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ADVANCING DIAGNOSTIC FRONTIERS: THE EVOLVING ROLE OF COMPUTED TOMOGRAPHY IN VETERINARY MEDICINE

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ABSTRACT

Computed Tomography (CT) has become a cornerstone in veterinary diagnostic imaging, offering unparalleled detail and accuracy. First introduced in 1972 by G.N. Hounsfield, CT generates high-resolution cross-sectional and 3D images, surpassing traditional radiography by eliminating superimposition. Modern CT systems, including high-speed, low-dose, dual-source, cone beam, and portable machines, accommodate diverse clinical applications. CT facilitates the diagnosis of various conditions, including brain tumours, nasal and ear diseases, spinal injuries, orthopaedic abnormalities, and respiratory, abdominal, and urogenital pathologies. Advanced techniques such as CT angiography provide precise imaging of vascular structures, aiding in detecting portosystemic shunts and vascular anomalies. Its ability to differentiate tissue densities and reconstruct 3D images enhances pre-surgical planning and therapy monitoring. However, challenges such as high costs, radiation exposure, and the need for specialized expertise limit its accessibility. Future advancements in CT technology, including cardiac imaging and brachytherapy planning, are anticipated to broaden its diagnostic and therapeutic potential in veterinary medicine. Continuous innovation and training are essential to fully harness the capabilities of CT, ensuring improved outcomes for veterinary patients. This review underscores CT's pivotal role in modern veterinary practice, addressing current applications and exploring its prospects for advancing diagnostic and therapeutic methodologies.

Keywords: Computed Tomography (CT), Veterinary diagnostics, 3D imaging

INTRODUCTION

The technique of computerized axial transverse scanning was first introduced in April 1972 by G.N. Hounsfield. In recognition of their contributions to the development of computed tomography (CT), Hounsfield and Alan Cormack, a physicist from Tufts University, were jointly awarded the Nobel Prize in Physics in 1982. The Hounsfield Unit (HU), used to quantify the density of various tissues, is named in Hounsfield's honor. This innovation has revolutionized diagnostic and therapeutic approaches in both human and veterinary medicine. A Computed Tomography (CT) facility comprises three primary areas: the gantry room, console room, and patient preparation room. The gantry room houses the CT scanner and is equipped with radiation-shielding walls, with a minimum thickness of 320 mm, and lead glass of at least 2 mm thickness to ensure safety. The console room contains two key components: a slave computer and an interpretation computer. The slave computer is specifically utilized for live image slicing in animals, facilitating real-time imaging and analysis. Interpretation computers are equipped with higher-resolution monitors compared to slave computers and are used for detailed image analysis through specialized inbuilt software. The CT machine operates by utilizing X-rays and advanced computer processing to generate cross-sectional (transverse) slices of internal structures. During scanning, the system captures 3600 images of the patient as they move through the gantry. These axial images can subsequently be processed using computer algorithms to produce 3D reconstructions, coronal sections, sagittal sections, and multiplanar reconstruction (MPR) images. Additionally, the CT unit must be certified for operation by the Bhabha Atomic Research Centre (BARC).

Fig. 1 : CT Gantry room in Madras Veterinary College, Chennai

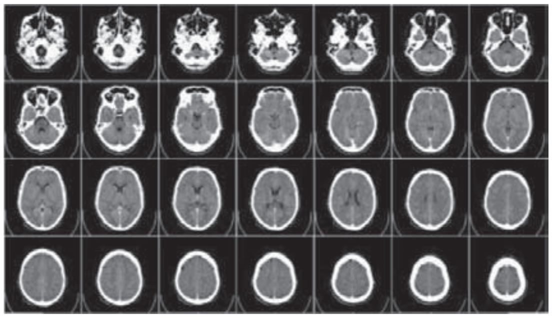

Fig. 2 : CT images printed

Tomography refers to imaging techniques that produce detailed representations of a specific cut, slice, or section of the body, eliminating superimposition from overlying structures (Fabiani, 2009). The term "computed" indicates the mathematical processing of data by a computer to determine the most probable density at any given point within the scanned tissue volume. During a CT scan, transmitted X-ray energy is captured by detectors positioned opposite the patient. This energy is then converted into an electrical signal, which is relayed to the CT computer for processing. The computer translates the electrical signals into digital information, which is subsequently used to generate and display images on a computer monitor.

The human eye can distinguish only 20–30 shades of gray; however, using a CT machine, it becomes possible to differentiate approximately 4,000 shades of gray, significantly enhancing the ability to analyze anatomy and pathology. In CT imaging, tissue density is quantified using Hounsfield Units (HU), which divide the full range of possible densities into 4,000 levels, spanning from –1,000 to +3,000. Air is assigned a value of –1,000 HU, water is set at 0 HU, and dense materials like lead are assigned values close to +3,000 HU. Examples of Hounsfield Units include: Liver: 50–70 HU, Brain gray matter: 37–41 HU, Fat: –80 to –100 HU, Lungs: –950 to –550 HU , Bone: 50–300 HU

Transverse images are perpendicular to the long axis of the body. A CT scan can produce transverse or axial images. One of the main advantages of CT over conventional radiography is the ability to eliminate superimposition. CT images are not only clear but can isolate a specific internal region. Multiplanar images result in higher quality reconstruction, because there are no gaps in data Each CT slice is formatted from multiple x-ray exposures captured as the scan completes a 360-degree rotation.

Modern Multislice CT Machine:

This tomographic image is usually referred to as a **slice**, and each of the individual attenuation points in the image is referred to as a **voxel** (volume element). Modern multislice CT scanners can acquire up to 620 cross-sectional images at once; each rotation may be as short as ¼ sec. These systems are capable of continuous rotation (helical or spiral scanning), in which motion of the patient through the scanner occurs in concert with the rotation of the scanner. One clinical application of spiral CT angiography is the diagnosis of pulmonary thromboembolism.

Multislice CT (MSCT) allows for simultaneous acquisition of 4, 8, and 16 slices respectively. With this, combined with a reduction in scanner rotation time, (to less than 0.5 seconds) imaging time can be accelerated by a factor of 8 to 32. Vessels with very small diameters are clearly visualized. There is improved spatial resolution along the length of the body allowing for high quality secondary reconstructions or 3-D visualization techniques.

Different type of CT machines:

1. Traditional (Spiral) CT

The traditional CT machine uses a single X-ray tube and detector. This type of CT machine Scans in a spiral motion, covering large areas quickly. Advantages are wide availability in hospitals and imaging centers, Fast scanning times (typically 10-30 seconds) and relatively low cost compared to newer technologies. The disadvantages are higher radiation doses due to overlapping scans and limited spatial resolution (around 1-2 mm)

2. High-Speed CT

High speed CT machine features a faster gantry rotation time (typically 0.3-0.5 seconds) and scans in a spiral or axial motion, reducing motion artifacts. The advantages are faster scanning times, reducing motion artifacts and patient discomfort, lower radiation doses due to reduced scan times and improved image quality. The disadvantages are higher cost compared to traditional CT and limited availability in some regions

3. Low-Dose CT

Low Dose CT machine is designed to reduce radiation doses (up to 50 per cent less) and uses advanced reconstruction algorithms and lower X-ray energies. The advantages are reduced radiation doses, making it suitable for pediatric patients, lung screening and cancer detection, patients requiring multiple scans having similar image quality to traditional CT. The disadvantages are lower image quality in some cases and limited availability in some regions


Traditional spiral CT


High Speed CT

4. Dual-Source CT

This CT machine features two X-ray tubes and detectors and scans in a


Low Dose CT

Dual Source CT

spiral or axial motion, improving spatial resolution. The advantages are improved spatial resolution (around 0.5-1 mm), faster scanning times and reduced radiation doses. The disadvantages are higher cost compared to traditional CT and complex operation requiring specialized training

5. Cone Beam CT:

This CT machine uses a flat-panel detector and a cone-shaped X-ray beam and scans in a circular motion, providing high spatial resolutionAdvantages are high spatial resolution (around 0.1-0.5 mm), low radiation doses, real-time imaging capabilities and disadvantages are limited availability in some regions and slower scanning times compared to traditional CT

6. Spectral CT (Dual-Energy CT):

The spectral CT scan features two X-ray tubes and detectors, operating at different energies and scans a spiral or axial motion, improving material differentiation. The advantages are improved material differentiation (e.g., iodine, calcium), reduced artifacts (e.g., beam hardening, metal artifacts) and enhanced image quality. Disadvantages are higher cost compared to traditional CT and complex operation requiring specialized training.

Cone Beam CT

Portable CT

7. Portable CT

The portable CT machine is compact, mobile design for use in various settings (e.g., ICU, OR, ER) and scans in a spiral or axial motion, providing flexible imaging. The advantages are mobile and flexible, reducing patient transport risks, convenient for critically ill patients or emergency situations. The disadvantages are lower image quality compared to traditional CT and limited availability in some regions.

Prerequisite before interpreting CT image:

The radiologist must have a firm knowledge of anatomy and physiology to ascertain the identity of structures in any plane through the body and evaluate changes in its anatomy or physiology. Knowledge of physiology and artifacts are also important in evaluating CT scans. Extensive experience and training are required to become adept in performing CT procedures and deriving the most information from the images.

Application of CT scan in different systems

CT scans are used to detect structural changes deep within the body, including tumors, abscesses, vascular abnormalities, occult fractures, and hematomas. Modern, high-speed scanners are also used to evaluate dynamic physiologic processes such as blood flow, changes in respiratory volume, and intestinal dynamics. Vascular lesions are usually not as well-defined, but intravascular contrast media aids in this regard.

CT application in Skull affections

CT can provide adequate diagnostic information for many brain lesions, intracranial masses and fluid-filled cavities. The ventricular system, tentorium cerebelli, and midline falx cerebri are readily visible on CT scans. CT scan used to diagnose inflammatory, neoplastic, developmental, degenerative or vascular diseases of the brain (Fuchs *et al*., 2003). Contrast study of using iodine contrast medium (600 -900 mg Iodine/kg) (Iohexol, Iopamidol) were studied for differentiating tumors either malignant or non-malignant intracranial lesions. Breakage of blood -brain barrier makes the contrast enhancement by 20-40 HU (Fike *et al*., 1986; Berry, 2002).

Meningiomas are typically peripherally located and homogeneously enhance. Astrocytomas and gliomas typically show peripheral enhancement with central lucent area. Choroid plexus masses are often relatively dense and enhance uniformly. Pituitary tumors may be recognized by their location and typically show uniform contrast enhancement. Brachial plexus tumors are a cause of forelimb lameness and can be identified with CT. CT evaluation of vaccine associated sarcomas has proven to determine the full extent of disease, often altering recommendations based on the CT images, including preoperative radiation therapy when surgery alone was deemed inadequate to affect local tumor control.

CT application in Ear Diseases

The diagnosis of external ear disease is straightforward using otoscope and positive contrast ear canalography. But to assess the role of tympanic membrane and its integrity in the pathogenesis of otitis media deserves CT findings. CT is more superior to conventional radiography in providing details on anatomy and pathology of middle and inner ear and treatment planning (Garosi *et al.,* 2003). High resolution CT with bone window is important for middle ear infection and to differentiate inflammatory changes, cholesteatome and neoplasm.

Fig. 3: 3D reconstruction image of skull with nasal tumor invasion (arrow) in a dog

CT application in Nasal tumors

The nasal cavity is surrounded by nasal, lacrimal, zygomatic, palatine, vomer, ethmoid and presphenoid bones. The cribriform plate is a sieve-like partition between nasal cavity and cranial cavity through which olfactory nerve bundle passes. Sino-nasal neoplasm and fungal rhinitis account for 75 per cent of the chronic nasal affections (Saunders and Schwarz, 2011)**.** Tumor of nasal cavity and paranasal cavity accounts for 1-2 per cent of all canine tumors (Kondo *et al.,* 2008). CT scan can delineate the tumor lesion more accurately as well as can stage the tumor. The dog with chondrosarcoma had better prognosis compared to adenocarcinoma.

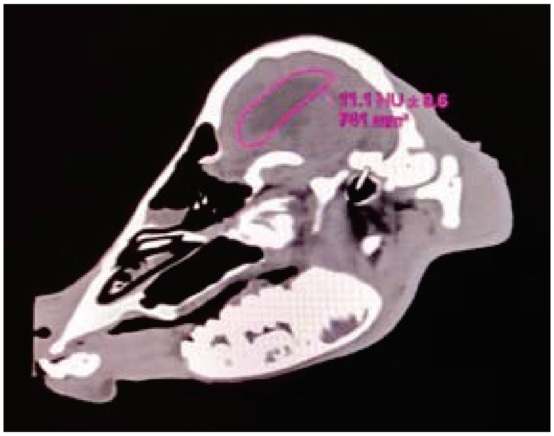

Fig. 4: Hydrocephalus (enlarged third ventricles of brain) in a calf

CT application in spinal affections

Vertebral fractures, luxation, extent of spondylosis, stable or unstable vertebral spinous process hairline fractures, pedicle fractures, spinal cord compression, oedema are detected due to the spatial resolution of the CT scan (Sharp and Wheeler, 2005). Non-mineralized disc extrusion, subdural and epidural hemorrhage diagnosis is better done when the iodine contrast medium injection into the subarachnoid space using myelography technique (Sharp *et al*., 1995). Diagnosis of intervertebral disc pathologies including mineralised or non-mineralised, spinal tumors and spinal surgical plan are more accurately assessed and usually appear more easier due to thin slice thickness on CT as compared with standard radiographs (Jones and Inzana, 2000). For the lumbosacral area, evaluation of bone remodeling, evidence of cauda equina compression by either soft tissue or bone remodeling within the spinal canal, and comparison of size and density of intervertebral foramina, both between right and left sides at the same space and between different intervertebral disc spaces is possible. In intervertebral disc protrusion or herniation, CT may provide valuable additional information following standard radiographic examination. With the exception of lesions in the caudal lumbar and sacral region, a myelogram with standard radiographs should be performed first, followed immediately by CT, if indicated. Good quality CT images demonstrate very thin contrast columns not visible on standard radiographs. CT can be used to demonstrate lateralization of a lesion.

CT application in Orthopaedic conditions

In veterinary orthopedics, plain radiography is an essential diagnostic tool. CT is indicated in conditions like cruciate ligament rupture, degenerative joint disease, panosteitis, hypertrophic osteodystrophy, Legg-Calve Perthes disease, osteomyelitis, bone tumors and

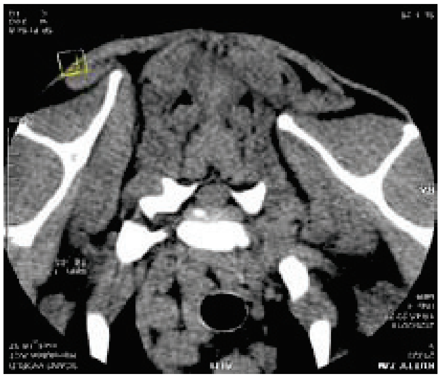

Fig 5 : Disc herniation (blue arrow head) with mild calcification (arrow) at T1-T2 level (axial section)

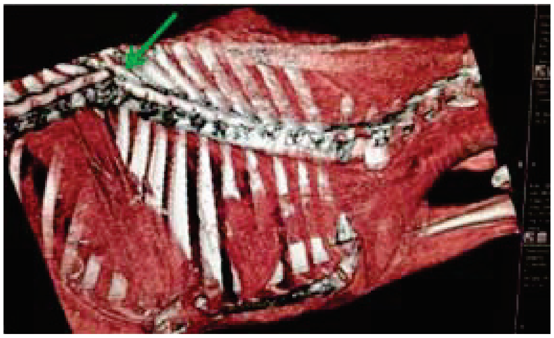

Fig. 6: 3D reconstruction image of vertebral fracture with spinal cord compression (arrow) in a calf

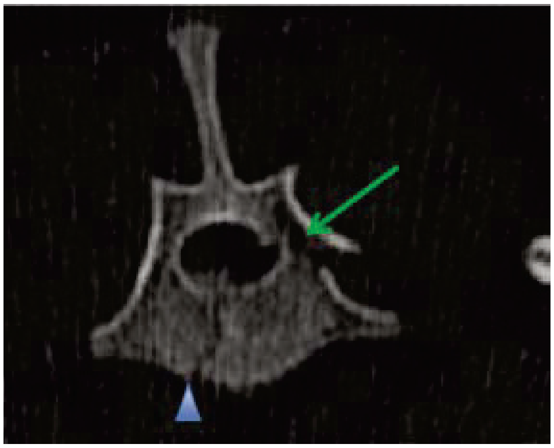

Fig. 7: Vertebral body (arrow head) and right pedicle (arrow) fracture in a Labrador dog

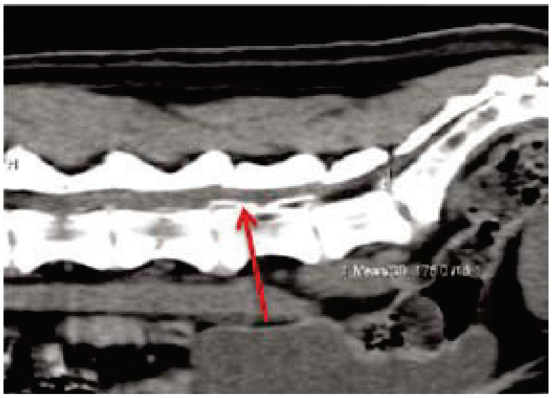

Fig. 8: Dural calcification (arrow) at L6 vertebra level

in all cases where plain radiography fails. Even though MRI is superior to CT in soft tissue ailments, for analyzing the bony lesion CT is inevitable for example cortical bone detail, fragmentation of the coronoid process. CT arthrography has been studied and can be helpful in diagnosing partial cranial cruciate tears. Complex fractures and their association to the previous anatomic structure can be depicted with three dimensional CT images. The ability to reconstruct images in three dimensions can help visualize the pathological abnormality, help to explain the prognosis to the owner and help plan for the best therapeutic remedies. CT performed on patients with pelvic trauma, including hemorrhage and muscular trauma, was critical in identifying soft tissue lesions that could not be visualized by radiographic examination.

Respiratory system

Respiratory diseases in dogs with are classified as upper airway disease (Brachycephalic Airway Syndrome and Laryngeal Paralysis), lower airway disease (bronchitis and bronchomalacia), pulmonary parenchymal disease (pneumonia and pulmonary contusions), vascular disease (pulmonary thromboembolism) and pleural space diseases that include pneumothorax and pleural effusion (Sharp, 2015).

CT is a gold standard diagnostic tool to stage the lung disease accurately during presurgical evaluation and to aid biopsies of the lesions which are invisible with fluoroscopy. CT imaging can guide the location of potentially risky tumor masses that are adjacent to cardiovascular structures. The cross- sectional images created by CT avoid the superimposition of intra- or extra thoracic structures over the lung fields and allows for a more thorough study of the costo-diaphragmatic and subpleural regions. Multiplanar reconstructions are also an option, allowing the clinician to evaluate for more detailed examination of suspicious lesions (Johnson *et al*., 2004).

Windowing is important for diagnostic interpretation and should not be done purely for aesthetic reasons. The density level of the organ of interest should be matched with the window level. The object contrast latitude must be matched with the window width. The structures that have an innately wide range of density, such as the lungs or nasal cavities (bone, soft tissue, air), require a large window, whereas structures with a restricted contrast range (all soft tissues, particularly white/grey matter of the brain) required a small window (Cardoso *et al*., 2007)

CT is considered the most sensitive method for detection of pulmonary metastases. Fitzgerald *et al.* (2017) observed, diffuse pulmonary ground glass opacity, considerable dilatation of peripheral bronchi and pneumomediastinum on computed tomographic images, although there was no indication of thickened bronchial walls. Without the necessity for tissue confirmation, CT data can now be utilized to identify idiopathic pulmonary fibrosis. Coia *et al.* (2017) noted that the most common lesion was increased lung

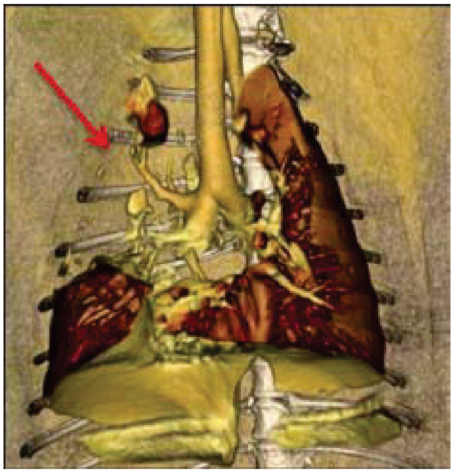

Fig 9. 3 D reconstruction: Complete loss of lung parenchyma of right cranial and middle lung lobes

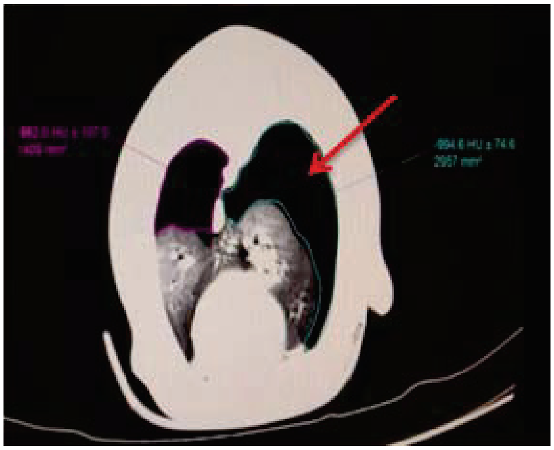

Fig. 10. Axial view of pneumothorax in a dog

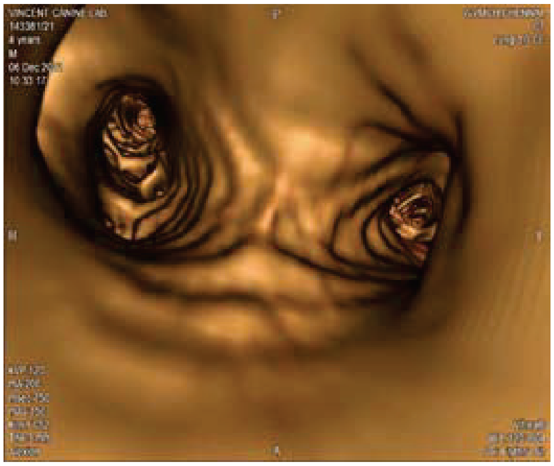

Fig 11. CT scan aided Virtual endoscopy of airway at the level of carina showing left and right principal bronchi

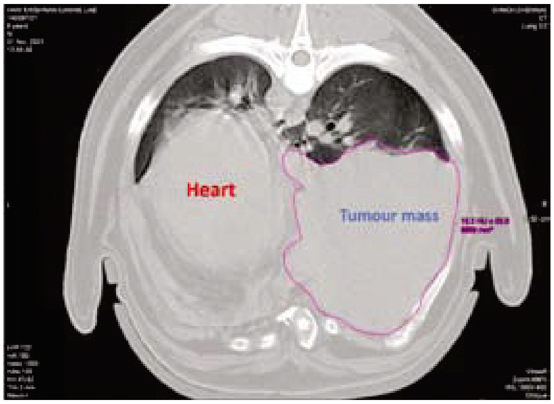

Fig 12. Axial view of thorax at the level of 8th thoracic vertebrae, space occupying mediastinal tumor mass is pushing the heart towards the left side. compression and reduction in lung volume and pleural effusion on the left ventral side.

attenuation as a result of ill-defined ground-glass opacity and consolidation.

CT application in Abdomen

Compared to conventional radiography, CT allows better distinction among specific tissue densities which helps in the detection of subtle changes in abdominal organ size, shape, margin, contour and position. With the advent of multislice CT scanner, data can be acquired rapidly using sedation or even gentle restraint, in place of general anesthesia for most studies (Oliveira *et al.,* 2011). Consequently, as more dogs undergo abdominal CT examination, there has been an increase in the identification of abdominal masses or nodules. CT is useful for the diagnosis of intra-abdominal masses, tumors in stomach, liver and spleen, foreign bodies, pancreatitis, pancreatic hyperplasia, pancreatic abscess or pseudocyst, cholecystitis, hepatic adenocarcinoma, splenic, hepatic infarcts and torsion. CT has been applied in the dog to evaluate the liver, spleen, adrenal gland, pancreas, GI tract and urogenital system (Fife *et al.,*2004; Zwingerberger *et al.,* 2005).

Computed Tomography of the Liver

Single and dual phase computed tomographic angiography has been used to evaluate the portal vein, its tributaries, and intrahepatic branches. CT angiography is a fast, minimally invasive procedure that will image all portal tributaries and branches as they fill with contrast medium during a single peripheral venous injection (Zwingerberger *et al.,* 2005). CT angiography is able to diagnose single and multiple portosystemic shunts, located

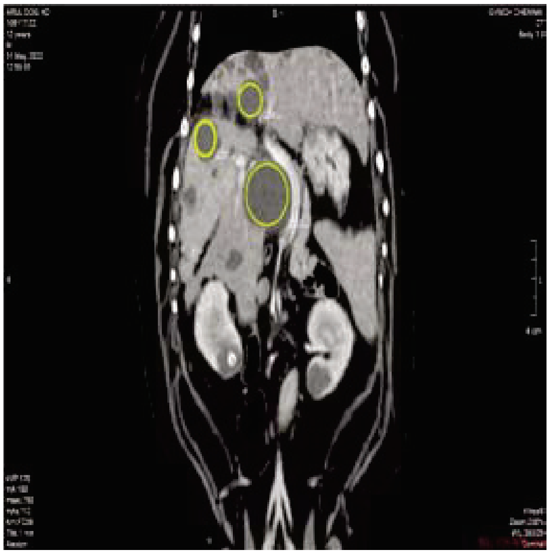

Fig 13: Coronal view: Showing multiple nodular masses in the liver pushing the caudal vena cava towards left

Fig 14: Axial view: Post contrast CT image showing multiple nodular hypoattenuating masses throughout the liver

Fig. 15: 3D reconstruction of chylothorax condition in a dog

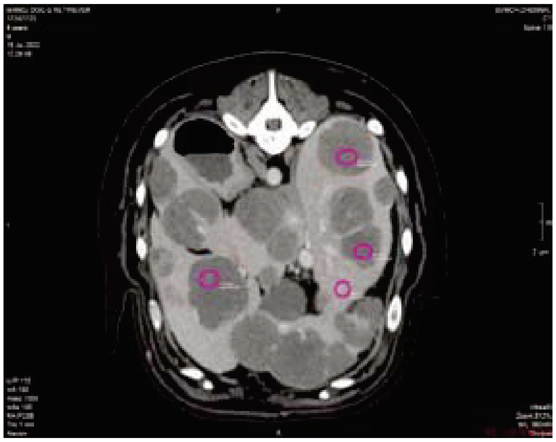

Fig 16: Axial view of liver tumor (hemangiosarcoma) in a dog

both within and outside of the liver. Helical computed tomography allows imaging of the entire liver to find out the focal hepatic lesions. Dynamic CT is useful in detecting benign and malignant hepatic neoplasms in dogs (Kutara *et al*., 2014Tanaka).

Fig 17: CT transverse view demarcating hypoattenuating well defined splenic mass

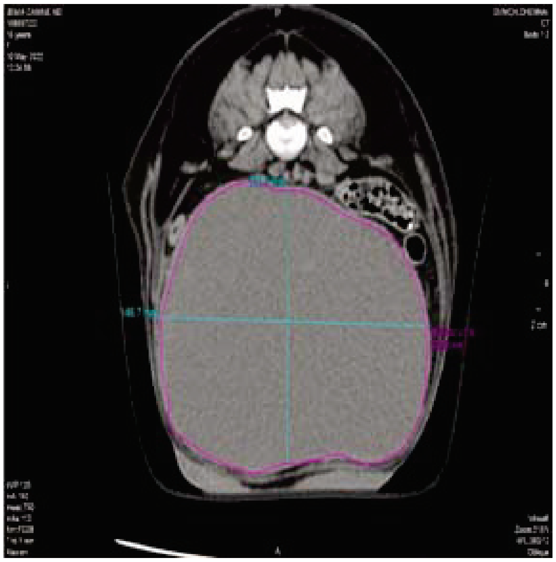

Fig 18: Transverse view-hypoattenuating (19.6HU) enlarged uterus

Burti *et al.,* (2021) described the CT features of focal liver lesions in dogs. They evaluated the following qualitative features: (1) margins (well or ill defined); (2) surface (regular or irregular); (3) appearance and enhancement of the lesion. They also quantitatively evaluated the attenuation of the normal and pathological lesion in both pre and post- contrast CT scan studies.

Computed Tomography of the Spleen

Trans-splenic CT portography can also be performed. In one study, the information gained from CT portography resulted in a decrease in surgical time necessary compared with similar surgeries performed without angiographic information.

CT used to distinguish malignant from non-malignant splenic masses in dogs. The malignant splenic masses had lower HU values than non-malignant masses pre and post contrast medium administration, a value of 55 HU was suggested as the best threshold value. On post-contrast images, nodular hyperplasia had the highest HU (90.3), haematomas had intermediate HU values (62.5) and malignant splenic masses had the lowest HU values (40.1) (Fife *et al.* (2004).

Computed Tomography of the Urinary System

Renal parenchyma

In CT, most of the renal parenchyma of the mass could not be visualized with the exception of a cranial section of the right kidney, and the mass was full of fluid with hypoattenuation (16 HU) with asymmetric kidneys (Kwon *et al.,* 2018). Renal cell carcinoma tends to show heterogeneous enhancement (Fig 21) and unilateral renal involvement, and vessel enhancement was detected in the corticomedullary phase. Conversely, renal lymphomas showed homogeneous enhancement, bilateral renal involvement, multiple masses and no vessel enhancement was detected in the corticomedullary phase (Tanaka *et al.,* 2019).

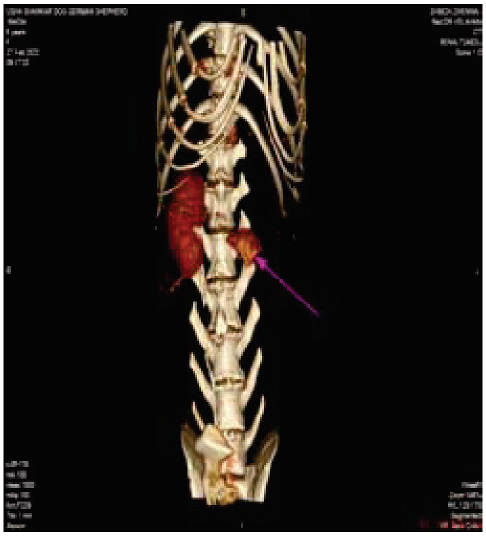

Fig.21: 3D view-heterogeneous hypoattenuating mass in the left kidney. Contrast is taken up only in the cranial pole of left kidney (arrow indicated) and the remaining portion of the kidney is tumor

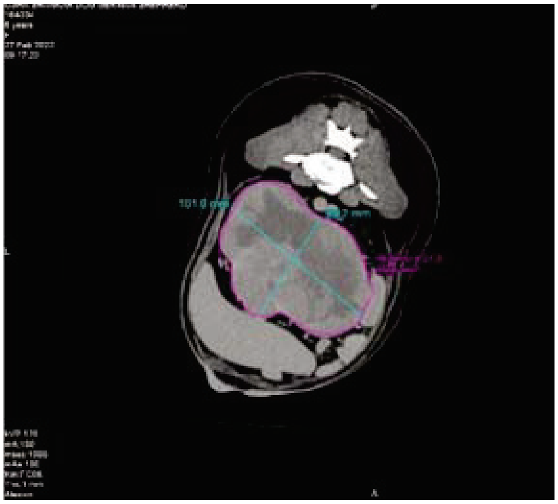

Fig 22: Transverse view of renal tumor Area of about 5520mm.sq.

Computed Tomography of the Urinary Bladder

Transitional cell carcinoma of

Fig 19: 3-Dimension Fly-thru view delineating Urinary Bladder mass

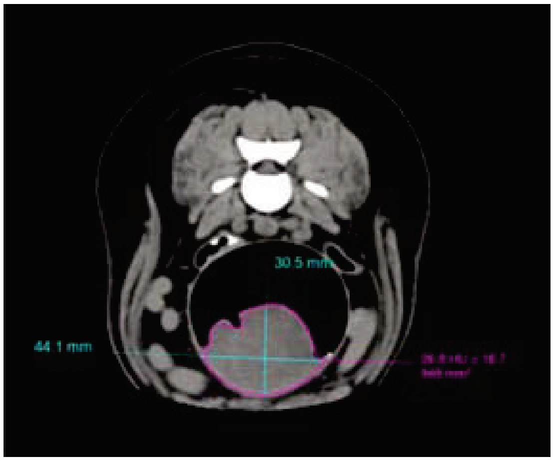

Fig 20: Axial view showing urinary bladder tumor

the urinary bladder was diagnosed with CT to determine extent of tumor size for pre-treatment staging and to assess tumor response to treatment via volumetric comparison measurements (Naughton *et al.*, 2012).

High-field magnetic resonance imaging (MRI) and computed tomography (CT) were characteristics of muscle-invasive bladder transitional cell carcinoma (TCC) in two dogs (Lee *et al.,* 2016). He found that non-contrast CT showed that the urinary bladder masses were irregular and iso-dense and contrast-enhanced CT showed, bladder wall in which the mass was attached was more intensely enhanced than the normal bladder walls, supporting invasion to the muscular layer.

Computed Tomography of the Ovary and Uterus

When imaged with computed tomography (CT), ovarian tumours in dogs appear as large soft-tissue attenuated masses located in the mid-ventral abdomen, with moderate or severe contrast enhancement (Rowan *et al.,* 2017). The uterine nature of a cystic mass occupying most of the abdomen and was subsequently diagnosed as a lipoleiomyoma which also revealed another solid uterine leiomyoma. Lipoleiomyoma was a large, fluid-filled mass with soft tissue septa, while leiomyoma was a small soft tissue mass that showed contrast enhancement and arose from the cranial uterine horn (Percival *et al.,*2018).

CONCLUSION

Computed Tomography (CT) has firmly established itself as a cornerstone of diagnostic imaging in veterinary medicine, offering unmatched detail and accuracy. Its ability to provide high-resolution cross-sectional and 3D images has enhanced the diagnosis and treatment of complex conditions across various systems, including the central nervous system, musculoskeletal structures, respiratory pathways, and abdominal and urogenital organs. Techniques like CT angiography have further refined the identification of vascular abnormalities, enabling precise pre-surgical planning and therapeutic interventions. Despite its transformative role, CT faces challenges such as high operational costs, radiation exposure, and the need for skilled personnel, which limit its widespread accessibility. However, the ongoing development of advanced modalities, including low-dose and portable CT systems, has begun addressing these limitations, broadening its applications and accessibility. The future of veterinary CT imaging appears promising, with advancements in areas such as cardiac imaging and brachytherapy planning offering new opportunities for innovation. Continuous efforts in training and technological upgrades will be critical to fully harness the potential of CT imaging. Overall, CT remains an indispensable tool in veterinary diagnostics, significantly improving patient care and paving the way for further advancements in veterinary medical science.

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