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The future of imaging in veterinary oncology: Learning from human medicine

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Introduction

Diagnostic imaging occupies a foundational role in oncologic practice, both in identifying primary tumors and metastatic spread during staging and in tracking disease evolution over time. Although imaging cannot substitute for histopathological confirmation, a range of modalities can assist in directing diagnostic sampling, and future imaging techniques may permit in vivo tissue characterization. Over recent years, substantial advances have occurred in image quality, detector sensitivity, and the development of contrast agents. As a result, imaging technologies long established in human medicine—including positron emission tomography (PET) and hybrid PET–computed tomography (CT)—are increasingly accessible within veterinary medicine.

Contemporary imaging approaches may be broadly categorized as anatomical, functional, or molecular. Each modality offers specific advantages and limitations with respect to tumor detection, characterization, and staging. The objective of this review is to outline the current capabilities and emerging directions of imaging in veterinary oncology, using representative disease examples to illustrate how these modalities contribute to diagnosis, staging, and therapeutic monitoring.

Imaging modalities

Radiography

Radiography remains a routine and essential imaging technique for establishing baseline assessment of the thoracic cavity and the musculoskeletal system. In conjunction with ultrasonography, radiographs provide information regarding organ size, spatial relationships, and skeletal involvement. As in human oncology, thoracic radiography continues to serve as the primary method for surveillance of pulmonary metastases, particularly in light of concerns surrounding cumulative radiation exposure associated with CT examinations (Brenner, 2010).

The transition from film-screen to digital radiography has significantly improved lesion detectability. Digital systems permit post-acquisition manipulation of image contrast and magnification, enabling identification of pulmonary nodules that are smaller than those detectable using earlier technologies.

Ultrasound

Ultrasonography has become the cornerstone of abdominal imaging in veterinary practice. It allows precise localization of lesions detected radiographically and facilitates detection of abnormalities not visible on radiographs. Despite its sensitivity, the sonographic appearance of intraparenchymal lesions is generally nonspecific, necessitating cytologic or histologic evaluation to establish a definitive diagnosis. An important exception is gastrointestinal disease, where changes in wall thickness, layering, and lymph node morphology may assist in distinguishing lymphoma from inflammatory conditions (Zwingenberger et al., 2010).

Ultrasound is widely employed to guide fine-needle aspiration and core biopsy procedures. Doppler techniques provide insight into vascular flow patterns and may identify vascular invasion, enhancing procedural safety. However, Doppler findings alone do not reliably differentiate benign from malignant processes. Even so, ultrasonography has proven valuable for oncologic staging (Flory et al., 2007). Contrast-enhanced ultrasound techniques adapted from human medicine further expand diagnostic utility, particularly for differentiating benign and malignant hepatic lesions and for improving visualization of otherwise inconspicuous abnormalities.

Several veterinary investigations have evaluated contrast-enhanced ultrasonography for splenic, hepatic, and renal lesions. These studies suggest that contrast patterns may help discriminate malignant from benign pathology, paralleling findings in human medicine (Rossi et al., 2008; Webster and Holloway, 2008; Ivancic et al., 2009; Kanemoto et al., 2009; Haers et al., 2010). Contrast agents have also been used to assess lymph node pathology and to enhance detection of small sentinel nodes prior to biopsy (Salwei et al., 2005; Lurie et al., 2006; Gelb et al., 2010).

In veterinary patients, ultrasonography remains the predominant abdominal imaging modality, largely due to smaller patient size, absence of ionizing radiation, reduced need for general anesthesia, and lower equipment costs relative to CT. Unlike many human examinations, which are often focused and technologist-acquired, veterinary abdominal ultrasound typically involves a comprehensive exploratory assessment performed or directly supervised by a veterinarian.

A major limitation of ultrasound is its restricted cross-sectional field of view compared with CT or magnetic resonance imaging (MRI). This constraint can lead to missed or mischaracterized lesions and prevents accurate measurement of large masses when the entire lesion cannot be visualized simultaneously. Measurement reproducibility is particularly poor for urinary bladder lesions, complicating longitudinal assessment during therapy (Hume et al., 2010).

Modern ultrasound systems offer extended field-of-view capabilities that generate panoramic representations of large lesions. While these images provide valuable qualitative context, they remain static and do not allow precise quantitative measurement. Although ultrasound is often used clinically to estimate tumor extent and margins for surgical or radiation planning, CT and

MRI provide more reliable data for these purposes. Nevertheless, ultrasonography remains well suited for disease screening, evaluation of multi-organ involvement, guided sampling, and follow-up assessments.

Computed tomography

Computed tomography provides cross-sectional imaging that can be reconstructed into virtually unlimited multiplanar and three-dimensional views from a single acquisition. Advances in scanner speed permit image acquisition with sedation or minimal restraint rather than general anesthesia in many cases (Oliveira et al., 2011). The large field of view inherent to CT enables comprehensive evaluation of extensive or complex lesions, supporting accurate surgical and radiation therapy planning.

High-resolution reconstructions are particularly advantageous for delineating tumor margins and vascular anatomy, especially in complex osseous neoplasms. Contrast-enhanced CT protocols can be tailored to capture arterial and venous phases, thereby improving visualization of tumor perfusion, vascular supply, and invasion (Nitzl et al., 2009).

CT is the most sensitive modality for detecting pulmonary lesions in both human and veterinary oncology (Nemanic et al., 2006; Choi et al., 2010; Somboonporn et al., 2010). Despite this sensitivity, thoracic radiography remains widely used due to lower cost and greater accessibility. While CT is the preferred modality for abdominal imaging in humans, its application in veterinary abdominal oncology is more limited, though expanding availability is expected to increase diagnostic expertise.

Public concern regarding radiation exposure from CT has grown following media attention to potential health risks. Current scanning protocols incorporate dose-optimization strategies to minimize exposure (Mayo, 2008; Brix et al., 2009; Sodickson et al., 2009; Brenner, 2010). Although comparable risks have not been clearly demonstrated in companion animals, similar considerations are likely relevant as CT use increases.

Magnetic resonance imaging

Magnetic resonance imaging represents the reference standard for neuroimaging in both human and veterinary medicine and is applicable across nearly all body systems. MRI produces large field-of-view images in any desired plane and employs diverse pulse sequences to accentuate soft tissue contrast based on molecular composition. Consequently, soft tissue resolution surpasses that of CT.

MRI requires longer acquisition times, necessitating general anesthesia in animal patients. Additionally, many radiation therapy planning systems rely on CT-derived electron density data, limiting the integration of MRI data for dose calculations.

Due to its exceptional soft tissue detail, MRI is particularly valuable for preoperative and preradiation delineation of tumors and their margins. It is also highly sensitive for post-therapy monitoring, though this sensitivity may reveal incidental abnormalities of uncertain clinical relevance (Koppelmans et al., 2011). Lesions often appear more extensive on MRI than with other modalities, which may reflect either true disease burden or overestimation (Kafka et al., 2004).

Nuclear medicine

Nuclear medicine imaging emphasizes physiological processes rather than structural abnormalities. By administering radioactive substances—termed radionuclides or radiopharmaceuticals when combined with targeting compounds—functional images are generated. Gamma cameras detect emitted radiation, and lesions are identified based on altered radiopharmaceutical uptake or metabolism.

Because nuclear medicine images provide limited anatomical detail, they are often combined with CT or MRI to integrate functional and structural information. Diagnostic nuclear medicine encompasses three principal techniques: planar scintigraphy, single-photon emission computed tomography (SPECT), and PET.

Nuclear scintigraphy

Planar scintigraphy utilizes a gamma camera composed of a collimator, scintillation crystal, and photomultiplier tubes to localize gamma emissions spatially. Static imaging captures radiotracer distribution at a single time point or over an interval, whereas dynamic imaging tracks tracer kinetics in real time, allowing evaluation of uptake, distribution, excretion, or flow.

Most veterinary applications employ technetium-99m (99mTc), a metastable radionuclide emitting a 140 keV gamma photon suitable for detection. Its chemistry allows incorporation into various targeting compounds. Gallium-67 citrate has also been used experimentally, such as in imaging oral melanoma metastases in dogs (Liuti et al., 2009). Scintigraphic studies typically require temporary patient isolation until radiation emission falls below regulatory thresholds.

Single photon emission computed tomography (SPECT)

SPECT imaging generates three-dimensional representations by rotating collimated scintillation detectors around the patient. This technique provides more accurate localization of tracer distribution than planar imaging. Identification of specific targets within tumors or organs may eventually inform patient selection for targeted therapies. In veterinary medicine, SPECT has been used to assess tumor metabolism in canine cancer patients (Ogilvie, 2000; Whittemore et al., 2004).

Positron emission tomography imaging (PET)

PET has become integral to cancer detection, staging, and monitoring in human medicine. In veterinary oncology, its use remains largely investigational due to the expense of equipment and tracers (Lawrence et al., 2009, 2010; Lee et al., 2010a). PET detects coincident 511 keV photons generated when a positron annihilates with an electron, enabling precise localization of tracer distribution.

Image resolution is high, constrained primarily by positron travel distance prior to annihilation and scanner performance. The first United States Food and Drug Administration–approved oncologic PET tracer, fluorine-18 fluorodeoxyglucose (18F-FDG), exploits increased glucose metabolism in cancer cells. FDG enters cells via glucose transporters and is phosphorylated by hexokinase, becoming metabolically trapped. However, uptake is not tumor-specific, as inflammatory and other metabolically active tissues may also accumulate FDG, leading to false-positive findings (Ballegeer et al., 2006).

In human oncology, FDG-PET is routinely used for staging numerous malignancies, including breast, lung, liver, head and neck cancers, brain tumors, and sarcomas (Alberini et al., 2011). Certain tumors, such as prostate carcinoma, demonstrate limited FDG uptake (Sharkey et al., 2007).

Veterinary experience with FDG-PET remains limited, though available data suggest uptake patterns in dogs parallel those observed in humans (Lawrence et al., 2010; Hansen et al., 2011; LeBlanc et al., 2012). Fluorine-18 has a short physical half-life of less than two hours, necessitating proximity to a cyclotron facility. Alternative radionuclides, such as copper-64 with a longer half-life, may expand logistical feasibility, though routine clinical use has not yet been established.

PET CT

In human medicine, PET is commonly integrated with CT to align functional data with precise anatomical localization (Lawrence et al., 2010). Only a limited number of veterinary centers currently offer PET/CT, and published reports remain sparse (Hansen et al., 2011; LeBlanc et al., 2009; Lee et al., 2010a,b,c; Souza et al., 2011). PET/MRI systems are available in even fewer locations but have been applied experimentally in veterinary patients (Kang et al., 2009, 2010; Wehrl et al., 2011).

Molecular imaging

Molecular imaging involves generating diagnostic images by targeting specific molecules or biological processes using the imaging modalities described above. Most molecular imaging applications rely on nuclear medicine techniques, though MRI contrast agents may also be designed to bind tumor-associated targets (Makowski et al., 2009).

Targets may include metabolic pathways unique to certain cancers, such as iodine uptake in thyroid neoplasia, or overexpressed antigens, such as prostate-specific membrane antigen (PSMA) in prostate cancer. The field is progressing toward highly specific in vivo diagnostic assays capable of identifying tumor type and providing early indicators of therapeutic response, enabling individualized treatment decisions.

Targeted monoclonal antibody imaging

Monoclonal antibodies (mAbs) exhibit high specificity for molecular targets and have been explored for both imaging and therapy. Their large molecular size and prolonged circulation result in slow blood clearance and elevated background activity, reducing image contrast. Additionally, many mAbs are xenogenic in humans and dogs, limiting repeated administration.

Capromab pendetide (Prostascint), which targets PSMA, is approved for imaging prostate cancer in humans. Evidence suggests PSMA expression occurs in approximately half of canine prostate cancers (Lai et al., 2008). Monoclonal antibodies directed against carcinoembryonic antigen (CEA) have been used for staging colorectal cancer (Obradovic et al., 2006), and CEA expression has been documented in canine cholangiocarcinoma and mixed hepatocellular carcinoma (Martin de las Mulas et al., 1995).

Targeted peptide imaging

Peptides engineered to bind specific cell surface receptors offer more favorable pharmacokinetics than mAbs, with faster blood clearance and improved target-to-background ratios despite lower binding affinity. Somatostatin analogues have been used for imaging endocrine tumors in dogs and endocrine tumors and lymphoma in humans, with potential therapeutic applications (Kwekkeboom et al., 2005).

In canine patients, radiolabeled somatostatin analogues have demonstrated accumulation in gastrinomas and insulinomas (Altschul et al., 1997; Lester et al., 1999; Garden et al., 2005). In humans, non-Hodgkin lymphoma expresses somatostatin receptors in the majority of cases (Lugtenburg et al., 2001; Raderer et al., 2001; Cholewinski et al., 2004; Ferone et al., 2005). Similarly, an indium-111–labeled somatostatin analogue delivering an anti-Bcl2 antisense molecule showed preferential uptake in canine lymphoma tissue (Statham-Ringen et al., 2012).

Pretargeted imaging

Pretargeting strategies enhance mAb imaging by separating tumor targeting from radionuclide delivery. An antibody is first administered to bind tumor tissue, allowed to clear from circulation, and then labeled in vivo with a radiolabeled biotin compound. This approach was successfully applied in a canine patient with metastatic prostate cancer, identifying all known lesions and revealing previously undetected metastatic disease (Lewis et al., 2004, 2006).

Selected disease entities

Hemangiosarcoma

Hemangiosarcoma is an aggressive, highly metastatic malignancy originating from endothelial precursor cells of myeloid lineage (Lamerato-Kozicki et al., 2006). Common primary sites in dogs include the spleen, skin and subcutis, right atrium, and liver, though virtually any tissue may be affected. Metastatic spread frequently involves the lungs, liver, heart, omentum, mesentery, kidneys, skeleton, adrenal glands, and brain (Snyder et al., 2008).

The disease closely parallels human angiosarcoma, with similar imaging features. Ultrasonography typically reveals a heterogeneous mass with mixed echogenicity and cystic regions (Abbott et al., 2004). On CT, lesions often appear poorly defined with variable contrast enhancement and necrotic areas. MRI findings are influenced by hemorrhage within and around the tumor, producing heterogeneous signal intensity on T1- and T2-weighted images. Gadolinium enhancement may assist in differentiating malignant from benign splenic lesions (Abbott et al., 2004). Thoracic radiography is routinely used to assess pulmonary metastasis.

Recommended staging for dogs and cats with hemangiosarcoma includes three-view thoracic radiographs, abdominal ultrasound, and echocardiography. Radiographs must be scrutinized carefully for subtle metastatic lesions, though thoracic CT offers superior sensitivity (Nemanic et al., 2006). Contrast-enhanced CT has been evaluated for differentiating malignant and benign splenic masses (Fife et al., 2004), though results have been inconsistent in clinical practice. Doppler ultrasound may help identify vascular tumors.

Contrast harmonic ultrasonography has been proposed for distinguishing metastatic hemangiosarcoma from benign hepatic lesions (Ivancic et al., 2009), though it does not reliably differentiate hemangiosarcoma from splenic hematoma. Hypoechoic lesions on contrast-enhanced studies are more likely malignant (Ohlerth et al., 2008). No sonographic feature is pathognomonic. Echocardiography is particularly valuable for detecting right atrial masses, with reported positive and negative predictive values of 92 percent and 64 percent, respectively (Fruchter et al., 1992).

Thyroid carcinoma

Thyroid imaging exploits the gland's unique ability to trap and organify iodine. Pertechnetate ($^{99m}TcO_4^-$) is the most commonly used imaging agent, accumulating in thyroid tissue and being excreted by organs secreting chloride-rich fluids such as salivary and gastric glands (Nap et al., 1994). Dogs with unresectable or metastatic thyroid carcinoma may respond favorably to radioiodine therapy if pertechnetate uptake is demonstrated (Turrel et al., 2006). Even patients with extensive pulmonary metastases may experience survival exceeding one year following treatment.

CT and MRI have recently been shown to provide the most reliable assessment of tumor margins in canine thyroid carcinoma, aiding surgical planning (Taeymans et al., 2013).

Bone tumors

The hydroxyapatite matrix of bone readily binds phosphorus-containing compounds, making it an effective target for imaging and therapy. By labeling phosphonate chelators with technetium-99m, planar scintigraphy can localize skeletal lesions. Bone scintigraphy is useful in osteosarcoma patients for detecting early osseous metastases or additional primary lesions, which occur in approximately 8 percent of cases (Jankowski et al., 2003).

Scintigraphy has also been employed to estimate tumor margins prior to limb-sparing surgery. While radiographs tend to underestimate microscopic tumor extent, scintigraphy may overestimate it, thereby providing a margin of safety (Leibman et al., 2001). MRI has been shown to most accurately delineate osteosarcoma extent compared with CT, radiography, and scintigraphy (Wallack et al., 2002).

Nuclear medicine also enables combined diagnostic and therapeutic applications. Samarium-153–EDTMP emits both gamma radiation for imaging and beta particles capable of palliating pain and slowing tumor progression (Barnard et al., 2007; Vancil et al., 2012). The intensity of technetium uptake in osteosarcoma has been correlated with prognosis in dogs treated with samarium-153–EDTMP (Forrest et al., 1992).

Adrenal incidentalomas: A by-product of advances in medical imaging

Widespread use of advanced imaging has led to increased detection of incidental abnormalities of uncertain clinical significance. In veterinary medicine, improved ultrasound quality and increased utilization have resulted in more frequent identification of adrenal nodules or masses (Myers, 1997). Similar trends in human CT and MRI have given rise to the term “adrenal incidentaloma” (Terzolo et al., 2009).

When an adrenal mass is discovered during oncologic staging, careful evaluation is required. The prevalence of adrenal tumors in dogs is estimated at 1.2 to 1.5 percent in referral populations, with lower rates in the general population (Myers, 1997). In cats, reported prevalence is approximately 2 percent. In veterinary oncology patients, metastatic involvement of the adrenal glands is more common than primary adrenal tumors (Myers, 1997; Labelle and De Cock, 2005). Common sources of adrenal metastases in dogs include pulmonary, mammary, and prostatic carcinomas, while in cats lymphoma, transitional cell carcinoma, and melanoma predominate (Labelle and De Cock, 2005).

Although functional testing protocols used in human medicine are not widely available for veterinary patients, imaging characteristics such as lesion size and internal architecture can inform suspicion of malignancy. Ultrasonography permits accurate measurement of adrenal

dimensions, with enlargement suggesting clinical relevance (Barthez et al., 1995). On MRI, adenomas typically appear isointense, whereas pheochromocytomas, carcinomas, and metastatic lesions are hyperintense relative to liver on T2-weighted images (Young, 2007). Definitive diagnosis ultimately requires histopathologic evaluation.

Conclusions

By adapting technological advances from human medicine, veterinary oncology has gained powerful tools for more accurate, rapid, and minimally invasive diagnosis, staging, and monitoring of cancer. Improvements in radiographic and ultrasonographic equipment enhance tumor detection in primary practice settings, while increasing access to CT and MRI at referral centers allows more precise assessment of tumor margins. The continued development of targeted PET, SPECT, and nuclear medicine agents promises increasingly comprehensive and less invasive tumor characterization. As these technologies become more widely available, veterinarians must develop familiarity with their principles and applications.

Conflict of interest statement

Neither author has any financial or personal relationships that could inappropriately influence the content of this paper.

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