DIAGNOSTIC ACCURACY OF SHEAR WAVE ELASTOGRAPHY IN COMPANION ANIMAL SOFT TISSUE INJURY: A SYSTEMATIC REVIEW

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CERTIFICATION

This is to certify that we have read this research paper entitled **'Diagnostic Accuracy of Shear Wave Elastography in Companion Animal Soft Tissue Injury: A Systematic Review'** by Chin Yi Lin, and in our opinion it is satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the course DVT 55204 – Research Project.

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DEDICATIONS

I hereby dedicate my dissertation work to my family. Warmest thanks to my mother, Koh, for accepting me and lifting me up as who I am today. My siblings, J.W. and Wendy, who have loved me dearly.

I dedicate this dissertation to many lecturers who have guided me throughout the process. Thanks to Prof. Ibrahim who always have faith in me and keep me going on no matter what. Proving what I thought I could not have accomplished has been one of the most rewarding moments of my life. Thank you, Dr. Wakil and Dr. Goni who have shepherded me through the thesis writing process.

I also dedicate this work to my friends, who directly or indirectly helped me – mentally or physically, in the process. Thanks for being the best cheerleaders in my life. I could not have done this without all the kind words and support.

I dedicate this work to myself. I will go further, farther and freer while upholding the honor of Hippocrates. I put my future in god’s hands and in the love of god, all glory to Him who has given me all I have.

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Abbreviation

ARFI	Acoustic radiation force impulse
CEUS	Contrast-enhanced ultrasound
E	Young's modulus
EHBO	Extrahepatic biliary obstruction
EHPSS	Extrahepatic portosystemic shunt
FNA	Fine needle aspiration
G	Shear modulus
LN	Lymph node
MHPSS	Multiple acquired portosystemic shunts
pSWE	Point shear wave elastography
ROI	Region of interest
STE	Strain elastography
SWE	Shear wave elastography
SWV	Shear wave velocity
TE	Transient elastography

ABSTRACT

An abstract of the research paper presented to the Faculty of Veterinary Medicine, Universiti Malaysia Kelantan, in partial requirement on the course DVT 55204 – Research Project

Shear wave elastography (SWE) is a novel diagnostic modality to evaluate tissue stiffness in relation to the tissue's molecular constitution and disease status. This imaging technique measures the propagation velocity of the shear wave in relation to the tissue's stiffness – the stiffer the tissue, the faster the waves are. This systematic review is conducted to identify the diagnostic accuracy and peculiar organ sensitivities towards SWE while evaluating if this technique is feasible in small animal clinical settings. Thus, a total of 15,339 publications from 2010 to 2022 were extracted from three databases, Google Scholar, PubMed, and Science Direct using different search strategies. A total of 17 studies have met the eligibility criteria after sequential screenings according to the inclusion and exclusion criteria. 25 examinations across 17 studies, 36.0% of studies discussed SWE in the canine or feline liver, specifically hepatic fibrosis, followed by 12.0% that discussed pancreatic lesions. Other parenchymatous organs were also discussed, including the mammary gland, kidney, spleen, peripheral lymph nodes, pancreas, prostate, kidney, thyroid, salivary glands, and muscles. Until now, the liver remained the most studied organ for the diagnostic accuracy of SWE in small animal practice. SWE was proven to positively correlate with other diagnostic standards including strain elastography, FNA biopsy, and histopathological examination, and is expected to be used as an adjunct diagnostic method in detecting tissue stiffness and parenchymatous organ injury with increased accuracy.

Keywords: *Shear wave elastography, canine, feline, diagnostic accuracy, feasibility*

ABSTRAK

Abstrak daripada kertas penyelidikan dikemukakan kepada Fakulti Perubatan Veterinar, Universiti Malaysia Kelantan untuk memenuhi sebahagian daripada keperluan kursus DVT 55204 – Projek Penyelidikan.

Shear wave elastography (SWE) adalah modality diagnostik baru bagi menilai kekerasan tisu yang berhubung dengan konstitusi molekul dan status penyakit. Teknik pengimejan ini mengukur halaju gelombang *shear wave* berhubung dengan kekerasan tisu – semakin keran tisu tersebut, semakin cepat gelombangnya. Semakan sistematik ini dijalankan untuk mengenalpasti ketepatan diagnostic teknik ini dan sensitiviti organ terhadap SWE, sementara menilai sama ada teknik tersebut boleh dilaksanakan dalam klinikal praktis haiwan kecil. Sejumlah 15,339 buah penerbitan dari tahun 2010 hingga 2022 telah diekstrak daripada tiga pangkalan data, termasuk Google Scholar, PubMed dan Science Direct dengan menggunakan strategi carian yang berbeza. Sebanyak 16 penerbitan telah memenuhi kriteria kelayakan selepas saringan berurutan dan penerbitan ini telah dipilih. Sebanyak Daripada 24 pemeriksaan, 36.0% daripada 16 penerbitan ini membincangkan SWE dalam hati anjing ataupun kucing, khususnya terhadap fibrosis hepatic, diikuti oleh 12.0% yang membincangkan lesi pada pancreas. Organ-organ lain termasuk limpa, nodus limfa periferal, pancreas, kelenjar prostat, kelenjar salivary, tiroid, buah pinggang dan otot turut dibincangkan. Sehingga kini, hati kekal sebagai organ yang paling banyak dikaji untuk ketepatan diagnostk SWE dalam amalan haiwan kecil. SWE telah terbukti mempunyai korelasi positif dengan piawaian diagnostik lain termasuk *strain elastography*, biopi FNA, dan pemeriksaan histopatologi. SWE dijangka untuk digunakan sebagai kaedah diagnostik tambahan dalam mengesan kekerasan tisu dan kecederaan organ dengan peningkatan ketepatan.

Kata kunci: *Shear wave elastography, anjing, kucing, ketepatan diagnostic, kebolehlaksanaan.*

1.0 INTRODUCTION

In recent decades, elastography has evolved as an innovative imaging technology. Using ultrasonography, the acoustic and mechanical characteristics of a region of interest can be assessed and displayed as a color-coded map. It is utilized to detect alterations in the organ's stiffness, which is correlated with the tissue's molecular composition, structural organization, and, most crucially, pathological condition (Figueira *et al.*, 2015). The elasticity and rigidity of tissue are frequently connected with pathological alterations involving inflammation, fibrosis, neoplasia, and calcification. When elastic tissue is subjected to mechanical excitation, the stiffness parameters of the tissue dictate the level of longitudinal displacement and deformation. These variations will then be monitored and recorded to provide images of elasticity. Furthermore, elastography can be divided into quasi-static and dynamic elastography, which pertains to strain imaging and shear wave imaging, respectively.

Shear wave elastography (SWE) is a dynamic elastography technology that generates low-velocity, lateral shear waves that can penetrate deeper layers of tissue. Shear waves can be produced by external vibration, physiologic motion, and acoustic radiation force (Shiina, 2015). There is a correlation between the propagation velocity of shear waves and tissue stiffness; the stiffer the tissue, the faster the waves travel. Using Doppler instruments, the wavelength at the vibration site can provide a real-time estimation of tissue stiffness in the area of interest (Figueira *et al.*, 2015). SWE is advantageous due to its more robust mechanical penetrating properties, which enable the detection of the lesion in obese patients or patients with ascites and pleural effusion. It has also been demonstrated to have more excellent reproducibility than other elastography procedures because the results are independent of the operator's skill. The fundamental principles of stress, strain, and elastic modulus should be understood to interpret the images generated from SWE. The differences in the elasticity of soft tissues when experiencing shear and compression are expressed by Young's modulus (*E*) or shear modulus (*G*) (Shiina, 2015).

Since the early 1990s, elastography has been utilised to define localised lesions of numerous organs, particularly in the human prostate, liver, breast, lymph nodes, musculoskeletal system, and thyroid gland (DeJong *et al.*, 2017). SWE has, to the author's knowledge, acquired increasing interest among small animal practitioners. In veterinary practices, it has been shown efficient for measuring the stiffness of the liver, lymph nodes, muscles, pancreas, spleen, kidney, prostate gland, and mammary tissue. By monitoring strain levels and ratios, SWE gives crucial information for distinguishing malignant from benign lesions in parenchymal organs, according to numerous studies. As a result, SWE is anticipated to generate new diagnostic information regarding the elasticity of tissues.

1.1 Research problem

In the past decade, noninvasive elastography has gained more attention in human and veterinary medicine and has become more commercially available. Studies have been carried out on the feasibility and reliability of SWE in diagnosing soft tissue injury in a human patient. However, there has been limited research that explored the level of diagnostic accuracy using SWE in small animals.

As the changes in tissue stiffness can help in the early detection and diagnosis of disease when morphological changes are not apparent, a thorough review of the available literature can contribute to understanding the principle and future of SWE in veterinary practices.

This study aimed to review the uses of SWE in small animal medicine to provide evidence-based information regarding the diagnostic accuracy of SWE compared to biopsy for the evaluation of tissue stiffness in the case of soft tissue injuries. The feasibility of the routine usage of SWE will also be discussed from the clients' and practitioners' perspectives.

1.2 Research questions

1.2.1 What is the level of diagnostic accuracy using SWE in small animals?

1.2.2 What are the peculiar organ sensitivities to SWE diagnosis?

1.2.3 What is the feasibility of the routine usage of SWE in veterinary practices?

1.3 Research hypothesis

1.3.1 SWE has better diagnostic accuracy for soft tissue injury than other diagnostic methods.

1.3.2 The liver is the most sensitive organ to SWE diagnosis.

1.3.3 SWE is feasible for routine use in the companion animal practices.

1.4 Objectives

1.4.1 To determine the level of diagnostic accuracy of SWE in soft tissue injury from the available literature

1.4.2 To identify the organ which is more sensitive to SWE diagnosis.

1.4.3 To identify the feasibility of routine usage of SWE in veterinary practices.

2.0 LITERATURE REVIEW

2.1 Principle of shear wave elastography

Shear wave elastography (SWE) is a technique for dynamic elastography that creates transverse shear waves that cause particles to oscillate perpendicular to the wave's direction. As the shear wave velocity (SWV) propagates through the tissue, it is measured and shown on a color-coded map. Each color pixel in the elastogram represents the location-specific mechanical properties (DeJong *et al.*, 2017). The stiffness of tissue within the area of interest (ROI) is compared to that of surrounding tissues. Each elastography's shear wave velocity is measured as Young's modulus (kPa) and shear wave velocity (m/s). Young's modulus quantifies the tissue's resistance to compressive deformation (strain) resulting from mechanical stimulation or forces (stress) put on the tissue. The greater Young's modulus, the greater the tissue's resistance to compressive deformation and, thus, the stiffer the material. Existing SWE techniques include 1-dimensional transient elastography (1D-TE), point shear wave elastography (pSWE), and 2-dimensional shear wave elastography (2D-SWE). 1D-TE, which became commercially available in 2003, is the most popular method for evaluating liver fibrosis in human patients utilizing the FibroScanTM system without direct B-mode image guiding (Shiina, 2015). 2D-SWE is the most recent imaging approach for shear waves that employs acoustic radiation forces. The linear or curve transducer generates repeated push pulses within a brief time frame, causing tissue displacement. The returning echo pattern will change over time, and the same transducer is used to monitor these changes. 2D-SWE enables real-time display of a colour quantitative elastogram superimposed on a B-mode image, enabling the operator to make decisions based on anatomical and tissue stiffness data (Sigrist *et al.*, 2017).

2.2 Routine usage of shear wave elastography in veterinary practices

In SWE, all tissues are assumed to be viscoelastic, isotropic, and incompressible. When a mechanical force (stress) is applied, the tissue response in local displacement and deformation (strain) is known as their mechanical properties.

Young's modulus (E) represents the relationship between the applied pressure and the resulting strain. It quantifies how difficult it is to deform a tissue via compression or shear stress and can be calculated using the following equation after externally applying stress (σ) and measuring the strain (ε),

$$E = \sigma / \varepsilon$$

A study of human breast tissue samples demonstrates that E levels are much greater in diseased than in normal glandular tissues (Samani *et al.*, 2007).

SWE has acquired significant attention throughout the years as one of the emerging diagnostic modalities utilized in clinical settings because of its noninvasiveness, real-time capabilities, and greater penetration strength. The approach has supplied valuable information for analyzing the rigidity of lymph nodes, pancreas, spleen, thyroid, breast tissues, prostate gland, kidney, muscles, and most notably, the liver. Transient elastography has been proven to assess and predict the course of human liver cirrhosis (Kim *et al.*, 2019). SWE has also been shown to correlate renal parenchymal stiffness with renal function deterioration in feline studies (Thanaboonnipat *et al.*, 2019). Recent research indicates that in the musculoskeletal system, SWE can be used to measure the shear elastic modulus of the thoracolumbar multifidus muscle in dogs, and the results correlate positively with age-related changes (Tokunaga & Shimizu, 2021).

2.3 Comparative diagnostic accuracy of SWE

The gold standard for detecting microscopic pathological changes in the tissue's molecular structure is a biopsy. It is a recognized difficult and invasive procedure that requires the patient to be under general anesthesia. Repeated biopsies may be necessary for certain circumstances to assess the progression of a disease or to account for the possibility of sampling error. SWE evolved gradually as a noninvasive and accessible diagnostic tool in human medicine for determining the severity of soft tissue injury, especially in the staging of hepatic fibrosis. Tamura et al. (2019) compared the liver shear wave velocity (SWV) of six dogs with clinically significant hepatic fibrosis, twenty-two without such fibrosis, and eight healthy dogs. Even though the SWVs of dogs with clinically relevant hepatic fibrosis were significantly greater than those without clinically relevant hepatic fibrosis, it is challenging to predict the absence or mild severity of hepatic fibrosis in dogs using 2D- SWE. The authors hypothesized that necroinflammatory activity within the hepatic parenchyma was difficult to stage and evaluate on SWVs because the necroinflammatory activity had a weaker effect on SWVs than hepatic fibrosis. Comparing the diagnostic accuracy of 2D-SWE to that of other diagnostic modalities, specifically biopsy, will require additional research.

3.0 MATERIALS AND METHODS

This systematic review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

3.1 Literature search and strategy

Three English electronic databases, Google Scholar, PubMed and Science Direct were used for literature searching. The search setting was fixed from 2010 to 2022 to identify all the literature published within the specific time frame. Specific search phrases include keywords of “shear wave elastography” OR “sonoelastography” AND “feline” OR “cat” OR “canine” OR “dog” AND “soft tissue injury” OR “parenchymal organ injury” OR “healthy” AND “diagnostic” OR “diagnosis” were used. Various combinations of the above terms were included in the searches across the three databases. All the search results were recorded and summarised in Table 3.1.

3.2 Screening, inclusion and exclusion criteria

To ensure the data retrieved from the literature are relevant to the scope of this review, several screenings were conducted based on the inclusion and exclusion criteria. The inclusion criteria of this review included all original studies that use 2D shear wave elastography (SWE) for clinical diagnosis or research in small animal medicine. Studies with detailed data sufficient to evaluate the diagnostic performance of SWE, i.e. Mean ± SD shear-wave velocities (SWVs) (m/s) or Young modulus elasticity measurements (*E*) were also included.

As for the exclusion criteria, conference proceedings, published books, review articles, and case reports regarding SWE were discounted. Exclusion criteria also included studies of other SWE techniques besides 2D-SWE (such as acoustic radiation force impulse SWE), SWE in species other than canine or feline, overview, pathogenesis or treatment for parenchymatous organ injury. Studies that focused on other elastographic techniques were excluded. The study focused on the region of interest besides parenchymatous organs were excluded.

After an appropriate search across databases, the first screening was conducted to remove unrelated studies and duplicates based on citations using EndNote X9. The second screening was conducted manually to remove studies focusing on general ultrasound techniques and scope irrelevant or beyond SWE based on the title. The final screening was performed manually based on the evaluation of the title, abstract and methodology of the publications to finalize the total number of literature to be reviewed according to the inclusion and exclusion criteria. The process and result of the screening are illustrated in Diagram 4.1.

3.2.1 Result synthesis

All of the literature was systematically reviewed and the result of the literature assessment was tabulated.

Table 3.1: Search strategy across different databases and literature retrieved

Database	**Google Scholar**	**PubMed**	**Science Direct**
Search strategy	Sonoelastography OR ultrasound elastography OR shear elastic modulus OR 2-D shear wave elastography OR elasticity imaging technique **AND** Veterinary OR small animal OR companion animal OR feline OR canine **AND** Diagnostic accuracy OR reliability OR evaluation OR assessment OR performance OR reproducibility	Sonoelastograph* OR ultrasound elastography* OR quantitative ultrasound OR shear elastic modulus OR 2-D shear wave elastography OR point shear wave elastography OR elasticity imaging technique* OR "Elasticity Imaging Techniques/veterinary"[Mesh] **AND** Veterinary OR small animal* OR companion animal* OR pet OR feline OR canine OR cat OR dog OR "Pets"[Mesh] **AND** Diagnostic accuracy OR diagnostic reliability OR evaluation OR examination OR assessment OR performance OR reproducibility OR "Data Accuracy"[Mesh] **AND**	Shear wave elastography OR sonoelastography **AND** Medicine OR feline OR canine **AND** Diagnostic accuracy OR reliability OR performance OR assessment

		Medical OR “Medicine” [Mesh]	
Number of literature retrieved	9,634	3,645	2,060
Total		15,339	

4.0 RESULTS

The search strategy identified a total of 534 publications that were eligible to be assessed after removing duplications and publications beyond the scope of interest. A total of 17 publications were selected for the systematic review after sequential screenings where the result is depicted in Diagram 4.1. Among the studies included, prospective studies (10 out of 17, 58.8%) and cross-sectional studies (7 out of 17, 41.2%) were analyzed. Table 4.1 summarizes the published studies and the region of interest for SWE diagnosis reported from 2010 to 2022. The raw data retrieved from the selected studies were summarized in Appendix 1. The 10 assessed tissues include the liver, mammary gland, muscle, spleen, kidney, pancreas, prostate, salivary gland, thyroid, and peripheral lymph nodes, whereby the liver was the organ most frequently studied across 16 studies (9 out of 25 examinations, 36.0%), followed by the pancreas (3 out of 25, 12.0%). The mammary gland, spleen, and kidneys were included in this review (2 out of 25 examinations, 8.0%, respectively), while thigh musculature, thoracolumbar multifidus muscle, prostate, salivary glands, and thyroid were the least studied among the publications (1 out of 25 examinations, 4.0%, respectively). Most publications focused on canine subjects (14 out of 17, 82.4%) while three studied feline shear wave elastography (3 out of 17, 17.6%).

Diagram 4.1: Flowchart illustrating methodology and result of screening for literature review

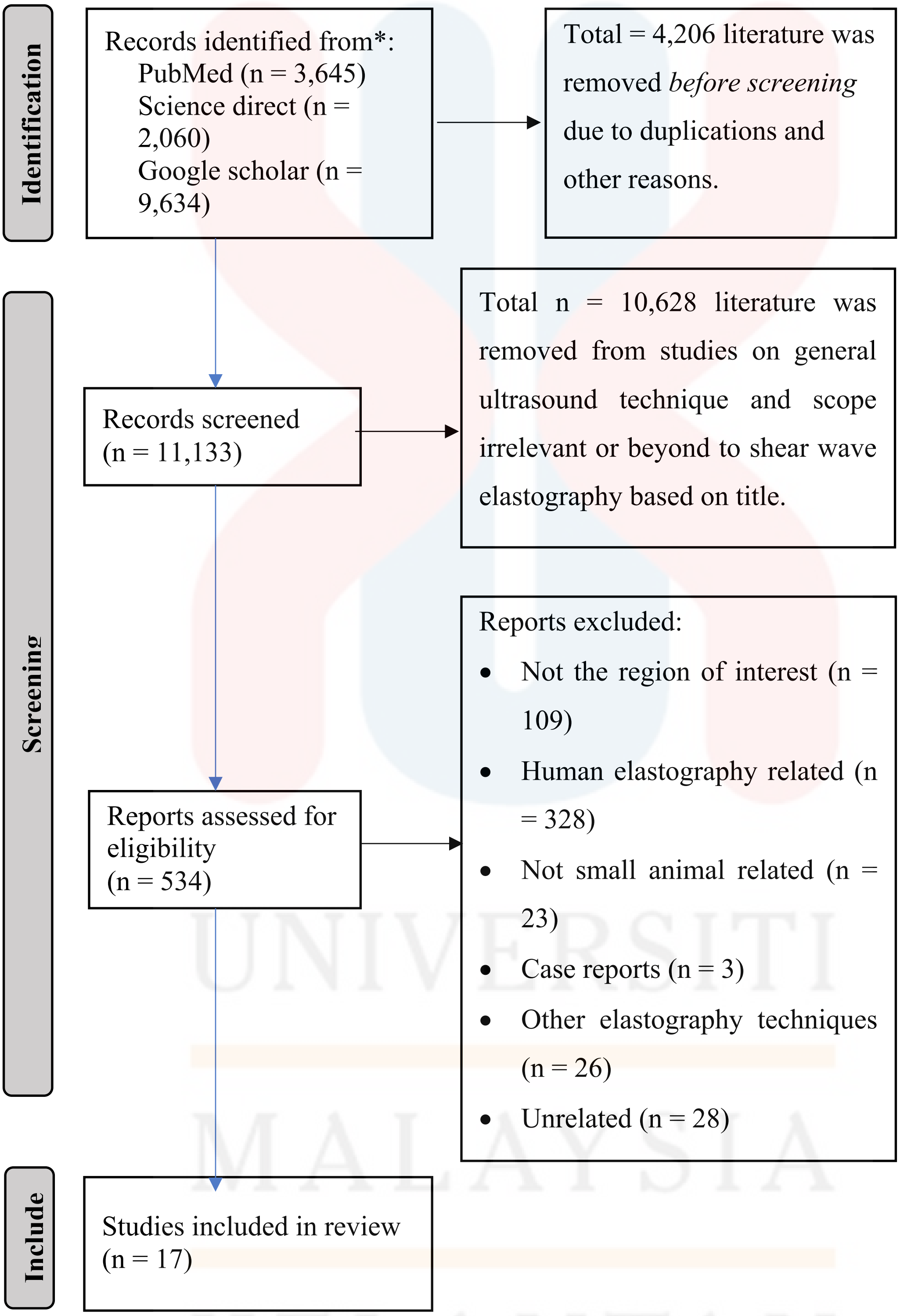

Table 4.1 Studies included for analysis

First author (Year of publications)	Subject	Organ of interest	Correlated diagnostic workup	Operator (experience in diagnostic imaging)
Glińska-Suchocka (2013)	12 canines	Mammary gland	FNA biopsy	NM
Feng (2016)	14 canines	Liver	Histopathology, plasma MEGX liver function test	NM
Shimizu (2019)	12 canines	Thigh muscles	NA	2 veterinarians (>20 y and 1 y)
Tamura (2019)	36 canines	Liver	Serum HA concentration and histopathology	NM
Tamura (2019)	8 canines	Liver and spleen	NA	1 operator (NM)
Thanaboonnipat (2019)	48 felines	Kidney	Serum biochemistry, urinalysis and uPIIINP	NM
Avante (2020)	25 canines	Pancreas	CEUS, ARFI and Doppler ultrasound	1 operatory (9 y)
Jung (2020)	9 canines	Liver, spleen, kidneys, pancreas, prostate, LNs,	NA	2 veterinarians (7 y and 2 y)

		salivary glands, and thyroid		
Kang (2021)	11 canines	Peripheral LNs	NA	3 trained operators (NM)
Kim (2020)	29 felines	Liver	NA	2 veterinarians (NM)
Park (2021)	18 felines	Liver	NA	1 operator (NM)
Tamura (2021)	20 canines	Liver	NA	3 trained operators (>10 y)
Tokunaga (2021)	12 canines	Muscles	MRI	2 sonographers (NM)
Cho (2022)	41 canines	Pancreas	Spec cPL immunoassay	1 veterinarian (6 y)
Massimini (2022)	22 canines	Mammary gland	STE and histopathology	1 operator (3 y)
Puccinelli (2022)	45 canines	Liver	NA	1 sonographer (NM)
Toom (2022)	21 canines	Liver	NA	NM

CEUS = contrast enhanced ultrasound; FNA = fine needle aspiration; HA = hyaluronic acid; LN = lymph node; NA = not available; NM = not mentioned; MRI = magnetic resonance imaging; STE = strain elastography; uPIIINP = urinary procollagen type III amino-terminal propeptide

4.1 Canine shear wave elastography

Jung *et al.* (2020) investigated numerous tissues, including the lymph nodes, pancreas, spleen, kidney, liver, prostate, salivary glands, and thyroid, in a study of canine shear wave elastography (SWE). The author reported that liver has an excellent reproducibility (ICC:

0.864-0.948) and most abdominal organs, with the exception of the right prostate (Intraclass correlation coefficient, ICC: 0.534) and axillary lymph node (ICC: 0.552).

The review showed that the liver remained the most studied organ in canine shear wave elastography, comprising 6 out of 16 studies or 37.5%. The reliability and performance of shear wave elastography on the normal healthy hepatic tissues hepatobiliary parenchymatous changes such as hepatic fibrosis, extrahepatic biliary obstruction, and hepatic vascular anomalies were investigated. A baseline reference range of hepatic stiffness in shear wave values (SWV) and Young's modulus were established by Jung *et al.* (2020) and Tamura *et al.* (2019) in healthy Beagles. The study conducted by Feng *et al.* (2016) and Tamura *et al.* (2019) revealed increased SWVs in dogs with hepatic fibrosis, as compared to healthy patients. The former discussed a significant positive correlation of liver stiffness between histologic grading and SWVs ($p < 0.001$), which shows that it was beneficial to incorporate this non-invasive imaging modality into assessing liver disease severity. However, Tamura *et al.* (2019) concluded that SWE was still insufficient for quantifying different levels of hepatic necroinflammatory activities because there was no significant difference in the SWVs between healthy dogs, dogs without inflammatory activity, and dogs with inflammatory activity ($p = 0.11$). Toom *et al.* conducted the initial investigation of SWE on canine hepatic vascular anomalies (2022). There were no significant differences between the mean SWVs of dogs with a surgically closed extrahepatic portosystemic shunt (EHPSS) and dogs with multiple acquired portosystemic shunts (MAPSS), indicating that SWE was unable to distinguish between the two groups. Even though liver was commonly assessed in 2D-SWE practices, including in the human medicine field, in another study by Tamura *et al.* (2021), the occurrence of extrahepatic biliary obstruction (EHBO) in hepatic fibrosis prediction was studied. The author concluded that EHBO could increase the SWVs of dogs without clinically significant alterations in the liver parenchyma, thus interfering with the noninvasive hepatic fibrosis prediction using this elastographic technique. Puccinelli *et al.* (2022) found that the use of anesthesia could be a source of variation in SWE studies.

SWE was also proved feasible for assessing pancreatic stiffness in acute pancreatitis, as concluded by Cho *et al.* (2022). High pancreatic SWVs were demonstrated in the canine patients with acute pancreatitis compared to the normal control group ($p < 0.05$). The author also revealed a positive correlation between SWVs and Spec cPL concentration ($p < 0.05$) which was suggested to be closely related to the increase in pancreatic stiffness from neutrophilic inflammation and pancreatic interstitial edema. A preliminary study conducted by Avante *et al.* (2020) demonstrated similar results as to Cho's, where a significant difference (p = 0.014) was observed between the mean SWVs of the pancreas between the healthy control group and the diseased group. Avante also concluded that the cutoff value of a healthy pancreas is at 1.98 m/s with a 78% sensitivity and 69& specificity, any SWV higher than this cutoff could represent pancreatic disease, in which acute inflammatory processes can resulted in lower SWV than in chronic alterations.

A study conducted by Glińska-Suchocka *et al.* (2013) on canine mammary gland neoplasia proved that benign neoplasms of the mammary gland (fibroadenoma and adenoma) had a significantly lower stiffness as compared to the malignant neoplasms (carcinomas). According to the author, it was safe to state that the noninvasive SWE enables the differentiation of benign and malignant neoplastic lesions of the mammary gland in bitches and can be suggested as a screening examination in the future. Another recent study by Massimini *et al.* (2022) discussed the correlations between SWE, STE, and histopathological examination in canine mammary nodular lesions. No significant correlations were found between STE and SWE ($p > 0.05$) whiel significant Pearson correlation coefficient between fibrosis and SWE-S ($p < 0.001$) were identified. Among the two elastographic techniques, SWE was found more replicable in quantifying canine mammary tumors, largely attributed to the changes in mammary tissue stiffness.

A few studies in healthy patients have proven the repeatability of SWE and these results could serve as baseline reference ranges in canine patients. According to Kang *et al.* (2021), the mandibular lymph nodes (LN) were the most superficial, and the medial retropharyngeal LNs were the deepest. Supported by Jung *et al.* (2020), no significant difference was identified from the SWVs of the different lymph nodes. In this study, 3 operators established a significant positive intra- and interobserver interclass correlation, further supporting that SWE is accurate and reproducible in assessing peripheral LNs.

Next, Shimizu & Ito (2019) investigated the relationship between the change in the shear elastic modulus and the change in muscle length, particularly on the thigh muscles, namely the cranial part of the sartorius, vastus lateralis, biceps femoris, and semitendinosus muscles. The results showed an increased shear elastic modulus when all muscles were elongated, which suggested that SWE can be used as an adjunct diagnostic modality in assessing the elastic properties of canine muscle. The intra- and inter-observer correlation coefficients were excellent except in the semitendinosus muscle, which was suggested to be due to different joint angles and acquisition methods. Another SWE study on musculature, particularly on the thoracolumbar multifidus muscles, conducted by Tokunaga & Shimizu (2021) also demonstrated the feasibility of SWE in measuring muscle stiffness. The authors have concluded that the thoracolumbar multifidus muscle stiffness decreased with age.

Studies by Tamura *et al.* (2019) and Jung *et al.* (2020) have demonstrated high repeatability and reproducibility for 2D-SWE of the spleen in canines. When comparing the right lobe of the liver to the spleen, the stiffness of the spleen was found to be significantly greater. For both the spleen and liver, the intra-day and inter-day coefficient of variation was less than 10%, which is clinically acceptable. It is safe to conclude, based on repeatability and reproducibility, that 2D-SWE is capable of assessing splenic stiffness in healthy dogs. According to Jung, however, the results of splenic elastography may be affected by the use of anesthesia drugs, as higher SWVs and Young's Modulus were observed in the anesthetized patient compared to the pre-anesthesia phase. Thus, it was demonstrated that anesthesia could be a source of variation in splenic SWE examinations.

4.2 Feline shear wave elastography

Three publications were revealed for the clinical applications of SWE in feline patients. A study conducted by Thanaboonnipat *et al.* (2019) showed a higher renal cortical *E* value in CKD patients than in healthy cat patients. There was a significant positive correlation between the renal cortical *E* values and three other parameters, which included plasma creatinine, blood urea nitrogen (BUN), and urinary procollagen type III amino-terminal propeptide (uPIIINP) ($p < 0.001$; $p < 0.05$; $p < 0.001$, respectively). At the same time, they negatively correlated with urine specific gravity and urine osmolality per plasma ratio ($p < 0.001$ and $p < 0.01$, respectively).

Next, supported by Kim *et al.* (2020), Park *et al.* (2021) concluded that a quantitative SWE of the liver in healthy adult cats is repeatable and feasible in clinical settings. Both studies demonstrated no significant correlation between the SWVs and the cat's body weight or between the SWVs and the depth of measurement. Kim further concluded that gabapentin administration was not a source a variability and the feline liver SWE can be reliably performed with or without anesthesia.

5.0 DISCUSSION

Feasibility and Reproducibility of Shear Wave Elastography in Small Animal Soft Tissue Organs

Several shear wave elastography (SWE) studies in healthy patients have set baseline reference ranges for future studies. A study conducted by Jung *et al*. (2020) has comprehensively evaluated the feasibility and reproducibility of 2D-SWE in multiple soft tissue organs, including the vital abdominal organs, salivary glands, thyroid, lymph nodes, and prostate gland of canine patients. Excellent reproducibility was demonstrated in the liver which once proven that liver is indeed sensitive toward elastographic assessment. There are no significant differences between studies conducted by Jung and Tamura *et al*. (2019) on hepatic shear wave values (SWVs) in healthy canines. The former concluded that the mean SWVs of the healthy canine right liver lobe was at 1.60 ± 0.11 m/s while the latter concluded at 1.51 (range, 1.44-1.66) m/s. As for the feline hepatic SWE study, Park *et al*. (2021) and Kim *et al*. (2020) demonstrated a reliable mean SWV of 1.46 (1.36-1.55) m/s and 1.52 ± 0.13 m/s respectively, in feline patients. Feng *et al*. (2016) compared the diagnostic accuracy of SWVs and histologic grading of canine liver stiffness due to induced hepatic fibrosis, ranging from F0 to F4 with increased severity. The median *E* was found to increase significantly from F0 (5.0 ± 0.4) kPa to F4 (28.3 ± 17.8) kPa, which supported the hypothesis that increasing organ stiffness due to disease severity will have a higher propagation velocity from reduced elasticity and viscosity. According to Feng, the 2D-SWE also had a better performance in assessing liver fibrosis than the conventional transient elastography. This statement was also supported by Massimini *et al*. (2022) as their study demonstrated the high reliability of SWE in quantifying the stiffness of canine mammary nodular lesions, which will be discussed later. In Feng's study, the 2D-SWE shows precise cutoff values of 8.0 kPa and 13.1 kPa for F2 and F4. The results demonstrated by mammary SWE correlated well with the histologic grading of experimental fibrosis with *p*

< 0.001. Although hepatic SWE has been proven with high reliability, this technique was still unable to differentiate between a canine patient with a closed extrahepatic portosystemic shunt (EHPSS) and a multiple acquired portosystemic shunt (MAPSS) as demonstrated by Toom *et al*. (2022) ($p = 0.33$). The authors suggested that similar results between the two groups could be due to insufficient liver fibrosis and alteration in hepatic stiffness caused by the persistent MAPSS. exThus future research regarding dynamic changes between the pre- and post-operative elastography results should be carried out for further investigation. Another study conducted by Tamura *et al*. (2021) studied the effects of extrahepatic biliary obstruction (EHBO) and hepatic stiffness assessment by using 2D-SWE in dogs. The study demonstrated that EHBO could reversibly increase the SWVs of dogs without clinically relevant hepatic fibrosis, as previously reported in human studies (Harata *et al*., 2011; Kubo *et al*., 2016). The cause of increased SWVs in EHBO still remains unknown – as the histopathological hepatic fibrosis stages were not different between dogs with and without EHBO. Therefore more studies need to be conducted to identify the true cause attributed to changes in elasticity in the case of EHBO, aside from the changes in structural organization and molecular constitution in relation to the peculiar organ's disease status.

The study conducted by Cho *et al.* (2022) has again proven that the increase in SWVs is significantly related to tissue stiffness, represented by the infiltration of inflammatory cells and the edematous parenchyma or expansion of the particular organ interstitium, driven by the chemical mediators and complement cascade. Spec cPL immunoreactivity test is currently recognized as one of the most sensitive method (sensitivity 70.0-90.0%; specificity 74.1-88.0%) to diagnose canine acute pancreatitis, by measuring the level of canine pancreas-specific lipase level (Cridge *et al*., 2021; McCord *et al.,* 2012; Cridge *et al.*, 2018; Haworth *et al.*, 2014). A moderate positive correlation ($r = 0.489$; $p < 0.05$) between the pancreatic SWVs and Spec cPL concentration was demonstrated in the case of acute pancreatitis canine patients. SWE of the right pancreatic lobe was performed in this study as the right pancreatic stiffness is more sensitive towards injury with a higher reproducibility, supported by Jung *et al.* (2020). The triangular canine pancreas is anatomically divided into the pancreatic body and two lobes. The study conducted by Jung demonstrated a significant difference in the SWVs between the body and the right lobe of the pancreas, which is not aligned with the findings from human studies using pSWE. Ferraioli *et al.* (2015) suggested that the difference in SWVs between different pancreatic regions is mostly due to technical factors, including the range of interest (ROI), angle and depth. However, this theory is less practical in the case of canine anatomy as both the body and the right lobe of the pancreas are located just superficially within the abdominal cavity. Jung concluded that the differences in SWE could be caused by probe compression during the investigation of the pancreatic body as it is located below the pylorus. Another study conducted by Avante *et al.* (2020) demonstrated that chronic pancreatic changes commonly had higher SWVs as compared to acute pancreatic alterations. Similar findings were also discussed in human patients by Goertz *et al.* (2016) by using ARFI technique. The high SWVs in chronic pancreatitis were suggested to be due to chronic fibrosis from prolonged inflammatory cascade which occurred within the pancreatic parenchyma, in which the increased fibrous content resulted in greater stiffness and decreased elasticity within the organ parenchyma.

A prospective study conducted by Massimini *et al*. (2022) demonstrated a significant correlation between the mean SWVs of mammary tissue and the extent of fibrosis. The SWVs were lower for benign mammary hyperplasia (100.8 ± 15.8 kPa) with a 37.06 ± 15.59% of fibrosis. However, for a benign mammary tumor with a 70.50 ± 0.79% of fibrosis, the SWVs increased to 137.4 ± 4.8 kPa, which again proved the correlation between tissue stiffness and SWVs ($p < 0.001$). The grade III malignant canine mammary tumor was reported to have a lower mean SWVs at 88.7 ± 56 kPa compared to grade I (114.9 ± 4.9 kPa). This result was supported by another study conducted by Glińska-Suchocka *et al*. (2013). The author discussed that the neoplastic changes in most malignant tumors had a lower elasticity and lesser tissue deformation since the malignant neoplastic tumors were growing rapidly. The stromal fibrous tissue infiltration did not take place within a short period of time thus they were accompanied merely by an inflammatory reaction. A similar finding was demonstrated in a study conducted on a group of 52 women with mammary gland lesion, conducted by Evans *et al*. (2010). However, in the case of *tumor mixtus*, cartilaginous and bone tissue infiltration could produce false positive results as they contributed to the higher tissue stiffness. A tissue biopsy or FNA should be carried out to determine the underlying tumor type because in such cases, the role of elastography is limited (Dobruch-Sobczak & Sudoł-Szopińska, 2011). Many publications in the field of human medicine have demonstrated positive results of the studies on sonoelastographic differentiation of the female mammary gland lesion, in which the performance of this diagnostic modality has been proved (Olgun *et al*., 2014; Youk *et al*., 2017; Evans *et al*., 2010). 2D-SWE is safe to differentiate between the benign and malignant neoplastic lesions of the mammary gland. Yet, it should be remembered that the identification of the exact tumor type requires a further diagnostic workup.

Tamura *et al.* (2019) evaluated the spleen stiffness of healthy dogs by using 2D-SWE in which the results can be served as a baseline reference. Due to the splenic anatomical tissue organization which consists of red and white pulp and also the fibroelastic reticular parenchyma, the mean SWV and mean E was higher as compared to the liver, which was 2.18 ± 0.27 m/s and 14.66 ± 3.79 kPa, respectively, across 8 healthy Beagles. Also supported by Jung *et al*. (2020), the acquisition of splenic elastographic images could be easily induced due to the superficial anatomical location of the spleen. In Tamura's opinion, splenic stiffness measured with 2D-SWE can be served as supporting evidence to assess secondary splenomegaly from portal hypertension. It can be used as a prediction tool to identify the onset or severity of portal hypertension in small animal patients with chronic hepatitis or cirrhosis.

As for the renal elastographic technique, the anatomical complexity of the kidney parenchyma renders inconsistent SWE values. A study conducted by Thanaboonnipat *et al*. (2019) demonstrated no significant difference across the average Young's modulus values of feline renal cortex and medulla bilaterally in each healthy and chronic kidney disease (CKD) group. However, higher average *E* values of the renal cortex and medulla of CKD patients (left kidney: 51.89 ± 11.25 kPa; 39.16 ± 13.07 kPa) were demonstrated in this study as compared to the normal control group (left kidney: 38.40 ± 7.12 kPa; 30.16 ± 5.97 kPa), with a p-value of $p < 0.001$ and $p < 0.01$, respectively. Similar findings were demonstrated in a human study conducted by Grosu *et al*. (2019), in which the SWV values are significantly lower in the CKD patient group as opposed to the healthy volunteer. According to Jung *et al*. (2020), canine renal medulla elastographic measurements are unreliable due to anatomical anisotropy of the renal pyramids, which can result in heterogenous propagation of the shear wave as depicted in the color map, within the region of interest.

The prior ARFI study conducted by Silva *et al*. (2018) demonstrated that the 2D-SWE approach might also be applied to other organs, such as peripheral lymph nodes. Significantly elevated SWVs were seen in the inguinal and axillary lymph nodes of canines with metastatic tumors. 2D-SWE was superior to B-mode and Doppler in detecting metastatic lymph nodes, with 100% sensitivity and 94% specificity in the axillary lymph node and 95% sensitivity and 87% specificity in the inguinal lymph node, respectively. In contrast, the study conducted by Kang *et al*. (2021) on healthy peripheral lymph nodes revealed no significant difference between the positions (peripheral, central, entire) and scanning planes (transverse, sagittal) of the LNs in relation to their respective SWVs. This is likely due to the less anatomical complexity of LNs and their relative sizes when compared to other organs, despite their anatomical division into cortex and medulla.

In a study of numerous soft tissue organs conducted by Jung *et al*. (2020), the salivary gland and thyroid exhibited dependable interobserver agreement and a homogenous colour map appearance without transducer compression. Cosgrove *et al*. (2017) demonstrated comparable results in their investigation of humans. In another human investigation, however, pSWE using ARFI imaging shown greater sensitivity and specificity in distinguishing thyroid nodules than 2D-SWE (90% and 79%; 73% and 66%, respectively) (Kyriakidou *et al*., 2018). The SWE of the salivary gland in humans has only been the subject of a few number of studies, but prior to Jung *et al*. (2020), there was no research had been conducted on canine populations. Additional research is necessary to investigate the technical aspects influencing the 2D-SWE in salivary glands and their relative accuracy in clinically afflicted dogs.

It is difficult to visualize the prostate elastography in the canine population due to its intrapelvic anatomical position. Quantitative elastography can only be performed on the visible portion of the prostate, and according to Jung *et al*. (2020), there was no significant difference between the left and right SWVs, which is validated by Feliciano *et al*. (2015) using the ARFI approach.

Shimizu & Ito (2019) investigated the shear elastic modulus of muscle, specifically on the thigh musculatures including the cranial portion of the sartorius, vastus lateralis, biceps femoris, and semitendinosus muscle. As the first study to investigate the feasibility of ultrasound SWE for muscle stiffness in the canine population, this study demonstrated an increase in the shear elastic modulus of muscle during muscle elongation, proving that changes in muscle stretch are responsible for the increase in muscle stiffness. Maïsetti *et al*. (2012), Koo *et al*. (2015), and Miyamoto *et al*. (2017) demonstrated comparable results in human medical research. Tokunaga & Shimizu (2021) also concluded that in adult Beagles, the thoracolumbar multifidus muscle stiffness decreased with age. The author's hypothesis regarding the relationship between muscle stiffness and the onset of intervertebral disk diseases was rejected as there was no significant difference demonstrated from the study. Further study is required in order to identify the reason of the segmental difference between the adult and young Beagle's muscle shear modulus.

Sources of Variation on SWE Measurement

Even though this innovative imaging technology has been demonstrated to be increasingly beneficial in clinical settings, there are still limitations and sources of variation in its use in small animal medicine. As numerous technological aspects are not standardized, the comparability of data across various system configurations and characteristics will vary. The study conducted by Tamara *et al*. (2019) regarding hepatic SWVs in healthy beagles demonstrated an SWVs difference between the left and right liver lobes in which the right lobe had significantly higher SWVs than the left lobe. Whereas in the study conducted by Jung *et al*. (2020), no significant difference were identified between different measurement sites and approaches to the liver. However, when comparing the SWVs between these two studies, Jung's demonstrated a generally higher hepatic SWVs than Tamara's (right lobe 7.57 ± 1.17 kPa and left lobe 7.8 ± 0.06 kPa; right lobe 6.93 ± 0.79 kPa and left lobe 6.02 ± 0.61 kPa, respectively). Yet, a direct comparison of the data across these two studies is difficult, as a different model of the ultrasound machine and probe were used. A multifrequency linear probe was used in the study conducted by Jung, and as supported by human literature by Ferraioli *et al*. (2018), the linear probe can derive a higher hepatic SWS than the convex probe in the case of liver fibrosis and cirrhosis.

Besides the technological aspects, the examination technique itself such as the application of anesthesia, selection of ROI, number of valid measurements, the plane of acquisition, pressure, and angle of the probe. The usage of sedatives and anesthesia can help in reduce respiratory motion in animals while making the elastography procedure smooth, especially in uncooperative patients (Holdsworth *et al*., 2014; Jung *et al*., 2020). However, a study conducted by Puccinelli *et al*. (2022) demonstrated that the median 2D-SWE was significantly higher in anesthetized dogs, which proved that anesthesia was a source of variability in the SWE values. The study conducted by Jung also described an increment in splenic SWVs in the post-anesthetic phase. Both of the findings could be due to the contribution of the anesthetic drugs in transient cardiovascular modifications and hemodynamics, which results in alterations in liver and splenic perfusion. Similar findings were also demonstrated in human medicine regarding hepatic congestion caused by right-sided congestive heart failure, cardiovascular anomalies, and disease conditions related to the heart valves (Ferraioli *et al*., 2020).

In addition to the patient's respiration and cardiac motion, the SWE can also be altered by patient-specific variables such as body weight, body condition score, sex, and anatomical geometry (Holsworth *et al*, 2014). According to Kim *et al*. (2020), the patient’s age, weight, and body condition score were not confounding factors for feline hepatic SWVs. Similar findings were also discussed by Jung *et al*. (2020) in canine patients. However, a pSWE study by Cosgrove *el al*. (2013) conducted in the canine populations demonstrated that sex and body weight had a significant effect on SWVs in certain organs. Tokunaga & Shimizu also concluded that thoracolumbar multifidus muscle stiffness in dogs was affected by their age. Thus, further studies with larger sample sizes across different breeds with even female to male numbers are required to examine the effect of patient factors to the SWVs.

Concurrent diseased status can also affect the SWV values in a SWE study. A study conducted by Tamara *et al*. (2021) in canine hepatic SWE has demonstrated that a concurrent biliary disease, particularly extrahepatic biliary obstruction can reversibly elevate the hepatic SWVs in a patient without clinically relevant hepatic fibrosis, as proven by histopathological examination, to such a degree that might cause confusion. The author also concluded that EHBO can interfere with predicting noninvasive hepatic fibrosis using 2D-SWE. A similar finding was also demonstrated in human studies conducted by Harata *et al*. (2011) however in this study, liver biopsies were not conducted as the biliary drainage in all patients was achieved by noninvasive techniques such as endoscopic or percutaneous transhepatic biliary drainage. Thus it is not clear whether the patients with EHBO in this study had accompanying histopathological hepatic fibrosis during measurement of SWV.

6.0 CONCLUSION AND RECOMMENDATION

In this review, the feasibility and sensitivity of shear wave elastography (SWE) in small animal soft tissue injuries were reviewed. It is safe to say that SWE has reliable accuracy and reproducibility in diagnosing small animal soft tissue injuries. Many studies have established a baseline for different organs which can be used as a reference. Up until December 2022, the liver remains the most studied organ in small animal practices. 2D-SWE has effectively proven its sensitivity and feasibility in small animal studies and is supported by many previous literature, in both human and veterinary medicine. However, to further investigate the reliability and reproducibility of 2D-SWE in diagnosing particular organ injury and alteration of tissue stiffness, additional studies must be conducted across species and breeds with other diagnostic modalities as references (e.g., other imaging or elastography techniques, cytological examination, histopathological examination, and blood work). Different sources of variation must be identified to ensure that the data are standardized.

As a recommendation to improve this review, more feline SWE studies should be included as there is a marked imbalance in the proportion of the studies across canine and feline SWE.

More studies that correlates the shear wave values to other diagnostic references should also be included to further investigate the accuracy and sensitivity of SWE itself. Other databases can be included to further improvise this review. Lastly, bias assessment and meta-analysis can be performed on all the literature included. This can further evaluate the quality of the data and the degree of reliability of the evidence, presented in this review.

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Appendix A: Raw data summary from each study included for the review

Author (year) ***Type of study***	OOI ROI	Subjects	Ultrasound system	Use of anaesthesia	Results	Conclusion
Glińka-Suchocka (2013) ***P***	MG	12 dogs with MG tumoral lesions	Aixplorer, 7.5-15 MHz probe	NM	The benign mammary tumor has a lower stiffness as compared to the malignant tumor, average 22.42 kPa and 235.44 kPa, respectively.	SWE effectively differentiate different MG lesion particularly between the benign and malignant neoplastic condition.
Feng (2016) ***CS***	Liver	12 experimental Beagles with induced hepatic fibrosis, 2 control animals	Aixplorer color Doppler ultrasound system, 4-15 MHz probe	Anesthetized, drugs were not mentioned	Positive correlation between SWE LSM and histologic hepatic fibrosis grading ($r = 0.835$, $p < 0.001$). Significant increase of G in the F4 group as compared to F3, F2 and F0.	SWE LSM has a significant correlation with hepatic fibrosis confirmed with histopathological examination and MEGX liver function test.

Shimizu (2019) ***P***	Thigh muscles	12 healthy Beagles	Aplio i600 with a high-frequency 10MHz linear array transducer (PLT-1005 BT)	Sedated with medetomidine 20 ug/kg, IM	Increment in the thigh musculature elastic modulus were demonstrated in all thigh muscle groups when it was elongated.	Changes in muscle length can caused an increment in shear elastic modulus of the thigh musculatures and SWE is feasible in assessing the stiffness of healthy dog musculature.
Tamura (2019) ***CS***	Liver	28 dogs with hepatic diseases and 8 normal healthy Beagles	Aplio 500 with a 3.5-MHz convex probe (PVT-375 BT)	All dogs were not anesthetized or sedated	High median SWVs were demonstrated in canine patient with significant hepatic fibrosis (2.04 m/s with the range of 1.81-2.26 m/s) than in healthy control group (1.51 m/s with the range of 1.37-1.67 m/s). However, SWE cannot significantly differenciate between dogs with necroinflammatory activity and those without the activity.	2D-SWE is feasible in detecting the disease condition of liver in canine patient particularly on hepatic fibrosis.

Tamura (2019) ***P***	Liver, spleen	8 healthy Beagles	3.5-MHz convex transducer	All dogs were not anesthetized or sedated	The hepatic and splenic SWVs as demonstrated in this study was 1.51 ± 0.08 m/s and 2.18 ± 0.27 m/s, respectively. Higher elasticity was identified in the splenic SWVs as compared to the hepatic values.	SWE showed feasibility in assessing both hepatic and splenic tissue stiffness in a healthy canine population.
Thanaboonnipat (2019) ***CS***	Kidney	23 CKD cats and 25 healthy cats	Resona-7 with a 9-MHz linear transducer	No, restrained manually	The E value in the feline renal parenchyma (both cortex and medulla) was significantly higher in the CKD group as compared to the healthy cat group. A positive correlation between the cortical E values, plasma creatinine and BUN was identified.	SWE showed feasibility in assessing the feline renal parenchyma stiffness and the uPIIINP/Cr can be use as a biomarker in diagnosing early feline renal fibrosis or CKD.
Avante (2020) ***P***	Pancreas	16 healthy dogs and 9 dogs with	ACUSON S2000 - SIEMENS, with a linear and convex	NM	The group with suspected pancreatic disease has a higher SWV than the	SWE has a good sensitivity and specificity as compared to CEUS and

		suspected pancreatic disease	multifrequency transducers (7.5-9.0 MHz)		healthy group (2.4 ± 0.5 m/s and 1.9 ± 0.3 m/s, respectively), with a sensitivity of 78% and a specificity of 69%.	Doppler ultrasound in identifying pancreatic alteration in canine study.
Jung (2020) ***P***	Liver, spleen, kidney, pancreas, prostate, LNs, SGs, thyroid	9 healthy Beagles	Aplio i600 with a 5.0-14.0 MHz linear-array transducer	All dogs were anesthetized with 0.75mg/kg zolazepam-tiletamine, IM and 0.03mg/kg medetomidine.	All abdominal organs showed moderate to excellent reproducibility except for the left hepatic lobe, while the renal medulla could not be assessed with SWE effectively. Anaesthesia significantly increase the splenic G. Significant differences in the SWE across different measuring site and scan approach of pancreas and kidneys were observed ($p < 0.001$), but not in the liver.	SWE is feasible and reproducible in canine practice with anaesthesia and measuring sites as the possible sources of variability.

Kim (2020) ***P***	Liver	29 healthy cats	Aplio i800 with a 12.0-MHz linear transducer	Gabapentin was prescribed during transport and examination 100mg/cat	SWVs and stiffness were lower in the right hepatic lobe than the left, with 1.52 ± 0.13 m/s and 1.61 ± 0.15 m/s respectively ($p = 0.005$, $p = 0.002$). No significant result detected from the patient's factor and usage of anaesthesia ($p > 0.05$).	Patient's factors (age, body weight, BCS) and usage of gabapentin does not influence the SWVs in feline hepatic study. SWE is reliable in feline study and these data can be served as a baseline reference.
Kang (2021) ***P***	PLNs	11 healthy Beagles	Aplio 500 and Aplio A with 10-MHz linear array transducer	Some dogs are sedated with medetomidine hydrochloride; maximum dose of 40 µg/kg, IM to minimize movement artifacts.	The image acquisition plane is significant in the LNs SWV, in which all scans examined in sagittal plane is higher than the transverse plan. The mandibular LN is the most superficial, with the highest SWVs while the medial retropharyngeal LN is the deepest.	SWV effectively measures the stiffness of PLNs with good reproducibility. This data can be served as a reference for other future SWE study.
Park (2021) ***P***	Liver	18 healthy cats	ARIETTA 830 ultrasound machine with a small 4-8 MHz	No sedation or anesthesia was used in all cats,	The right hepatic SWVs were higher as compared to the left hepatic lobe, with	pSWE was feasible in quantifying the hepatic stiffness in healthy

			curved-array transducer and 2-12 MHz linear-array transducer.	restrained manually.	1.36-1.55 m/s (1.46 m/s) and 1.26-2.47 m/s (1.36 m/s), respectively.	felines. These data can be served as a baseline reference for other future studies.
Tamura (2021) ***CS***	Liver	7 dogs with EHBO and 13 healthy Beagles	Aplio 500 with a 3.5-MHz convex transducer (PVT-375BT)	All dogs were not anesthetized or sedated	A significantly higher median SWVs were identified in the EHBO group as compared to the healthy control group, with 1.91 (1.8102.54) m/s and 1.57 (1.37-1.64) m/s, respectively, although there was no histopathological relevant hepatic fibrosis in the patient with EHBO, after a FNA biopsy examination.	EHBO can reversibly increase and interfere the canine hepatic SWVs at the degree that is similar to clinically significant hepatic fibrosis.
Tokunaga (2021) ***P***	Thoracolumbar multifidus muscle	5 young dogs with IVDH onset < 2yo and 7 adult dogs with	Aplio a450 with a 10-MHz linear array transducer (PLT-1005 BT)	All dogs were sedated with medetomidine intramuscularly	Increment of multifidus length and cross-sectional area towards the caudal. The multifidus E of T13 < L3 for the young group	SWE effectively measures the length of the canine multifidus muscle at the thoracolumbar region. Decreased multifidus

		IVDH onset > 2yo			while E for L1-L3 in the adult group is lower as compared to the young group.	stiffness can be related to age.
Cho (2022) ***CS***	Pancreas	31 healthy dogs and 10 dogs with acute pancreatitis	EPIQ 5 with a 4-18 MHz linear array transducer	All dogs were manually restrained without sedation or anaesthesia	The acute pancreatitis patient has a significantly higher SWVs as compared to the healthy control group, with 2.67 ± 0.20 m/s and 2.30 ± 0.26 m/s, respectively ($p < 0.05$). Moderate positive correlation was found between the Spec cPL concentration and the acute pancreatitis shear wave values.	SWE showed high feasibility in diagnosing acute pancreatitis, in which SWVs significantly increased as compared to the healthy canine patients. It can be used as an adjunct diagnostic method in order to diagnose the acute pancreatic condition in canine patient.
Massimini (2022) ***P***	MG	22 female dogs with MG lesion	Logiq S8 with a 9L-D multi-frequency linear probe	NM	Similar mean SWVs for STE and SWE were demonstrated across the benign and malignant mammary lesion.	SWE showed high reliability and correlation with histologic mammary fibrosis. SWE also demonstrated better

					Significant correlation was revealed between the level of fibrosis, STE and SWE. ($p < 0.001$ and $p < 0.001$, respectively).	repeatability as compared to other elastography technique (STE).
Puccinelli (2022) ***CS***	Liver	45 healthy dogs	Aplio a CUS-AA000 by one sonographer, with a 3.5 MHz convex probe	IM injection of dexmetomidine, methadone and ketamine, followed by IV propofol for induction and isoflurane for maintenance.	Higher SWVs were demonstrated in the patient administrated with anesthetic drugs than other awake dogs.	Anesthesia can help with reduced respiratory motions however, it also contributed to variability in the canine hepatic SWE assessment.
Toom (2022) ***P***	Liver	15 dogs with closed EHPSS and 6 dogs with MAPSS	Philips ElastQ Imaging and an eL 18-4 ultra-broadband linear array transducer	NM	No significant was demonstrated between the median hepatic SWVs in the canine group with closed EHPSS and those with MAPSS (2.83 ± 0.11 m/s and 2.71 ± 0.17 m/s, respectively).	SWE is insufficient in distinguishing closed EHPSS and those with MAPSS.

CEUS = contrast-enhanced ultrasound; CKD = chronic kidney disease; CS = cross-sectional; EHBO = extrahepatic biliary obstruction; EHPSS = extrahepatic portosystemic shunt; IVDH = intervertebral disk herniation; LSM = liver stiffness modulus; MAPSS = multiple acquired portosystemic shunts; MG = mammary gland; NM = not mentioned; OOI = organ of interest; P = prospective; PLNs = peripheral lymph nodes; ROI = region of interest; SG = salivary gland; STE = strain elastography; SWE = shear wave elastography