25	1.07	1.18	12.5	9	28	35.01	0.49	11.96	10.76	9.47	1.14	7.31
15	Shabu	1.03	1.08	0.96	12.2	9.1	25.77	28.92	0.34	7.65	9.34	6.36	1.47	5.69
16	Pudding	1.03	1.01	1.01	11.6	8	31.03	61.03	1.5	7.75	13.12	8.64	1.52	4.98
17	Seenual	1.21	0.91	1.33	12.7	9.4	25.74	38.2	0.58	12.33	21.14	9.04	2.34	3.94
18	Hilo	0.86	0.74	1.16	11.5	7	38.46	36.95	0.55	9.86	17.97	17.14	1.05	4.11
19	Simba	1.13	0.96	1.18	14.7	10.7	27.17	25.35	0.26	10.93	13.81	7.65	1.81	6.31
20	Malai	1.21	0.91	1.33	14.7	10.2	30.84	28.83	0.33	6.26	7.25	5.37	1.35	7.01
21	Jikchow	1.17	0.81	1.44	12.8	9.4	26.74	34.6	0.48	8.55	11.82	7.95	1.49	8.14
22	Maru	1.2	0.84	1.42	10.4	7.8	25.3	35.88	0.53	11.63	11.13	6.56	1.7	8.02
23	Tanos	1.1	0.84	1.31	10.4	8.1	22.89	41.57	0.7	8.31	11.78	5.3	2.22	7.01

Abbreviations: Aa: myocardial velocity associated with atrial contraction; Ao: aorta; Ea: early diastolic myocardial relaxation velocity; LA: left atrial; LA FS: left atrial fractional shortening; LAA FLOW: left atrial appendage flow velocity; LAA PG: left atrial appendage maximal pressure gradient; LAD: left atrial diameter in LA diastole; LAS: left atrial diameter in LA systole; LA/Ao: left atrium to aorta ratio; MV A: mitral valve peak A wave, MV E: mitral valve peak E wave; MV Ea/Aa: mitral inflow Ea wave-to-Aa wave of tissue doppler; MV E/Ea: mitral inflow E wave-to-tissue doppler Ea wave; PG: maximal pressure gradient; Sa: systolic myocardial velocity; vel: peak velocity; V: peak velocity

Appendix E: Doppler echocardiographic measurement value of normal group

No.	Name	Doppler Measurement														
		MV E vel	MV E PG	MV A vel	MV A PG	MV E/A	IVRT	AV Vmax	AV PG	PV Vmax	PV PG	PVein S vel	PVein D vel	PVein A vel	PVein A dur	PVein S/D
1	ไรจู	76.75	2.36	56.4	1.27	1.36	0.059	102.1	4.17	95.67	3.66	40.34	37.84	13.92	0.068	1.07
2	ไทเกอร์	56.43	1.27	52.31	1.09	1.08	0.043	88.56	3.14	85.26	2.91	53.55	40.37	18.12	0.052	1.33
3	น้ำหวาน	68.18	1.86	57.12	1.3	1.19	0.039	89.96	3.24	91.74	3.37	43.91	28.56	17.49	0.067	1.54
4	Harvard	91.74	3.37	79.25	2.51	1.16	0.047	119.23	5.69	86.44	3.4576	29.99	38.55	17.14	0.054	0.78
5	Shanon	88.66	3.14	47.12	0.89	1.88	0.047	96.59	3.73	75.69	2.29	57.67	42.53	16.58	0.043	1.36
6	Croissant	72.8	2.12	82.89	2.75	0.88	0.043	98.03	3.84	107.04	4.58	32.44	45.41	22.71	0.057	0.71
7	Kanomping	54.78	1.2	70.02	1.96	0.78	0.043	72.08	2.08	72.11	2.08	35.68	23.79	13.7	0.058	1.5
8	Meow	61.76	1.53	52.83	1.12	1.17	0.058	79.96	2.56	76.39	2.33	42.84	53.55	12.49	0.043	0.8
9	Lee Minho	69.61	1.94	59.62	1.42	1.17	0.03	90.15	3.606	69.25	1.92	59.97	41.05	17.14	0.034	1.46
10	Peepo	75.38	2.27	53.55	1.15	1.41	0.045	78.67	2.48	86.5	2.99	55.61	47.37	18.12	0.045	1.17
11	Brownie	86.39	2.99	62.47	1.56	1.38	0.043	90.32	3.26	86.03	2.96	53.19	40.34	19.99	0.043	1.32
12	Yelly	83.62	2.8	68.38	1.87	1.22	0.04	102.15	4.17	102.84	4.23	59.73	51.08	13.18	0.047	1.17
13	Den	74.97	2.25	63.9	1.63	1.17	0.046	90.1	3.604	92.46	3.42	48.19	40.7	15.35	0.054	1.18
14	Eclair	78.67	2.48	66.32	1.76	1.19	0.04	90.2	3.608	106.68	4.55	80.73	59.73	29.24	0.045	1.35
15	Shabu	53.19	1.13	39.98	0.64	1.33	0.043	88.89	3.16	75.68	2.29	48.55	46.05	14.99	0.065	1.05
16	Pudding	65.33	1.71	47.84	0.92	1.37	0.052	106.74	4.56	74.61	2.23	76.75	50.33	28.92	0.032	1.52
17	Seenual	83.13	2.77	51.76	1.07	1.61	0.034	92.1	3.39	86.39	2.99	79.25	63.9	13.57	0.036	1.24
18	Hilo	73.8	2.18	66.93	1.79	1.1	0.031	95.31	3.63	84.6	2.86	69.61	43.55	22.13	0.035	1.6
19	Simba	87.1	3.03	82.82	2.74	1.05	0.049	87.46	3.06	72.11	2.08	38.2	29.27	13.57	0.06	1.3
20	Malai	50.82	1.03	61.27	1.5	0.83	0.054	76.41	2.34	86.5	2.99	45.05	31.36	13.34	0.051	1.44
21	Jikchow	96.23	3.7	48.3	0.93	1.99	0.054	69.56	1.94	93.35	3.49	56.95	43.61	25.95	0.043	1.31
22	Maru	89.24	3.19	81.39	2.65	1.1	0.031	94.24	3.55	87.82	3.08	68.18	38.55	11.42	0.043	1.77
23	Tanos	82.65	2.73	56.7	1.29	1.46	0.047	86.5	2.99	89.6	3.21	51.76	36.77	12.14	0.036	1.41

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Abbreviations: AV: atrial valve; dur: duration; E/A: mitral inflow peak E-to-A wave velocities ratio; Ea: early diastolic myocardial relaxation velocity; IVRT: isovolumic relaxation time; MV A: mitral valve peak A wave, MV E: mitral valve peak E wave; MV Ea/Aa: mitral inflow Ea wave-to-Aa wave of tissue doppler; MV E/Ea: mitral inflow E wave-to-tissue doppler Ea wave; PG: maximal pressure gradient; PV: pulmonic valve; Pvein A: pulmonary venous A wave; Pvein D: pulmonary venous diastolic wave; Pvein S: pulmonary venous systolic wave; Pvein S/D: pulmonary venous peak systolic-to-diastolic ratio; Sa: systolic myocardial velocity; vel: peak velocity; Vmax: maximal velocity

Appendix F: Left atrial strain, strain rate and volume derived from two-dimensional speckle tracking echocardiography in normal group

No.	Name	LASr	LAScd	LASct	LASRs	LASRe	LASRa	GS %	LA EDV avg (ml)	LA ESV avg (ml)	LA EF avg %	TPSD
1	ไรจู	29.65	-18.58	-11.08	2.01	-4.37	-4.50	26.48	3.21	1.75	45.59	155.1
2	ไทเกอร์	18.68	-15.14	-3.54	1.69	-6.30	-2.49	11.58	1.87	1.3	30.55	43.93
3	น้ำหวาน	26.39	-11.22	-15.17	3.37	-3.35	-4.45	27.68	1.4	0.94	32.99	56.06
4	Harvard	19.81	-11.19	-8.62	2.83	-2.29	-2.63	-0.21	3.14	1.69	46.04	4.55
5	Shanon	21.37	-13.10	-8.27	1.58	-5.62	-2.05	22.28	1.97	1.28	35.06	46.35
6	Croissant	21.63	-6.28	-15.35	1.74	-3.98	-3.55	7.45	1.28	0.84	34.44	32.65
7	Kanomping	18.72	-7.97	-10.75	2.49	-1.43	-2.83	-18.49	1.86	1.09	41.78	3.5
8	Meow	19.13	-6.62	-12.51	2.04	-2.24	-1.66	-7.72	1.11	0.76	33.75	23.60
9	Lee Minho	15.53	-9.22	-6.30	1.76	-4.00	-2.64	9.47	2.18	1.36	37.67	48.64
10	Peepo	24.25	-15.08	-9.18	2.23	-6.56	-2.65	-7.755	2.28	1.43	37.165	10.525
11	Brownie	14.44	-10.70	-3.74	2.02	-2.98	-0.88	11.53	2.2	1.3	41.04	18.85
12	Yelly	26.32	-13.90	-12.42	2.64	-3.56	-5.11	31.48	2.04	1.31	35.71	32.92
13	Den	14.64	-4.92	-9.72	2.23	-5.94	-0.09	16.05	1.2	0.83	31.29	41.56
14	Eclair	22.57	-14.87	-7.70	1.99	-3.37	-2.10	-9.18	3.11	1.5	51.77	8.05
15	Shabu	20.73	-16.74	-3.98	3.58	-5.40	-1.86	-0.64	1.61	1.18	26.77	4.2
16	Pudding	19.36	-13.61	-5.75	2.01	-4.25	-1.46	-6.09	2.5	1.32	47.15	2.8
17	Seenual	17.48	-10.98	-6.50	3.68	-3.79	-1.92	19.65	2.36	1.47	37.78	38.94
18	Hilo	38.68	-19.76	-18.92	3.96	-11.98	-10.00	3.69	1.16	0.81	29.69	2.8
19	Simba	15.91	-12.13	-3.78	1.96	-2.98	-0.81	10.94	4.75	3.44	27.61	59.73
20	Malai	21.80	-12.33	-9.47	1.13	-5.14	-1.29	21.18	3.1	1.96	36.63	25.99
21	Jikchow	26.64	-13.42	-13.22	2.29	-6.40	-3.07	29.46	2.19	1.38	34.79	24.35
22	Maru	20.41	-12.92	-7.49	1.75	-6.26	-2.49	18.52	1.15	0.7	38.56	36.79
23	Tanos	25.06	-16.71	-8.35	2.25	-7.99	-2.43	-5.18	1.225	0.775	35.995	14.365

Abbreviations: avg: average; cd: during LA conduit phase; ct: during LA contraction phase; EDV: end-diastolic volume; EF: ejection fraction; ESV: end-systolic volume; GS%: global strain; TPSD: total peak systolic dispenser; LAS: left atrial global longitudinal strain; pLASR: peak of left atrial strain rate; r: during LA reservoir phase

Appendix G: M-mode echocardiographic value of cardiogenic and non-cardiogenic arterial thromboembolism

No.	Name	M-mode															
		IVSd	IVSs	LVIDd	LVIDs	LVPWd	LVPWs	IVS%	LVPW%	FS	LV EDV	LV ESV	LV SV	LV EF	LA	Ao	LA/Ao
Cardiogenic arterial thromboembolism																	
1	มีลาภ	0.41	0.9	1.35	1.35	0.62	0.77	119.61	23.08	27.59	5.9	4.55	5.99	56.83	2.29	0.96	2.38
2	ข้าวปุ้น	0.37	0.53	1.76	1.27	0.59	0.75	43.48	27.03	28.18	9.2	3.87	5.33	57.94	2.61	0.9	2.91
3	Kola	0.86	0.96	0.82	0.43	0.72	0.86	11.11	20	47.06	1.19	0.2	0.99	83.15	1.7	0.74	2.3
4	Mavin	0.98	1.03	0.72	0.34	0.67	0.85	5.10	26.19	53.33	0.84	0.1	0.74	88.41	1.87	0.62	3
5	Sumo	0.47	0.8	1.37	0.82	0.54	0.85	70.59	58.97	43.4	4.84	1.21	4.38	78.31	1.51	0.82	1.83
6	NEENO	0.37	0.82	1.25	0.3	0.67	0.78	121.74	16.67	75.64	3.74	0.07	3.67	98.05	1.79	0.69	2.6
7	เหมียว	0.62	0.88	1.69	0.78	0.62	1.03	42.86	64.1	53.5	8.28	1.06	7.21	87.07	1.97	0.78	2.51
8	วีโก้	0.53	0.67	1.46	0.83	0.51	0.75	27.27	46.88	42.86	5.62	1.25	4.37	77.74	2.24	0.72	3.11
9	Katty	0.42	0.54	1.39	0.99	0.45	0.67	30.77	50	28.74	4.99	2.02	2.97	59.54	1.43	0.72	1.98
10	Teelek	0.67	1.23	1.73	0.46	0.82	1.11	83.33	35.29	73.15	8.78	0.24	8.53	97.21	2.21	0.7	3.14
11	ไจ๋	0.69	0.9	1.59	0.8	0.61	0.91	30.23	50	49.49	7	1.12	5.88	83.96	1.62	0.88	1.84
12	ถุงเงิน	0.62	0.92	1.02	0.42	0.62	0.77	48.98	24.49	59.26	2.17	0.18	1.99	91.79	1.02	0.81	1.25
13	กุมภา	0.3	0.48	1.28	0.69	0.29	0.43	57.89	50	46.25	4	0.74	3.26	81.49	1.36	0.66	2.07
14	ทั้ม	0.93	1.11	1.32	0.77	0.66	0.97	19.12	47.92	41.67	4.31	1	3.31	76.71	2.31	0.69	3.36
15	Money	0.49	0.63	1.54	0.93	0.41	0.59	27.78	43.33	39.29	6.46	1.71	4.76	73.56	1.52	1.03	1.48
Non-cardiogenic arterial thromboembolism																	
1	Aeli	0.45	0.54	1.42	0.81	0.57	0.82	20	44.44	43.36	5.27	1.14	4.13	78.34	1.2	0.77	1.55
2	Jibi	0.39	0.65	1.32	0.64	0.48	0.64	67.74	34.21	51.43	4.34	0.61	3.73	85.98	1.38	0.7	1.96
3	Boonchoke	0.43	0.56	1.28	0.68	0.34	0.61	32.14	80.9	47.07	4.01	0.72	3.29	82.22	1.01	0.68	1.48
4	Lucky	0.41	0.61	1.21	0.49	0.42	0.76	47.22	78.38	59.43	3.46	0.29	3.17	91.66	1.18	0.61	1.94
5	Tungtong	0.51	0.67	1.35	0.7	0.46	0.65	32.35	41.94	48.35	4.62	0.77	3.85	83.31	1.2	0.83	1.45
6	ชมพู่	0.47	0.64	1.35	0.59	0.36	0.59	37.84	62.07	56.07	4.56	0.48	4.08	89.39	1.06	1.06	1

Abbreviations: Ao: aorta; EDV: LV end-diastolic volume; EF: ejection fraction; ESV: LV end-systolic volume; FS: fractional shortening; HR: heart rate; IVSd: interventricular septum in diastole; IVSs: interventricular septum in systole; IVS%: percentage of fractional thickening of interventricular septum; LA: left atrial; LA/Ao: left atrium to aorta ratio; LV: left ventricle; LVIDd: left ventricular internal diameter in diastole; LVIDs: left ventricular internal diameter in systole; LVPWd: left ventricular posterior wall in end-diastole; LVPWs: left ventricular posterior wall in systole; LVPW%: percentage of fractional thickening of left ventricular posterior wall; SV: stroke volume

Appendix H: Two-dimentional, left atrial and TDI measurement value of cardiogenic and non-cardiogenic arterial thromboembolism

No.	Name	2D measurements			Left atrial measurement					TDI Measurement				
		LA	AO	LA/Ao	LAD	LAS	LA FS	LAA FLOW V	LAA FLOW PG	Sa	Ea	Aa	MV Ea/Aa	MV E/Ea
Cardiogenic arterial thromboembolism														
1	มีลาภ	1.92	0.87	2.2						5.46	12.52	5.56	2.25	6.06
2	ข้าวปุ้น	3.01	0.76	3.96						4.57	4.17	7.35	0.57	20.1
3	Kola	1.52	0.72	2.11						6.16	6.26	4.17	1.5	6.67
4	Mavin	1.53	0.53	2.88						5.07	7.15	5.27	1.36	6.34
5	Sumo	1.42	0.66	2.17						4.57	8.45	4.47	1.89	6.91
6	NEENO	1.46	0.75	1.94	18.7	16.7	11.11	25.88	0.27	6.56	7.15	5.86	1.22	6.69
7	เหมียว	1.93	0.81	2.38	20.5	16.8	17.97			6.86	11.23	8.25	1.36	6.49
8	วีโก้	2.12	0.65	3.24	23.7	21.6	8.78			5.56	11.92	4.87	2.45	13.66
9	Katty	1.52	0.77	1.97	14.6	13.5	7.69	11.6	0.06	4.57	6.76			
10	Teelek	1.99	0.65	3.06	22.7	21.5	5.63	19.7	0.16	5.37	7.25	4.67	1.55	9.3
11	ไจ๋	1.35	0.72	1.89	15.9	13.3	16.16	18.31	0.14	5.17	6.46	4.57	1.41	16.9
12	ถุงเงิน	1.02	0.72	1.43				18.21	0.13	7.75	5.37	8.05	0.67	8.72
13	กุมภา	1.37	0.58	2.38	13.8	12.2	11.63			7.95	6.96	9.94	0.7	17.45
14	ทั้ม	2.22	0.68	3.29	23.2	21.1	8.88	14.46	0.09	5.24	3.97	7.45	0.53	22.45
15	Money	1.52	0.91	1.68	15.5	14	9.73			7.05	6.76	5.46	1.24	11.31
Non-cardiogenic arterial thromboembolism														
1	Aeli	1.03	1.01	1.01	15.8									
2	Jibi	1.21	0.91	1.33						7.45	7.45	5.46	1.36	10.36
3	Boonchoke	0.86	0.74	1.16						8.35	8.55	14.31	0.6	11.81
4	Lucky	1.13	0.96	1.18	11.3	9	20.2	55.7	1.240996	7.75	11.72	10.13	1.16	8.06
5	Tungtong	1.21	0.91	1.33	11.6	9.1	21.79	44.8	0.802816	8.74	13.41			8.95
6	ชมพู่	1.17	0.81	1.44	10.4	8.1	22.89	52.86	1.12	6.46	10.63	10.53	1.01	8.45

Abbreviations: Aa: myocardial velocity associated with atrial contraction; Ao: aorta; Ea: early diastolic myocardial relaxation velocity; LA: left atrial; LA FS: left atrial fractional shortening; LAA FLOW: left atrial appendage flow velocity; LAA PG: left atrial appendage maximal pressure gradient; LAD: left atrial diameter in LA diastole; LAS: left atrial diameter in LA systole; LA/Ao: left atrium to aorta ratio; MV A: mitral valve peak A wave, MV E: mitral valve peak E wave; MV Ea/Aa: mitral inflow Ea wave-to-Aa wave of tissue doppler; MV E/Ea: mitral inflow E wave-to-tissue doppler Ea wave; PG: maximal pressure gradient; Sa: systolic myocardial velocity; vel: peak velocity; V: peak velocity

Appendix I: Doppler echocardiographic measurement value of cardiogenic and non-cardiogenic arterial thromboembolism

No.	Name	Doppler Measurement														
		MV E vel	MV E PG	MV A vel	MV A PG	MV E/A	IVRT	AV Vmax	AV PG	PV Vmax	PV PG	PVein S vel	PVein D vel	PVein A vel	PVein A dur	PVein S/D
Cardiogenic arterial thromboembolism																
1	มีลาภ	75.86	2.3	50.46	1.02	1.5	0.05	81.75	2.67			25.74	21.62	14.07	0.058	1.19
2	ข้าวปุ้น	83.89	2.82	19.99	0.16	4.2	0.04	52.83	1.12	29.63	0.35					
3	Kola	41.77	0.7	69.25	1.92	0.6		107.09	4.59	92.46	3.42	44.98	29.27	22.49	0.083	1.54
4	Mavin	45.34	0.82	31.77	0.4	1.43	0.04	64.61	1.67	48.91	0.96					
5	Sumo	58.39	1.36	32.87	0.43	1.78	0.059	65.09	1.69			20.76	24.44	14.06	0.083	0.8
6	NEENO	47.84	0.92	30.7	0.38	1.56	0.043	80.32	2.58			36.05	30.34	14.64	0.027	1.19
7	เหมียว	72.82	2.12	39.27	0.62	1.85	0.057	104.95	4.41	116.73	5.45	30.7	28.56	19.28	0.079	1.08
8	วีโก้	162.91	10.62				0.036	92.27	3.41	96.74	3.74	35.7	50.33	27.49	0.054	0.71
9	Katty						0.086	61.04	1.49	55.69	1.24	16.78	13.92			1.21
10	Teelek	67.47	1.82	51.05	1.04	1.32	0.047	137.3	7.54	71.04	2.02	77.82	42.12	14.99	0.054	1.85
11	ไจ๋	109.12	4.76				0.054	117.43	5.52	81.75	2.67	40.78	28.7	40.78	28.7	10.95
12	ถุงเงิน	46.76	0.87	52..83	1.12	0.89	0.058	78.54	2.47	83.13	2.77	43.91	32.13	15.71	0.046	1.37
13	กุมภา	121.37	5.89	42.29	0.72	2.87	0.054			60.69	1.47	26.77	64.97	12.85	0.061	0.41
14	ทิ้ม	89.24	3.19	22.13	0.2	4.03	0.043	102.45	4.2	92.46	3.42	41.77	27.13	11.42	0.09	1.54
15	Money	76.39	2.33	36.41	0.53	2.1	0.05	60.33	1.46	106.38	4.53	20.7	22.13	8.21	0.054	0.94
Non-cardiogenic arterial thromboembolism																
1	Aeli	54.26	1.18	31.06	0.39	1.75	0.054	76.39	2.33			29.99	22.13	9.28	0.072	1.3
2	Jibi	77.46	2.4				0.047	55.69	1.24	79.61	2.53	27.49	22.49	17.14	0.065	1.22
3	Boonchoke	100.62	4.07				0.043			100.92	4.07					
4	Lucky	94.46	3.57	50.53	1.02	1.87	0.041	77.11	2.38	88.17	3.11	34.98	45.34	12.14	0.041	0.77
5	Tungtong	120.07	5.77	1.32	1.32	2.09	0.041	98.55	3.88	106.85	4.57	52.48	34.36	9.44	0.038	1.53
6	ชมพู่	89.86	3.23	69.68	1.94	1.29	0.047	104.76	4.39	89.38	3.2	39.89	32.68	27.87	0.046	1.22

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Abbreviations: AV: atrial valve; dur: duration; E/A: mitral inflow peak E-to-A wave velocities ratio; Ea: early diastolic myocardial relaxation velocity; IVRT: isovolumic relaxation time; MV A: mitral valve peak A wave, MV E: mitral valve peak E wave; MV Ea/Aa: mitral inflow Ea wave-to-Aa wave of tissue doppler; MV E/Ea: mitral inflow E wave-to-tissue doppler Ea wave; PG: maximal pressure gradient; PV: pulmonic valve; Pvein A: pulmonary venous A wave; Pvein D: pulmonary venous diastolic wave; Pvein S: pulmonary venous systolic wave; Pvein S/D: pulmonary venous peak systolic-to-diastolic ratio; Sa: systolic myocardial velocity; vel: peak velocity; Vmax: maximal velocity

Appendix J: Left atrial strain, strain rate and volume derived from two-dimensional speckle tracking echocardiography in cardiogenic and non-cardiogenic arterial thromboembolism

No.	Name	LASr	LAScd	LASct	LASRs	LASRe	LASRa	GS %	LA EDV avg (ml)	LA ESV avg (ml)	LA EF avg %	TPSD
Cardiogenic arterial thromboembolism												
1	มีลาภ	2.68	-1.62	-1.06	0.31	-0.97	-0.23	2.71	13.81	13.26	4	62.53
2	ข้าวปุ้น	1.31	-0.71	-0.60	0.21	-0.33	-0.27	1.25	36.82	36.12	1.91	49.21
3	Kola	3.98	-1.48	-2.50	0.59	-0.51	-0.61	-0.14	7.56	7.02	7.11	3.16
4	Mavin	3.30	-1.32	-1.99	0.87	-0.30	-0.20	-1.44	8.48	7.65	9.74	11.39
5	Sumo	3.06	-1.50	-1.56	0.58	-0.45	-0.33	0.55	5.49	5.07	7.6	2.8
6	NEENO	4.87	-1.57	-3.31	2.71	0.90	0.64	-2.64	4.29	3.7	13.73	9.98
7	เหมียว	4.86	-1.87	-3.00	1.77	-0.64	-0.06	-1.02	6.46	6.13	5.59	12.74
8	วีโก้	2.71	-1.75	-0.96	1.09	-0.50	-0.04	0.89	18.39	16.77	8.83	6.32
9	Katty	4.50	-3.63	-0.86	0.26	-0.59	-0.12	-4	3.32	2.81	15.47	127.98
10	Teelek	2.02	-1.48	-0.54	0.60	-0.20	-0.16	1.03	10.41	10.08	3.21	1.03
11	ไจ๋	4.73	-3.83	-0.90	0.62	-1.86	-1.04	4.87	6.36	5.8	8.87	49.28
12	ถุงเงิน	11.92	-4.39	-7.53	1.21	-3.78	-1.67	4.19	1.02	0.835	19.315	42.545
13	กุมภา	10.84	-6.35	-4.49	1.96	-2.31	-2.30	9.17	3.19	2.87	9.91	31.36
14	ทั้ม	1.82	-0.77	-1.05	0.48	-0.06	-0.08	0.08	13.27	12.81	3.49	2.56
15	Money	2.23	-0.73	-1.50	0.58	-0.41	-0.20	2	8.89	8.32	6.43	33.6
Non-cardiogenic arterial thromboembolism												
1	Aeli	3.39	-1.48	-1.91	0.64	-0.68	-0.50	-1.9	3.64	3.3	9.48	9.41
2	Jibi	4.13	-1.38	-2.76	0.61	-0.75	-0.70	2.82	4.31	3.3	23.52	44.22
3	Boonchoke	23.71	-15.44	-8.27	1.39	-10.48	-3.45	19.13	1.44	0.93	35.27	8.91
4	Lucky	14.40	-6.96	-7.44	2.31	-2.18	-5.55	15.82	1.58	1.34	14.8	36.44
5	Tungtong	29.24	-6.10	-23.14	3.21	-10.82	-1.53	26.49	1.59	1.38	13.37	28.14
6	ชมพู่	17.80	-6.27	-11.53	2.16	-1.52	-5.75	14.77	2.96	1.94	34.53	64.36

Abbreviations: avg: average; cd: during LA conduit phase; ct: during LA contraction phase; EDV: end-diastolic volume; EF: ejection fraction; ESV: end-systolic volume; GS%: global strain; TPSD: total peak systolic dispenser; LAS: left atrial global longitudinal strain; pLASR: peak of left atrial strain rate; r: during LA reservoir phase

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	Tosuwan J and Surachetpong SD. 2021. Reversible pulmonary hypertension secondary to bronchopneumonia in a kitten. The Thai J. Vet. Med. 51, 3 (Aug. 2021), 621–627.

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